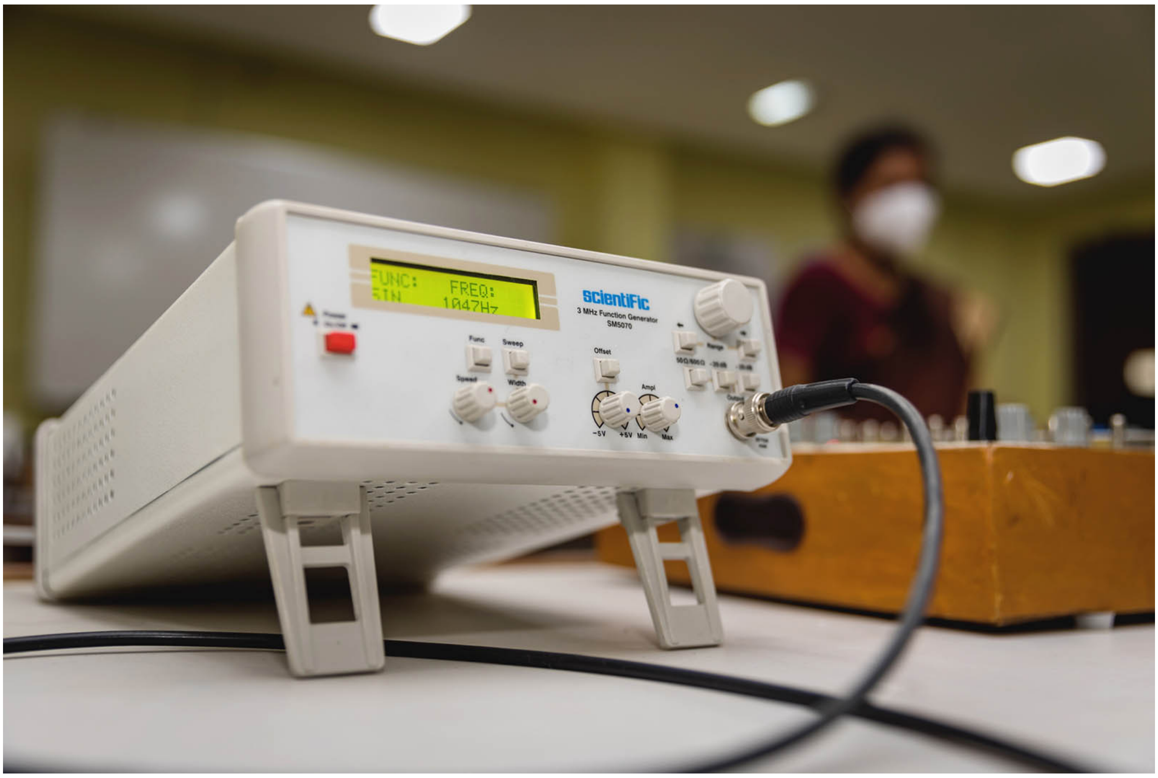


Electronics and Instrumentation

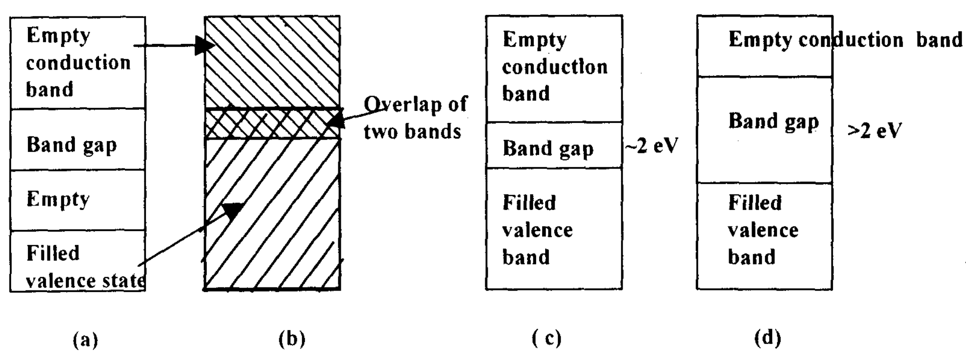
SEMICONDUCTOR DEVICES & RECTIFIERS

Semiconductor Devices & Rectifiers

The valence band[1] of semiconductors(germanium, silicon etc) is full, i.e. in normal conditions, a semiconductor behaves as an insulator. The conduction band of semiconductors is almost empty, i.e. it can easily receive electrons from the valance band. Moreover, the forbidden gap[2] between the two bands is very small (about 1 eV) so that a very small amount electrical energy can push the electrons from valence band into conduction band[3]. As the temperature is further increased, more electrons jump into conduction band, i.e. its conductivity increases with rise in temperature.

ENERGY BAND DIAGRAMS OF CONDUCTORS, SEMICONDUCTORS AND INSULATORS

The electrical property of a solid material depends upon its energy band structure i.e. the arrangement of the outermost electron bands and the way these are filled with electrons. The band that contains the highest-energy or valence electrons is termed as the valence band. The conduction band is the next higher energy band which is under normal circumstances remain unoccupied. The positions of the valence and conduction band in different solids are shown in the diagram.



a and b	for conductors like copper, gold
c	for semiconductors like Si, Ge
d	for insulators like diamond

Between c and d, the difference lies in the magnitude of the energy gap.

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[1] The last orbit in an atom is called “valence orbit”. The range of energies possessed by valance orbit is called “valence band.

[2] The gap between valence and conduction bands is called “forbidden band”.

[3] The higher band above the valence band, in which electrons are “ready to conduct” is called “conduction band.

PROPERTIES OF SEMI-CONDUCTORS

- The resistivity of a semi-conductor is more than that of a conductor but less that of an insulator.
- Semi-conductors have negative temperature co-efficient of resistance i.e., the resistance of semi-conductor decreases with the increase in temperature and vice-versa.
- When some suitable impurity (e.g.., arsenic gallium) is added to a semi-conductor, its conduction properties change appreciably.

COMMONLY USED SEMI-CONDUCTOR MATERIALS

There are many varieties of semi-conductor materials used such as germanium, silicon, selenium, boron etc, but germanium & silicon are the two most frequently used semi-conductor material in electronics. Both elements have the same crystal structure and similar characteristics.

Germanium and silicon are tetravalent elements having four electrons in their outer shells. In pure form, these four valence electrons are covalent bonded with the electrons of neighboring four atoms. Hence, there are no free electrons available for electrical conduction in these semi-conductor materials. It is due to this fact that germanium and silicon act as insulators under ordinary conditions and at very low temperature (say $0^{o}K$). However, at higher temperatures, some electrons may succeed to liberate themselves and get transferred to the conduction band.

It may be noted here that semi conductive materials are never used in their pure form as such but are used in doped form, where some trivalent or pentavalent element is added in them so as to obtain desired properties. this would become clear from the following articles.

DOPING

Under ordinary conditions, a pure semiconductor behaves like an insulator. But when an extremely small amount of impurity(trivalent or pentavalent atom) is added, it starts behaving like a conductor. The process of adding impurity to a pure semi-conductor to make it an extrinsic semi-conductor, is called *doping*.

Methods of Doping: The methods that are considered for doping of solid materials are

(i) Molecular beam epitaxy
(ii) Metaorganic vapour phase epitaxy
(iii) Ion Implantation
(iv) Diffusion
(v) Ion/proton exchange

Doping by diffusion to obtain desired electrical characteristic is carried out by two stages, namely predeposition and drive in. During the first stage, a carefully controlled quantity of desired dopant in introduced on the silicon crystal surface. The predeposition of the dopant on Si substrate is done by using a vapour phase medium, e.g. PH_3, B_2H_6 or B_2O_3. The dopant vapour is allowed to mix with a stream of carrying gas like Hydrogen and to pass over the hot substrate. the concentration profile of the dopant depends on the partial pressure of the vapour as well as the solubility behaviour of the dopant into substrate. During the second stage i.e. drive-in the dopant is allowed to get redistributed to obtain the final concentration vs. depth profile. The drive-in is often carried out in an oxidizing atmosphere to re grow the oxide layer over the freshly-diffused region. An approximate estimation of the depth of diffusion of dopant can be made by using the equation

$x = \sqrt{(Dt)}$ where x is depth. D is the diffusion coefficient characteristics of the **dopant** and substrate and t is the diffusion time.

INTRINSIC SEMICONDUCTORS

A pure semiconductor or a semiconductor in its purest form is called "intrinsic semiconductor".

At absolute zero temperature, a pure (or intrinsic) semiconductor behaves as an insulator. If its temperature is raised, the covalent bonds are broken. Whenever a free electron is generated, a hole is created simultaneously. In other words, free electrons and holes are always generated in pairs. Therefore, concentration of electrons and holes in an intrinsic semiconductor will always be equal. This type of generation of electron/hole pairs is called " thermal generation".

The energy required for lifting an electron from valence band to the conduction band is equal to the forbidden gap. In case of Ge, it is 0.72 eV, and in case of Si, it is 1.12 eV. Due to more gap, less number of electron/hole pairs will be generated in silicon than in germanium at room temperature. In other words at room temperature conductivity of pure silicon will be less than that of germanium.

An electron carries a negative charge and a hole is assumed to carry an equivalent positive charge. Both are called charge carriers and can constitute "**electron current**" and **hole current** respectively.

Both the charge carriers(electrons and holes) move at random or haphazardly within the crystal. When an electron during thermal generation leaves the valence band and enters the conduction band, a hole is created in the valence band. Now this free electron moves at random in the conduction band and the hole(created) moves at random in the valence band.

Current flow is due to movement of electrons and holes in opposite directions. The number of electrons is equal to number of holes but hole mobility is practically half of electron mobility.

The total current is given by $I = I_e + I_h = I = n_1 e(\mu_e + \mu_h)\frac{AV}{l}$

where v_e = drift velocity of electrons

v_h = drift velocity of holes

n_1 = number of electrons in semi-conductor

P1 = number of holes semi-conductor

e = Electron charge

A = cross section of semi-conductor

since in intrinsic semi-conductor n1 = p1

$$R = \frac{V_{in} - V_o}{I_Z - I_L}$$

$$= \eta_1 eA(\mu_e + \mu_h)E$$

Where μ_e is electrons mobility = $\frac{v_e}{E}$; μ_h is hole mobility; E is Electric field

Also $E = \frac{V}{l}$, where l is the length of intrinsic semi-conductor

$$I = n_1 e(\mu_e + \mu_h)\frac{AV}{l}$$

$$\frac{V}{I} = \frac{l}{A}.\frac{1}{n_1 e(\mu_e + \mu_h)}$$

Where P is conductivity of the semi-conductor material. It is given by

$$P = \frac{1}{n_1 e(\mu_e + \mu_h)} \text{ ohm meter}$$

Example

The intrinsic carrier concentration for silicon at room temperature (300 K) is 1.5 x 10^{10}/cm^3. If the mobilities of electrons and holes are 1300 cm^2 /V sec and 450 cm^2/V sec respectively, what is the conductivity of silicon(intrinsic) at 300 K ? If the silicon is doped with 10^{18} boron atoms per c.c., what is its conductivity ?

Solution

N_I = carrier concentration = 1.5 x 10^{10}/cm^3

Mobility of electrons μ_n = 1300 cm^2/V

Mobility of holes μ_n = 400 cm^2/V

Conductivity of intrinsic semiconductor is

$\sigma = (\mu_n + \mu_p) qn_I = (1.5 \times 10^{10})(1.60 \times 10^{-19})(1300 + 400) =$ **40.8 x 10^{-6} mho**

Given doping level = 10^{18}/cc

Conductivity of the resulting p-type semiconductor is given by

$\sigma = p\mu_p q = 10^{18} \times 400 \times 1.6 \times 10^{-19} =$ **64 mho**

Example

What is the concentration of holes in Si crystals having donor concentration of 1.4 x $10^{24}/m^3$ when the intrinsic carrier concentration is 1.4 x $10^{18}/m^3$? Find the ratio of electron to hole concentration.

Solution

The concentration of p_n of holes in n type semiconductor is

$n_n p_n = n_i^2$. Given n_I = 1.4 x 10^{18}, n_n = 1.4 x 10^{24}.

$P_n = n_i^2/n_n = (1.4 \times 10^{18})^2/(1.4 \times 10^{24}) = 1.4 \times 10^{12}/m^3$

Now $n_n/p_n = n_i^2/p_n^2 = (1.4 \times 10^{18})^2/(1.4 \times 10^{12})^2 = \mathbf{1 \times 10^{12}}$

Example

Prove the relation $\sigma = e(n\mu e + P\mu h)$ mho/m.

Solution

The current flowing through a pure semiconductor is carried by two kinds of charge carriers, electrons(e) and holes(h). The resulting conductivity of a semiconductor depends firstly on the concentration of the mobile charge carriers and secondly on the mobility. When an electric field of E volts/metre is applied, the current densities contributed due to motion of electrons and holes are given by

$$J_n = env_n \text{ A/m}^2 \quad (1)$$

$$J_p = ePv_p \text{ A/m}^2 \quad (2)$$

Where e = charge of an electron(or hole) = 1.6 x 10^{-19} coulomb

n,P = densities of free electrons and holes in carriers/m^3

v_n, v_p =drift velocity of free electrons and holes in m/s.

The conductivities due to the electrons and holes, respectively, are given by

$$\sigma = J_n/E \quad (3)$$

$$\sigma_p = J_p/E \quad (4)$$

Putting value of J_n and J_p in equations (3) and (4) from equations (1) and (2)

$$\sigma_n = env_n/E = en\mu_e \quad [\text{because } \mu_e = v_n/E] \quad (5)$$

$$\sigma_p = env_p/E = en\mu_n \quad [\text{because } \mu_n = v_p/E] \quad (6)$$

where μ_e, μ_n = mobility of free electrons and holes defined as drift velocity per unit field.

The total conductivity of a semiconductor, being the sum of conductivities contributed by free electrons and holes, is given by

$$\boldsymbol{\sigma = \sigma_n + \sigma_p = en\mu_e + eP\mu_n = e(n\mu_e + P\mu_n)} \textbf{ mhos/m.}$$

Example

The resistivity of pure silicon at room temperature is 3000 ohm m. Calculate the intrinsic carrier density. Given the electron and hole mobilities are 0.14 m^2/Vs and 0.05 m^2/Vs, respectively.

Solution

The intrinsic charge carriers in pure silicon are electrons and holes in equal numbers.

$$n = n_e = n_h = \frac{\sigma}{(\mu_e + \mu_h)e}$$

$$= \frac{1}{(0.14 + 0.05)x3000x1.62x10^{-19}} = 1.095x10^{16}\ m^{-3}$$

Example

Find the conductivity and resistivity of a pure silicon crystal at temperature 300°K. The density of electron hole pair per cc at 300°K for a pure silicon crystal is 1.072 x 10^{10} and the mobility of electron μ_n = 1350 cm^2/volt-sec and hole mobility μ_h = 480 cm^2/volt-sec.

Solution

Conductivity of pure silicon crystal is given by

$$\sigma = n_i e(\mu_e + \mu_n) n_i = 1.072x10^{10}$$

$$\sigma_i = 1.072x10^{10} x1.6x10^{-19}(1350 + 480) = 3.14x10^{-6}\ mho/cm$$

μ_n = 1350 cm^2/volt-sec

μ_h = 480 cm^2/volt-sec

$$e = 1.6x10^{-19}$$

Resistivity of silicon crystal is given by

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{3.14x10^{-6}} = 3.18x10^5\ ohm - cm$$

Problem (AMIE Summer 2011, 6 marks)

The intrinsic resistivity of silicon at 27^0C is 2.8 x 10^3 ohm m. The electron and hole mobilities are 0.38 and 0.18 m^2/Vs, respectively. Calculate intrinsic carrier density at the given temperature. (Answer : 3.986 x 10^{15} carriers/m^3)

EXTRINSIC SEMICONDUCTOR

The number of free electrons and holes produced by thermal energy in a pure semi-conductor is generally too small at room temperature. The number of free electrons and holes may, however, be increased by adding a few atoms of another elements to semi-conductor (known as doping).

Depending upon the type of impurity added, the extrinsic semi-conductors are divided into the following two types;

- N-type semi-conductor, and
- P-type semi-conductor

N-Type Extrinsic Semi-Conductor

When the type of impurity added to a semi-conductor is such that there exist a large number of free electrons in the semi-conductor, it is called an N-type semi-conductor. Examples of impurities for this type of semi-conductor are pentavalent impurities like arsenic, antimony and phosphorous. Such impurities which produce N-type semi-conductors are known as donor impurities which produce N-type semi-conductors are known as donor impurities because they provide or donate excess electrons in the semi-conductor crystal.

Consider a pure germanium crystal which has four valence electrons. When a small amount of any pentavalent impurity like arsenic is added to such a crystal, a large number of free electrons exist in the crystal. Arsenic has five valence electrons. An arsenic atom fits in the germanium crystal in such a way that its four valence electrons form covalent bonds with four germanium atoms. The fifth valence electron of arsenic atom finds no place in the covalent bonds and is thus free.

Therefore, for each arsenic atom added one free electron will be available in the germanium crystal. Though each arsenic atom provides only one free electron yet an extremely small amount of arsenic impurity provides enough atoms to supply millions of free electrons.

N-Type conductivity. The current conduction in an N-Type semi-conductor is by electrons i.e. negative charges and is called N-Type conductivity. Electrons are the **majority carries** in N-type semi-conductors, while holes are **minority carries**.

P-Type Extrinsic Semi-Conductor

When the type of impurity added to a semi-conductor is such that there exists a large number of holes in the semi-conductor, it is called P-type semi-conductor. Typical examples are trivalent impurities like gallium, indium or boron. Such impurities are called acceptor impurities because the holes created can accept electrons.

Consider a pure germanium semi-conductor. When a small amount of trivalent impurity like gallium is added to germanium, there exist a large number of holes in the crystal Gallium is trivalent i.e. its atom has three valence electrons. Each atom of gallium impurity fits into the germanium crystal but only three covalent bonds can be formed.

In the fourth covalent bond only germanium atom contributes one valence electron while gallium has no valence electron to contribute as all its three valence electrons are already engaged in covalent bonds with germanium atoms. In other words, fourth bon is incomplete, being short of one electron. This missing electron in the fourth bond is called a hole.

Thus one hole is created in the crystal by the addition of one atom. The number of holes in the germanium semi-conductor depends on the amount of gallium added. The hole is a positive charge equal to charge of one electron with opposite polarity. It acts as a virtual positive charge although there is no physical charge. It follows that in P-type semi-conductor, there exist a large number of holes.

P-type conductivity. The current conduction in a P-type semi-conductor is by holes and is called P-type or hole-type conductivity. Holes are referred to as **majority carries**.

Consider a P-type semi-conductor. Under the influence of potential difference the electrons n the crystal will tend to move towards the positive terminal and jump into available holes of gallium atoms. Since free electrons are not available in P-type germanium the electrons which are moving towards the positive terminal come from covalent bonds. The tendency of electrons to leave the covalent bonds is due to the fact that holes are available in front of them. An electron from one covalent and jumps into the hole in front of it thus leaving the hole in the bond it has left. This electron now jumps into the next available hole and so on. As this process continues it is clear that holes are shifted towards the negative terminal of the battery. It should be noted that in P-type conductivity electrons are simply transferred from one atom to a neighboring atom.

IONIZATION ENERGY

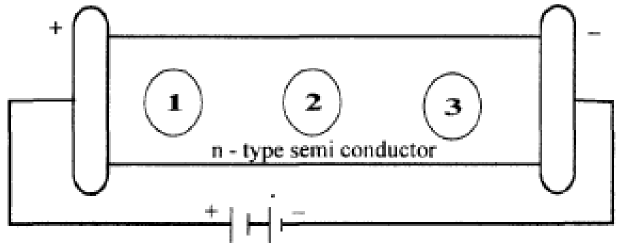
If intrinsic semiconductor is doped with phosphorus, it becomes n-type as Phosphorus is pentavalent. The 4 electrons in the outer orbit of Phosphorus are shared by the 4 Germanium atoms and the fifth electron of Phosphorus in the outer orbit is a free electron. But in order that this electron is completely detached from the parent Phosphorus atom, some energy is to be supplied. This energy required to separate the fifth electron is called Ionization Energy. The value of ionization energy for Germanium is 0.012 eV, and in Silicon, it is 0.044 eY. For different impurity materials, these values will be different, in Silicon and Germanium. As this energy is small, at room temperature, we assume that all the impurity atoms are ionized.

TOTAL CURRENT IN A SEMICONDUCTOR

Drift Current In N Type Semiconductor

Within a semiconductor, intrinsic or impure, because of the thermal energy, covalent bonds are broken and electrons are holes move in random directions. These collide with lattices, get deflected and move in a different direction, till they collide with another carrier. Such a random motion is defined as mean free pat" length 'I', the distance a carrier travels between collisions and the average time between collisions 't'. The average velocity of motion v = 1/t. Over a period of time which is » 't', average movement is zero or net current is zero.

But when electric field is applied all the electrons are aligned in a particular direction and move towards the positive electrode and holes in the opposite direction. The resulting current is called *Drift Current*.

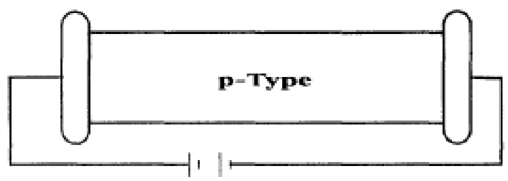


Drift Current in N Type Semiconductor

Drift Current In P Type Semiconductor

The mechanism is the same to as explained above. The holes in the acceptor type semiconductor moves towards the negative electrode and enter into it, pulling out one electron from the

negative electrode from the acceptor atoms (see figure), the hole has moved away, i.e. it has acquired an electron.



So electrical neutrality or of its original condition is disturbed. This results in above figure. Drift current in p-type semiconductor electrons from the acceptor atom being pulled away. These free electrons enter the positive electrode. The acceptor atoms having lost one electron steal another electron from the adjoining atom resulting in a new hole. The new holes created thus drift towards negative electrode.

DIFFFUSION CURRENT

This current results due to difference in the concentration gradients of charge carriers. That is, free electrons and holes are not uniformly distributed all over the semiconductor. In one particular area, the number of free electrons may be more, and in some other adjoining region, their number may be less. So the electrons where the concentration gradient is more move from that region to the place where the electrons are lesser in number. This is true with holes also.

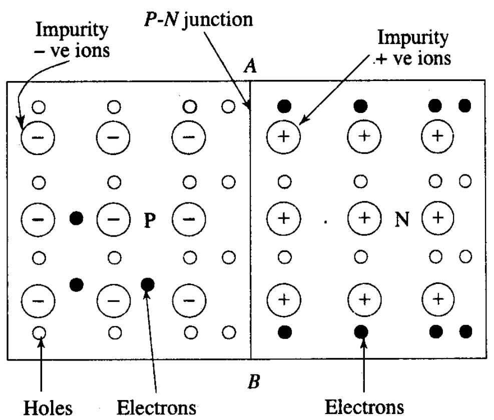
If diffusion current is caused by holes, the equation of diffusion current is

$$i_p = e \, x \, D_p \, x \frac{dp}{dx}$$

P-N JUNCTION DIODE

When a P-type semi-conductor is joined to an N-type semi-conductor by a special technique, the contact surface is known as P-N junction. Most semi-conductor devices contain one or more P-N junctions. The P-N junction is of great importance because it is the control element for semi-conductor devices.

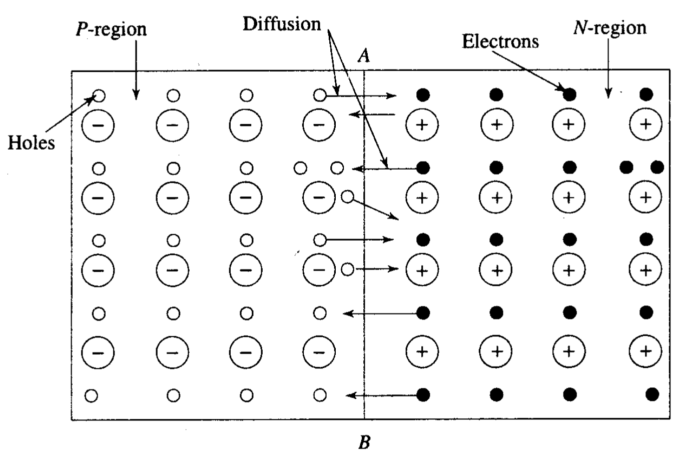
Consider two semi-conductor materials P-type and N-type a shown in given figure.



A P-N Junction

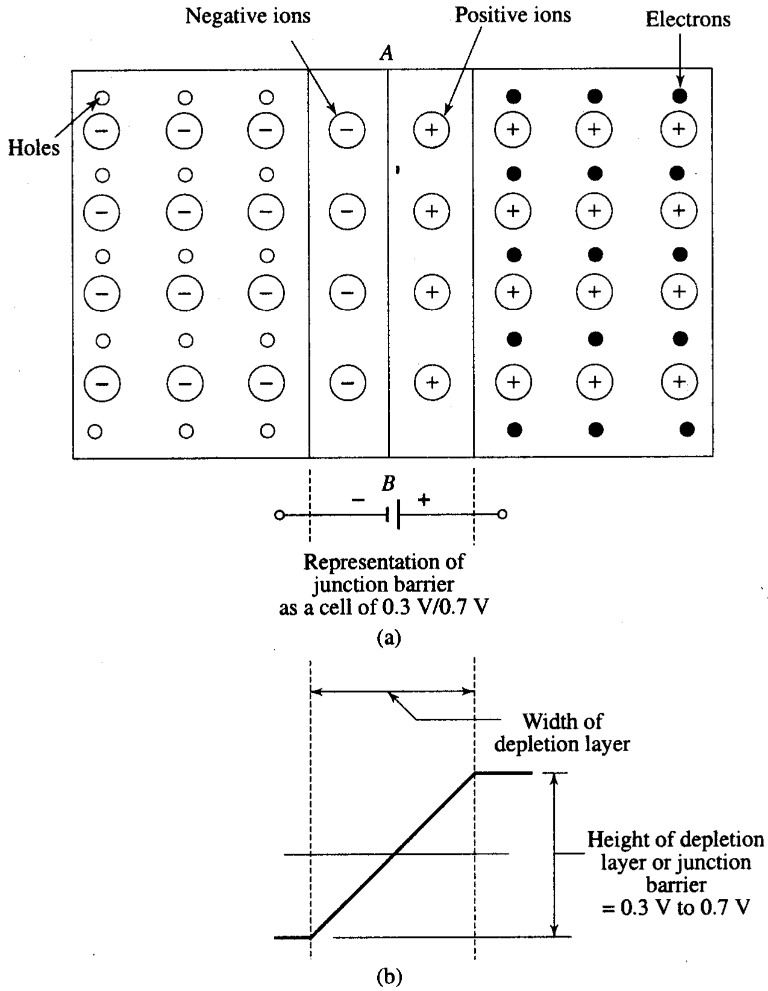
In N-type semi-conductor, there is a high concentration of free electrons, while P-type semi-conductor possesses many holes. When P-N junction is formed, the electrons diffuse from N-type while holes diffuse in opposite direction. When electrons diffuse over the junction into P-type, a net positive charge is build up on N-side of the junction. Similarly a net negative charge is established on P-side of the junction. Once these net charges are established by initial diffusion, they prevent further diffusion due to repulsive force. The result is that a barrier is set up against further movement of carriers. This is called **potential or junction barrier**. The barrier potential may be 0.3 to 0.7 V approximately increasing with the amount of doping.

Following figure shows diffusion in P-N Junction.



Diffusion in P-N Junction

Following figure shows formation of potential barrier.



Formation of Potential Barrier

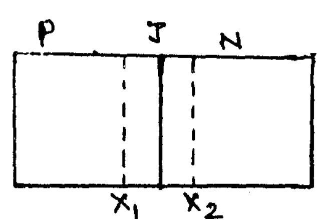
HEIGHT OF POTENTIAL BARRIER

We know that the current due to electron is given by

$$J_e = e\mu_e nE + eD_e \frac{dn}{dx} \qquad \text{(i)}$$

and $$\frac{D_e}{\mu_e} = \frac{KT}{e}$$

(ii)



In open circuited P-N junction, the current must be zero. Considering the electron component only

$J_e = 0$ from equation (I).

$$0 = e\mu_e nE + e\frac{D_e dn}{dx}$$

or $$\frac{dn}{h} = -\frac{e}{KT}Edx \qquad \text{(iii)}$$

If n_p is the number of electron in p-type semiconductor and n_n is number of electrons in n-type semiconductor.

Now integrating eq.(iii) across the junction.

$$\int_{n_p}^{n_n}\frac{dn}{n} = \frac{e}{KT}\int_{x_1}^{x_2}(-E)dx \qquad \text{(iv)}$$

The integration of (-E) from X_1 to X_2 leads to the value of barrier potential (V_B) with n-positive to p. The result of integration is

$$\frac{n_n}{n_p} = \exp e^{V_B/KT} \qquad \text{(v)}$$

This is the relation between the electron density at the junction face in the n-region to electron density in junction face in the p-region. The exponent represents the ratio of barrier height to average height of charges.

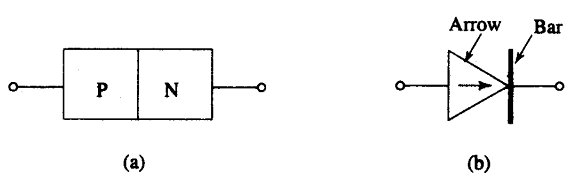
We know that $n_n = N_D$ and $n_p = n_i^2/N_A$

From equation (v)

$$V_B = \frac{KT}{e}\log\left(\frac{N_A N_D}{n_i^2}\right)$$

SYMBOL OF DIODE

Figure (a) shows the construction and Figure (b) shows the symbol of a semiconductor diode. The arrow in the symbol shows the direction of current through the diode, while the bar represents the N type material.

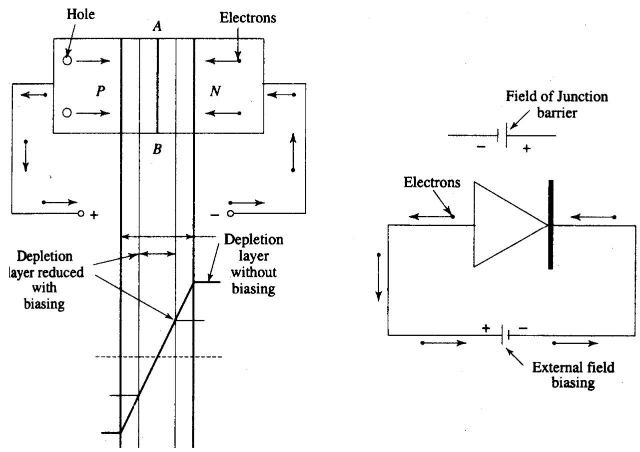


Forward Biasing

When the external voltage is applied such that +ve terminal to P-side and –ve to N-side, as shown in figure (a) such biasing is known as “Forward biasing”.

Figure (a) shows forward biasing to a P-N junction diode. In this biasing the electric field produced by the external battery works opposite to the electric field produced by junction barriers. As a result of this, the height of junction barrier goes on reducing as shown in

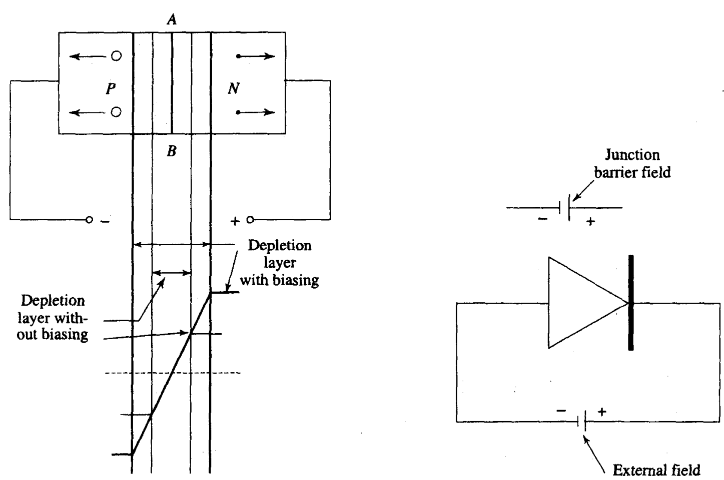
Figure (a) and at 0.3 V(for Ge) and 0.7 V (for Si), the barrier totally vanishes, i.e. depletion layer disappears. This establishes a conducting path and holes from P side and electrons from N side start moving through the junction. This establishes a current; in other words, the diode conducts current which depends upon the amount of applied forward bias. Figure 6 shows symbolic representation of forward biasing a diode.



(a) and (b) Forward biasing of P-N Junction/Symbolic representation of forward biasing

Reverse Biasing

When the +ve terminal of applied voltage is connected to N-side and –ve terminal to P-side, then the potential barrier is increased thus obstructing the flow of current, as shown in given figure (a). Such type of arrangement is referred to as reverse biasing.

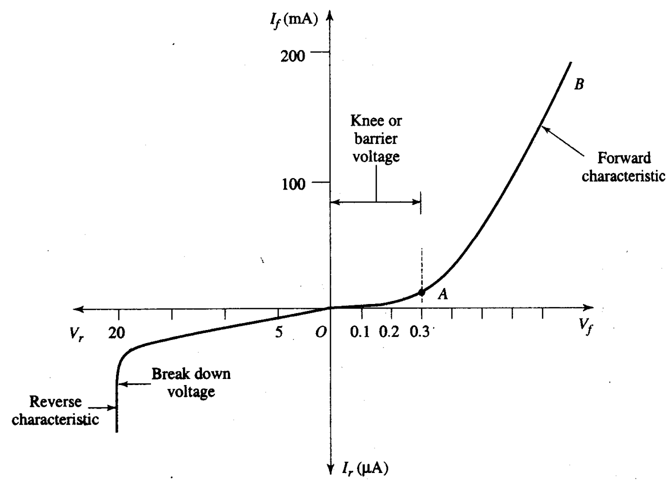


(a) and (b) Forward biasing of P-N Junction/Symbolic representation of forward biasing

Refer to Figure (a). In this biasing the electric field produced by the external battery acts in the same direction as the junction barrier, as a result of which the height of the barrier goes on increasing further. This strengthens the depletion layer still higher and not a single electron or hole can cross through the junction. In other words, no current conduction occurs in the diode. Figure (b) shows reverse bias applied symbolically.

VOLT-AMPERE (V/ I) CHARACTERISTIC OF DIODES

The curve between voltage across a diode and current flowing through it is called its V-I characteristics. The characteristic curve has 3 important parts.(Figure below).



V/I Characteristic of a Diode

(i) **Zero External Voltage** : When the external voltage is zero, no current flow takes place due to junction barrier (See point O in this figure).

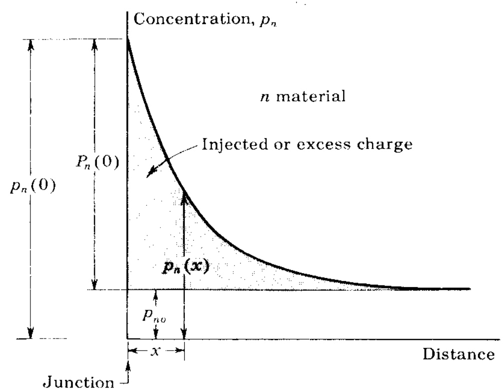
(ii) **Forward Bias :** When forward bias is applied, i.e. the positive terminal of the external battery is connected with the P(arrow) side and negative terminal with the N or(bar) side as explained in the last article, the junction barrier weakens and at 0.3 V (for Ge) and at 0.7 V (for Si) called knee voltage, it disappears completely (See OA). Up to point A, the current is very small and after A it rapidly rises (AB). The portion OB is called Forward characteristic of the diode. The current (forward current) in forward characteristic is due to majority carriers.

(iii) **Reverse Bias** : If connections of the circuit are reversed, i.e. positive terminal of the external battery is connected with the N(bar side) and negative terminal with P(arrow side), as explained already the junction barrier strengthens and practically no current flows through the diode.

DIFFUSION CAPACITANCE OF A P-N JUNCTION DIODE

The capacitance which exists in a forward biased junction is called diffusion capacitance. It is due to the arrangement of minority carriers with the change in forward bias.

We assume that, one side of the diode, say p-material is heavily doped so that the current I is carried across the junction entirely by holes moving from p to n side or $I = I_{pn}(0)$. The excess minority charges Q will exist only on the n-side, given by the shaded area of given figure multiplied by the diode cross section A and the electronic charge, e.



Hence $$Q = \int_0^\infty A.e.P_n(0)\varepsilon^{-x/Lp}.dx = A.e.L_p P_n(0)$$

where L_p = diffusion length

$P_n(0)$ is injected excess charge at junction

and $$C_D = \frac{dQ}{dV} = A_e L_p \frac{dP_n(0)}{dV} \quad \text{(A)}$$

The hole current is given by $I_{pn}(x)$

$$I_{pn}(x) = \frac{AeD_p P_n(0)}{L_p}\varepsilon^{-x/L_p}$$

where D_p = diffusion constant in square metre/second.

With x = 0

$$I = \frac{A.e.D_p P_n(0)}{L_p}$$

and $$\frac{dP_n(0)}{dV} = \frac{L_p}{AeD_p}.\frac{dI}{dV} = \frac{L_p}{AeD_p}g \quad \text{(B)}$$

where g = dI/dV is the diode conductance.

From above equations (A) and (B)

$$C_D = \frac{{L_p}^2 g}{D_p}$$

We know that $L_p = \sqrt{D_p \tau_p}$

where $\tau_{p=}$ τ is mean lifetime of the holes.

$$\tau = \frac{{L_p}^2}{D_p}$$

Then $C_D = \tau g$

But $g = I/\eta V_T$, hence

$$C_D = \frac{\tau I}{\eta V_T}$$

We see that the diffusion capacitance is proportional to current I.

Diode Rectifiers

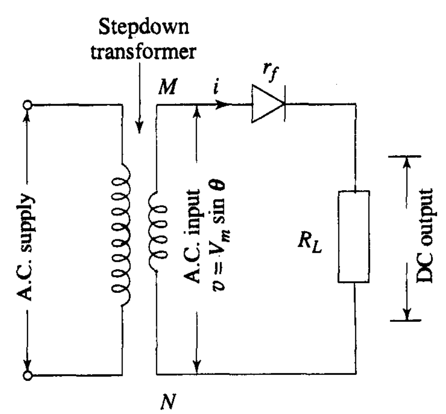
We know that the generation, transmission and distribution of A.C. is economical but at few places, we need D.C. supply, e.g. electronic devices and circuits. Here, we convert the available A.C. supply into D.C. supply. The process is called "**rectification**" and the devices used for rectification are called, "**rectifiers**". Diodes are used as rectifiers.

The rectifiers can be classified as :

- Half wave rectifiers
- Full wave rectifiers (i) Centre tap rectifiers (ii) Bridge rectifiers

HALF WAVE(H.W.) RECTIFIERS

These circuits rectify only the half(positive) cycle of the A.C. supply and hence the name. The circuit use only one diode. The AC supply to the diodes is given through a step down transformer which steps down the voltage to be supplied to the diode. The output D.C. voltage is obtained across a load. (See figure).



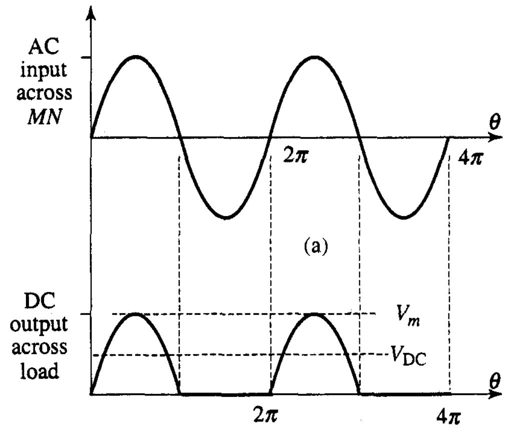
A.C. to D.C. conversion

The step down voltage appears across secondary MN of the transformer. This becomes the A.C. input to the diode.

- When positive cycle of the A.C. input appears across the diode, i.e. the end M is positive and end N is negative, the diode becomes forward biased and is short circuited. As a result, the whole A.C. input of the positive cycle appears across the load.

- When negative cycle of the supply appears, i.e., end M becomes negative and N positive. The diode is reverse biased and is open circuited. As a result, the whole A.C. input of the negative cycle appears across the diode and output across the load is zero.

Figure below shows wave form for A.C. input and D.C. output.



Efficiency of Half Wave Rectifiers

The ratio of D.C. power output across the load to the applied A.C. power input to the diode is known as "**rectifier's efficiency**(η)"

i.e. $$\eta = \frac{\text{D.C. power output}}{\text{A.C. power input}}$$

Step 1 : D.C. power output

Let

(i) voltage across secondary of the transformer be $v = V_m \sin\theta$.

(ii) resistance of diode = r_f (when forward biased).

(iii) Load resistance R_L

The instantaneous value of current through the circuit (see figure 11).

$$i = \frac{v}{r_f + R_L} = \frac{V_m \sin\theta}{r_f + R_L}$$

Maximum current $I_m = \dfrac{V_m}{r_f + R_L}$ Hence $i = I_m \sin\theta$.

D.C. output power obtained across the load $R_L = I_{dc}^2.R_L = I_{av}^2.R_L$

From the basic knowledge of electrical engineering we know that the DC or average value of a half rectified wave is I_m/π.

i.e. $I_{dc} = I_{av} = I_m/\pi$.

Hence output power = $(I_{dc})^2.R_L = (I_m/\pi)^2.R_L$

Step 2 : A.C. power input

Again, from the knowledge of electrical engineering, the I_{rms} of a half rectified wave is given by

$$I_{rms} = I_m/2$$

Hence A.C. power input $P_{ac} = I_{rms}^2.(r_f + R_L) = (I_m/2)^2.(r_f + R_L)$

Step 3 : Rectification efficiency

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(I_m/\pi)^2.R_L}{(I_m/2)^2(r_f + R_L)}.\frac{4I_m^{\ 2}.R_L}{\pi^2 I_m^{\ 2}(r_f + R_L)} = \frac{4}{\pi^2}.\frac{R_L}{(r_f + R_L)} = \frac{0.406R_L}{r_f + R_L}$$

If diode resistance r_f may be neglected then $\eta = \frac{0.406R_L}{R_L} = 0.406 = 40.6\%$

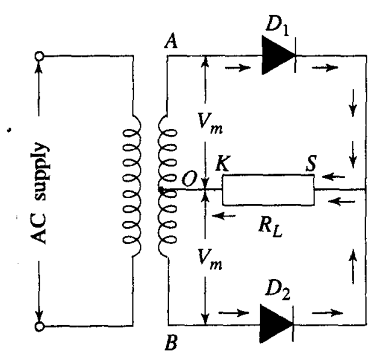
FULL WAVE(F.W.) RECTIFIERS

In these circuits more than one diode is used. This enables the circuit to possess both the cycles of the A.C. supply. During both the cycles, current flows through the load in the same direction.

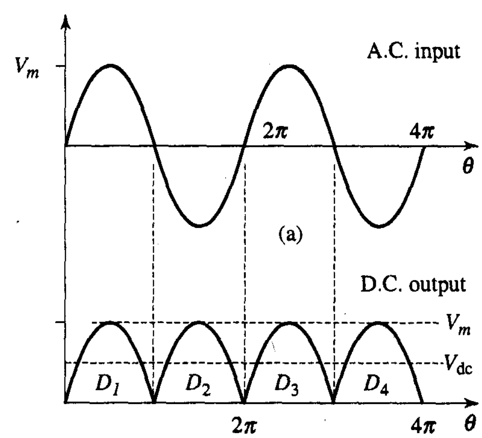
Centre Tap F.W. Rectifier

The circuit uses a step-down transformer with the centre tapped secondary. In addition to this, two diodes are connected as shown in figure (a). One diode processes positive half cycle and the other negative half cycle.

During positive half cycle of the A.C. supply, diode D_1 is forward biased as the end A is positive and B negative. This makes diode D_1 forward biased and D_2 reverse biased. As a result current flows through the diode D_1 and through the load R_L as shown by arrows. The load D_2 does not conduct during this period.



(a)

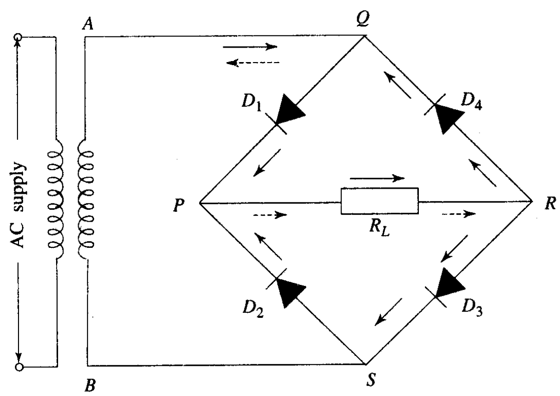


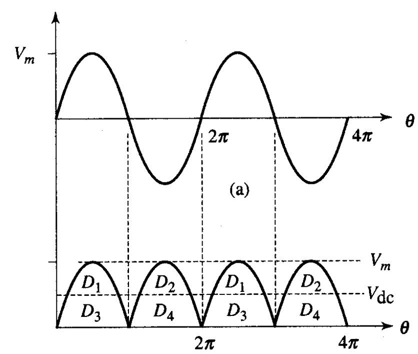
(b)

During negative cycle, end B becomes positive and A negative. This makes D_2 forward biased and D_1 reverse biased. The D_2 conducts and current flows through D_2 and load R_L as shown by arrows. The diode D_1 does not conduct during this period. It can be seen that the current in both the cases flows through R_L from S to K, hence we get a unidirectional(direct) current. Figure (b) shows the wave form for A.C. input and D.C. output.

F.W. Bridge Rectifier

As already mentioned, in the case of centre tap and rectifier circuit, it is difficult to locate D.C. correctly the centre point on the secondary of the transformer, and this may give distortion in the rectified D.C. output. Moreover, PIV value is also high in C.T. rectifier circuit. These drawbacks have been eliminated in bridge rectifier which employs 4 diodes.





(a) **(b, c)waveform (A.C. D.C.)**

By using 4 diodes, its output is twice that of the C.T. circuit for the same secondary voltage. As shown in the Figure (a), the load R_L is connected between the two ends P and R, the arrangement gives it the shape of the bridge hence the name.

During positive half cycle of the secondary voltage, the end A of the secondary becomes positive and B becomes negative. As a result the diodes D_1 and D_3 become forward biased which conduct. The direction of current is shown by solid arrows, i.e. AQPRSBA.

During the negative cycle, the end A, becomes negative and B becomes positive. The diodes D_2 and D_4 become forward biased and conduct in the direction shown by dotted arrows, i.e. BSPRQAB.

It can be seen that current in both the cases flow through R_L from S to K. Hence we get a unidirectional(direct) current. Figure (b and c) shows waveform for A.C. input and D.C. output, respectively.

Efficiency of an F.W. Rectifier

Recall that the ratio of the output D.C. power to the input A.C. power is called the efficiency of rectification.

Let the A.C. voltage to be rectified be given by the equation

$v = V_m \sin\theta$ (secondary voltage)

v = instantaneous voltage

where forward resistance of diode = r_f and load resistance = R_L.

Now the instantaneous value of current is given by

$$i = \frac{v}{r_f + R_L} = \frac{V_m \sin\theta}{r_f + R_L}$$

D.C. output power. From the basic knowledge of electrical engineering, the average current (I_{DC}) of a full rectified wave is given by :

$I_{D.C.} = 2\ I_m/\pi$, where I_m is the maximum value of current.

Hence D.C. power output $P_{DC} = I_{D.C.}^2.R_L = (2I_m/\pi)^2.R_L$ (i)

A.C. input power. Again from the basic knowledge of electrical engineering, we know that for FW rectified wave,

$I_{rms} = I_m/\sqrt{2}$

Hence A.C. input power,

$P_{AC} = (I_{rms})^2.(r_f + R_L) = (I_m/\sqrt{2})^2\ (r_f + R_L)$ (ii)

Efficiency

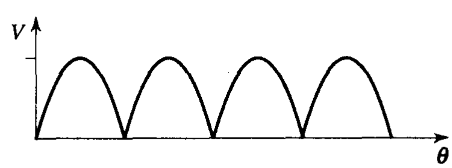
$$\eta = P_{D.C.} / P_{A.C.} = \frac{(2I_m/\pi)^2.R_L}{(I_m/\sqrt{2})^2(r_f + R_L)} = \frac{0.812R_L}{r_f + R_L}$$

The efficiency will be maximum, if diode resistance r_f is negligible.

i.e. $$\eta = \frac{0.812R_L}{R_L} = 0.812 = 81.2\ \%$$

RIPPLE FACTOR

The output of a rectifier (Figure) as mentioned already is not pure but contains D.C. as well as A.C. components. The A.C. components are responsible for ***pulsations*** in the wave. These A.C. components are called **ripples**.



The ratio of RMS value of A.C. components in the rectifier output is called ripple factor (R.F.)

Ripple factor = A.C. Components/D.C. Components = $I_{A.C.}/I_{D.C.}$.

If $I_{A.C.}$ is more than $I_{D.C.}$, clearly ripple factor is more than 1; in other words, the output is more of A.C. nature than D.C.. Inversely, the lesser the $I_{A.C.}$, the more pure is the D.C. output.

For proper functioning, electronic devices require pure D.C. The ripples are undesirable and they badly affect their performance.

The frequency of ripples in D.C. output is as follows:

(i) In case of H.W. rectifier output, this is the same as the frequency of supply mains.

(ii) In case of F.W. rectifier output, this is double that of the frequency of supply mains.

i.e. if supply frequency is f, the frequency of H.W. rectifier output is also f, whereas the frequency of F.W. rectifier output is 2f.

Mathematical Analysis

By definition the rms value of total current is given by

$$I_{rms}^2 = I_{D.C.}^2 + I_{A.C.}^2$$

$$I_{rms} = \sqrt{I_{D.C.}^2 + I_{A.C.}^2}$$

$$I_{A.C.} = \sqrt{I_{rms}^2 - I_{D.C.}^2}$$

Hence ripple factor = $\dfrac{I_{A.C.}}{I_{D.C.}} = \dfrac{\sqrt{I_{rms}^2 - I_{D.C.}^2}}{I_{D.C.}} = \sqrt{\left(\dfrac{I_{rms}}{I_{D.C.}}\right)^2 - 1}$

Now (I) For H.W. rectification

We know that $I_{rms} = I_m/2$ and $I_{D.C.} = I_m/\pi$

Ripple factor = $\sqrt{\left(\dfrac{I_m/2}{I_m/\pi}\right) - 1} = 1.21$

As can be seen Ripple factor is more than 1, H.W. rectification is quite ineffective.

(iii) For F.W. Rectification

$$I_{rms} = I_m/\sqrt{2}, I_{D.C.} = 2I_m/\pi$$

Ripple factor = $\sqrt{\dfrac{I_m/\sqrt{2}}{2I_m/\pi} - 1} = 0.48$

If Ripple factor is less than 1, it shows that F.W. rectification is more effective than H.W. rectification.

Filter Circuits

As we have seen that the output obtained from rectifiers contains A.C. ripples also. If such a pulsating D.C. is fed to electronic devices/circuits, it produces hum and the performance of the device circuit is not satisfactory. Therefore, it is necessary that the undesired A.C. from ripples may be removed(filtered). The circuit which remove or filter out A.C. ripples from rectifier output and provide a smooth D.C. are known as filter circuits.

TYPES OF FILTER CIRCUITS

Important filter circuits used in electronic devices are :

(i) Shunt capacitor filter

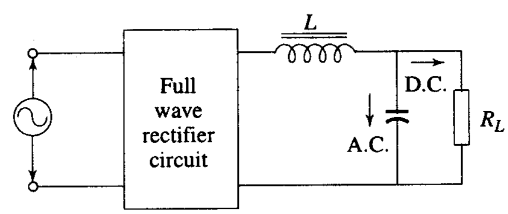
(ii) Series inductor filter

(iii) Choke input LC filter

(iv) Capacitor input π filter

Choke input LC filter

In this circuit, a choke L(in series) as well as a capacitor C(in shunt, i.e. parallel) is connected. The combined action of both improves the effectiveness of the circuit. The inductor blocks A.C. components and allows D.C. components to reach the load. The capacitor in its turn allows A.C. components to pass through it and D.C. components to the load. Therefore, by these combined actions of the two most of the D.C. components manage to reach the load. The effectiveness of the circuit can be improved further by using designed number of LC networks.

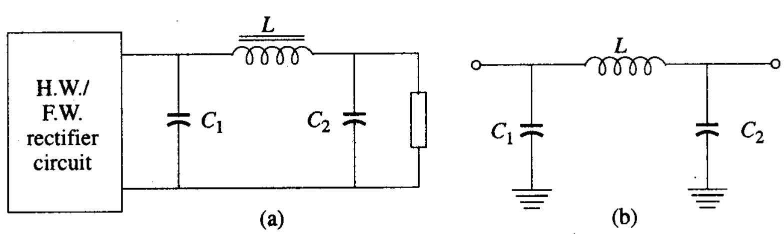


Choke input LC filter

Above figure shows the circuit.

Capacitor input π filter

This is just like LC filter circuit plus an additional capacitor across the output (figure a). This gives the circuit a shape of π(figure b) and hence the name.



Capacitor input π filter

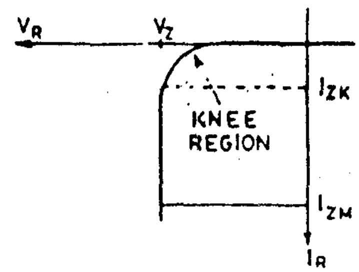
C_1 block D.C. components which, therefore, move towards the load. It provides low resistance path to A.C. components which flow through the inductor L.

L allows D.C. components, but blocks A.C. components and is heated up.

C_2 filters those components which manage to cross C_1 and L , and only pure D.C. appears across the load.

This is the most superior filter circuit and gives almost pure D.C. Can be used with H.W as well as F.W. circuits. Costly and heavier.

ZENER BREAKDOWN



There are two types of reverse breakdown in a **Zener diode**. One is the **avalanche breakdown** which occurs in rectifier diodes at a sufficiently high reverse voltage. The other type is **Zener breakdown** which occurs in a Zener diode at low reverse voltage. A Zener diode is highly doped to reduce the breakdown voltage, causing a very narrow depletion layer. As a result an intense electric field exists within the depletion layer. Near the breakdown voltage(V_Z), the field is intense enough to pull the electrons from their valance bands and create current.

Zener diodes with breakdown voltages of less than 5V operate predominantly in Zener breakdown. Those with breakdown voltages greater than approximately 5V operate predominantly by an avalanche breakdown. Both types are called Zener diodes. Zeners with breakdown voltage between 1.8 V to 200 V are commercially available.

Figure 23 shows the reverse portion of the characteristic curve of a Zener diode. As the reverse voltage V_R is increased the reverse current I_R remains extremely small upto the "**knee**" of the curve. At this point the breakdown effect begins, the Zener resistance R_z begins to decrease as the current I_Z increases rapidly. From the bottom of the knee, the breakdown V_Z remains essentially constant. It maintains an essentially constant voltage across its terminals over a specified range of reverse current values, I_{ZK} is the minimum reverse current that will bring the Zener in the breakdown region and I_{ZM} is the maximum Zener current that the Zener diode can pass without exceeding the power ratings. The regulating current range is from I_{ZK} to I_{ZM} of the Zener diode.

Zener Diode & Its Characteristics:

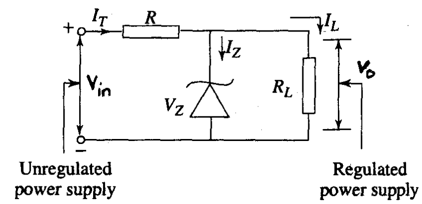
It is a P-N junction diode. It behaves like ordinary P-N junction diode. The only difference between a Zener diode and an ordinary diode is that a Zener diode has a sharply defined knee in its reverse characteristics as a figure previously shown..

Its forward characteristic is similar to that of a diode. when as Zener diode is reverse biased the reverse current is small so long as the reverse voltage is small. As the reverse voltage is increased a certain stage is reached when quick breakdown of the junction occurs and a large leakage current starts flowing through the Zener diode. The voltage at which the junction breaks down is known as Zener breakdown voltage V_B. By controlling the junction width and doping densities of diode, it is possible to make it to breakdown at a sharp specified Zener voltage.

Applications Of Zener Diode

Zener diode has wide industrial and commercial applications, some of these are

Voltage Regulation. A Zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The circuit is shown in figure.



The Zener diode of voltage V_z is connected in parallel with the load R_L across which constant output V_o is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across the load.

The total current I passing through R equals the sum of diode current and load current, i.e.

$$I = I_Z + I_L.$$

It will be seen that under all condition, $V_o = V_z$

Hence, $V_{in} = IR + V_o = IR + V_z$

Zener diode is reverse connected across the input voltage (V_{in}) whose variations are to be regulated. The Zener diode will maintain a constant voltage $V_z(=V_o)$ across the load so long as the input voltage V_{in} is more than V_z. This will cause the diode to conduct a large current I_z. Consequently the voltage drop across the resistance R will increase and this resistance absorbs any source voltage that is in excess of V_Z.. Hence a constant voltage $V_o = V_Z$ is maintained across the load (R_L). V_o would remains unaffected.

$$V_o = V_{in} - IR = V_{in} - (I_Z + I_L) R$$

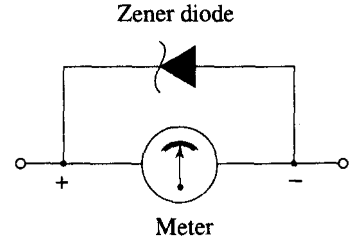
Incidentally, it may be noted that

$$R = \frac{V_{in} - V_o}{I_Z - I_L}$$

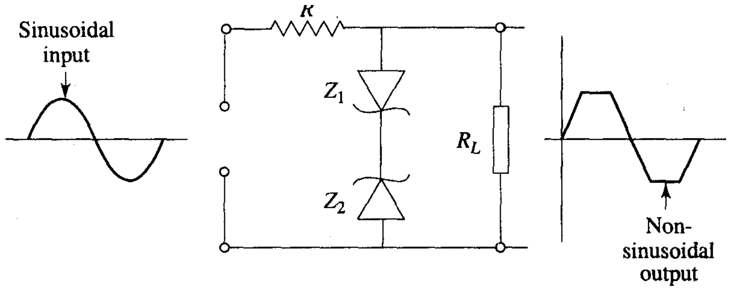
It may be noted that when diode current reaches its maximum value I_L. becomes zero. In that case

$$R = \frac{V_{in} - V_o}{I_d(\max.)}$$

Meter Protection. Zeners are employed for the protection of multimeters against overloads. In case of sudden overload, the extra current finds its path through the Zener, which is connected in parallel to the meter. No need to mention that the Zener should be connected in reverse bias. See figure.



Wave Shaping. Zener diodes are also used to obtain non-sinusoidal waves, which are required in the operation of television and other devices. Figure 26 shows how Zeners can be used in the circuit for obtaining a clipped output from a sinusoidal input.

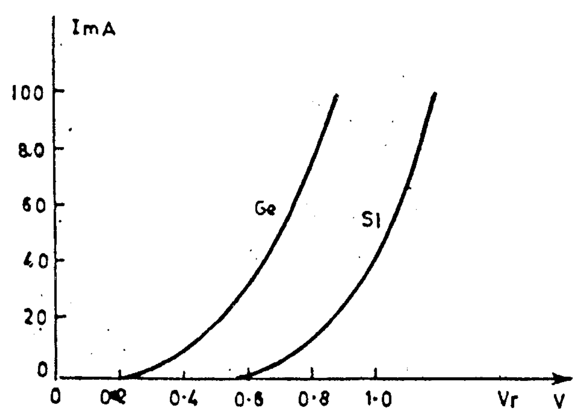


Getting non sinusoidal waveform

Switching with Zener Diode. Zener diode can produce sudden change from low current to high current, and hence is useful for switching operation. The use of Zener diode in switching operation has made possible an extremely fast performance in computer applications.

CUT IN VOLTAGE

Silicon diodes have, in general, higher PIV and current ratings and wider temperature ranges than germanium diodes. PIV ratings for silicon is in the neighborhood of 1000 V, whereas the maximum value for germanium is in the vicinity of 400 V. Silicon can be used where the temperature rises may be about 200^0C where in case of germanium upto 100^0C. The disadvantage of silicon as compared to germanium shown in given figure, is the higher forward bias voltage required to reach the region of upward swing. It may be noted that there exists a cut in offset, threshold or break point voltage V_r below which the current is very small(less than 1%). Beyond V_r the current rises very rapidly. From figure, V_r is approximately 0.2 V for germanium and 0.6 for silicon.



Cut in voltage

It can be seen that the break in the silicon diode characteristics is offset, about 0.4V with respect to the break in the germanium diode characteristics. The reason for this difference is to be found, inpart, in fact the reverse saturation current in germanium diode is normally larger by a factor of about 1000, than the reverse saturation current in a silicon diode of comparable ratings. I_0 is in the range of microamperes for a germanium diode and nano-amperes for a silicon diode at room temperature.

Since $\eta = 2$ for small currents in silicon, the current increases as $e^{v/2V}{}_G$ for the first several tenths of a volt and increases as $e^{V/vT}$ only at higher voltages. This initial smaller dependence of the current on voltage accounts for the further delay in the rise of the silicon characteristics.

AVALANCHE BREAKDOWN

This type of breakdown takes place in devices with thicker junction like semiconductor diodes. In this breakdown, electric field of the depletion layer becomes very high such that a high reverse voltage, electrons acquire very high velocities that they dislodge valence electrons from the semiconductor atom. This is a "cumulative" process and the field at the depletion layer attains such a high value that the process leads to the flow of an infinite large current which breaks down the junction permanently. The device can not regain its original position and is burnt off.

THERMAL BREAKDOWN

If a diode is biased and the bias voltage is well within the breakdown voltage at room temperature, there will be certain amount of current which is less than the breakdown current. Now keeping the bias voltage as it is, if the temperature is increased, due to the thermal energy, more number of carriers will be produced and finally breakdown will occur. This is *Thermal Breakdown*.

In zener breakdown, the covalent bonds are ruptured. But the covalent bonds of all the atoms will not be ruptured. Only those atoms, which have weak covalent bonds such as an atom at the surface which is not surrounded on all sides by atoms will be broken. But if the field strength is not greater than the critical field, when the applied voltage is removed, normal covalent bond structure will be more or less restored. This is Avalanche Breakdown. But if the field strength is very high, so that the covalent bonds of all the atoms are broken, then normal structure will not be achieved, and there will be large number of free electrons. This is *Zener Breakdown*.

In Avalanche Breakdown, only the excess electron, loosely bound to the parent atom will become free electron because of the transfer of energy from the electrons possessing higher energy.

ASSIGNMENT

Q.1. (AMIE W11, 4 marks): Differentiate between intrinsic and extrinsic semiconductors and find relation between dopants concentrations.

Q.2. (AMIE W07, 6 marks): Define an intrinsic material, a negative temperature coefficient and covalent bonding.

Q.3. (AMIE S08, 8 marks): Define the following terms, which are related to a semiconductor: (i) Dopant; (ii) Donors; (iii) Ionization energy; (iv) p -type semiconductor.

Q.4. (AMIE W09, 6 marks): Define the following :

(i) Intrinsic semiconductor

(ii) Extrinsic semiconductor

(iii) Mobility of hole.

Q.5. (AMIE W08, 12 marks): (a) Make a comparative study amongst the following related to a semiconductor.

(i) Intrinsic and extrinsic semiconductors.

(ii) Degenerate and non-degenerate semiconductors.

(iii) Drift and diffusion current.

(iv) Donor and acceptor impurities.

Q.6. (AMIE S09, 5 marks): How can an intrinsic semiconductor be extrinsic? Make a comparative study between a p-type and n -type of extrinsic semiconductor.

Q.7. (AMIE W05, S08, 10, 13, 6 marks): Explain the difference in conduction among insulators, semiconductors and conductors, showing the energy band diagrams.

Q.8. (AMIE W10, 5 marks): Explain the concept of mobility and conductivity of a semiconductor material in an electric field. Derive an expression for its current density. Modify the expression considering diffusion current.

Q.9. (AMIE W13, 6 marks): What is capacitive filter and how does it work ?

Q.10. (AMIE W07, 6 marks): What is a Zener diode and where it is mostly used?

Q.11. (AMIE S09, 10, 13, 5 marks): Make a comparative study between an avalanche p - n junction diode and a Zener diode.

Q.12. (AMIE S11, 6 marks): What is Zener breakdown? How is it different for Avalanche breakdown? Explain.

Q.13. (AMIE W10, 5 marks): Why is Zener diode used in a circuit ? Explain why a series resistance is used with a Zener from an unregulated supply to, have a fixed reference voltage. Mention the procedure for appropriate choice of the value of series resistance with the Zener diode.

Q.14. (AMIE W11, 6 marks): Draw and explain V-I characteristics of Zener diode.

Q.15. (AMIE S05, 6 marks): What is the effect of temperature on a P-N junction diode? Explain the characteristic curves of silicon diode for various temperatures.

Q.16. (AMIE W05, 6 marks): How do the transition region width and contact potential across a p-n junction vary with allied bias voltage?

Q.17. (AMIE W06, 6 marks): Draw the piecewise linear volt-ampere characteristic of a p n diode. What is the circuit model for the ON-state?

Q.18. (AMIE W06, 6 marks): Define peak inverse voltage. What is the peak inverse voltage for a full wave circuit using ideal diode ?

Q.19. (AMIE S07, 4 marks): Discuss how charge carriers are made available for controlled conduction in a semiconductor device.

Q.20. (AMIE S07, 4 marks): What is the potential energy barrier of a p-n junction diode ? How does it arise and what is its order of magnitude?

Q.21. (AMIE W09, 6 marks): What is the important difference between the characteristics of a simple switch and those of an ideal diode?

Q.22. (AMIE S10, 4 marks): Define the following terms: (i) 'cut-in voltage' of a p-n junction diode (ii) 'knee voltage' of a p-n junction diode.

Q.23. (AMIE S11, 8 marks): Distinguish between majority and minority carriers in a semiconductor. Also, define and explain mobility of charge carriers.

Q.24. (AMIE W07, 6 marks): Describe in your own words how 'diffusion' and 'transition' capacitance differ.

Q.25. (AMIE W05, 13, 8 marks): Draw the circuit diagram of a full wave rectifier with capacitive filter and derive expression for (i) ripple factor (ii) d.c. voltage

Q.26. (AMIE W06, 8 marks): Sketch the circuit for a full wave rectifier. Derive the expression for (i) the dc current (ii) the dc load voltage (iii) the dc diode voltage (iv) the rms current.

Q.27. (AMIE W10, 6 marks): Draw the simple circuit for one full wave rectifier using two diodes. For full wave rectifier, find the above four expressions.

Q.28. (AMIE S08, 09, 10 marks): With a neat circuit diagram, explain the operation of a full wave rectifier circuit. Prove that its efficiency is 81.2%.

Q.29. (AMIE S12, 5 marks): Describe full wave rectifiers with capacitive filters. How do you find its ripple factor?

Q.30. (AMIE W10, 6 marks): Find and compare the values of maximum efficiency and ripple factor for half wave and full wave rectifiers mentioned above.

Q.31. (AMIE S07, W08, 13, 8 marks): Draw and explain a full wave bridge rectifier circuit. What is its rectification efficiency ?

Q.32. (AMIE W11, 10 marks): Draw and explain the circuit of a bridge rectifier. Derive expressions for average and rms output currents for a 10 ohm load.

Q.33. (AMIE W10, 13, 8 marks): Draw the simple circuit of one half wave rectifier using diode. With half wave rectifier, using sinusoidal input having diode of forward resistance r and load resistance R_L, find the expressions for (i) average value of current, (ii) rms value of current, (iii) rectifier efficiency, and (iv) ripple factor.

Q.34. (AMIE W12, 10 marks): Give the simple circuit diagram for half wave and full wave rectifiers using semiconductor diode. Find the expressions for efficiency of these rectifiers.

Q.35. (AMIE S10, 4 marks): Make a comparative study between different types of rectifier circuits.

Q.36. (AMIE W12, 10 marks): What are the values of ripple factors for these rectifiers. Comment on the improvement of ripple factor on the type of rectification. Describe the operation of capacitive filter in this context on further improvement of ripple factor.

Q.37. (AMIE S07, 4 marks): What is the value of series resistance required when 10W, 10V, 1000mA zener diodes are connected in series to obtain 20 V regulated output from a 35 V d.c. source?

Answer: 15 Ω

Q.38. (AMIE W07, 8 marks): Find the conductivity and resistivity of an intrinsic semiconductor at temperature of 300K. It is given that $n_{ij} = 2.5 \times 10^{13}/cm^3$, $\mu_m = 3800\ cm^2/sV$, $\mu_p = 1800\ cm^2/sV$, $e = 1.6 \times 10^{-19}$ C.

Answer: 44.5 Ω cm

Q.39. (AMIE S08, 6 marks): At 300 K the intrinsic carrier concentration of silicon is 1.5 x 10^{16} m^{-3}. If the electron and hole mobilities are $0.13 m^2$/V-s and $0.05 m^2$/V-s, respectively, determine the intrinsic resistivity of silicon at 300 K.

Answer: 2.314 x 10^4 Ωm

Q.40. (AMIE W08, 8 marks): A specimen of silicon has square cross-section of 2 x 2 cm^2 and length of 2 cm. The current is due to electrons whose mobility is $1300 cm^2$/V-S. An applied d.c. voltage of 1 V across the bar produces a current of 8 mA in it. Calculate (i) concentration of free electron, and (ii) drift velocity.

Answer: 4.8 x 10^{22} m^{-3}, 6.5 m/s

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