Basic Electronics Engineering

UNIT I : DIODE CIRCUITS

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Topics:

Half wave rectifier, Full wave rectifier, power supply filters and Capacitor filters, Diode limiting (clippers) and Clamping circuits, Voltage multipliers, Zener diode & its applications, LEDs and Photodiodes.

Objectives: The objective of this unit is to study various types of diodes and their applications.

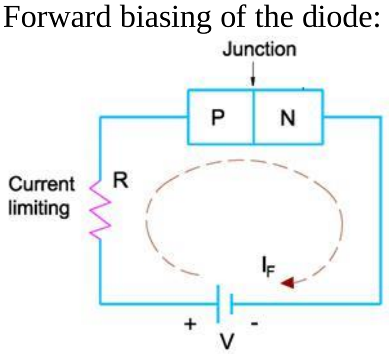
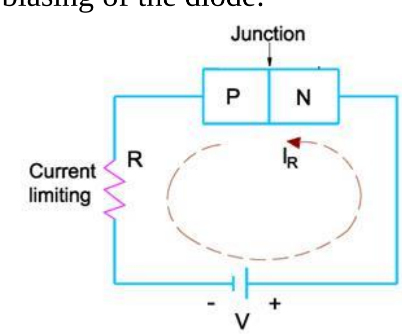
Outcomes:

At the end of this unit, the learner will be able to:

1. Compare Half wave, Full wave center tapped and Bridge rectifier.
2. Draw block diagram of Power supply and understand use of capacitor filter.
3. Understand Clipping and Clamping Circuits.
4. State types of Voltage Multipliers.
5. Understand Zener diode Characteristics and its application.
6. Compare Light Emitting Diode and Photodiode.

Pre-requisites: Learner should be familier with the Semiconductor Theory and basics of diode before learning diode circuits. To summaries the prerequisites in short, as this is very important basics for the learner to start with diode circuits.

. We will summaries it through the difference between the two types as forward biasing and reverse biasing.

Sr.No.	Forward Biasing	Reverse Biasing
1	Here, anode is connected to the positive terminal of the external DC source and cathode is connected to the negative terminal of the DC source.	Here, anode is connected to the negative terminal of the external DC source and cathode is connected to the positive terminal of the DC source.
2	Depletion region is narrow.	Depletion region is wider.
3	As the depletion region is narrow, the forward resistance offered by the diode is very less.	As the depletion region is wider, the resistance offered by the diode is very high.
4	Ideally, the forward resistance offered by the diode is zero.	Ideally, the resistance offered by the diode is infinite.
5	When diode is forward biased, large current flows through the diode.	When diode is reverse biased, current does not flow through the diode. But due to minority charge carriers a very small amount of current flows through it called as reverse saturation current.
6	Forward voltage drop for Silicon diode is 0.7V and 0.3V for Germanium diode.	Reverse voltage is approximately equal to the applied voltage and its polarity opposite to the polarity of forward voltage.
7	Forward biasing of the diode: 	Reverse biasing of the diode: 

UNIT-I: DIODE CIRCUITS

1. Rectifier:

Rectifier is an Electronic device which converts alternating current (A.C) into Pulsating direct current (D.C.) using one or many P-N Junction diodes.

1.1.1. Half Wave Rectifier (HWR):

In half wave rectifier only one diode is used. The name is given like HWR because here the input power is delivered to the output only for the half cycle. The diode conducts only during positive or negative half cycle of A.C. supply. According to diode orientation in the circuit positive or negative half cycle of A.C. supply is eliminated at the output.

Circuit Diagram and Explanation:

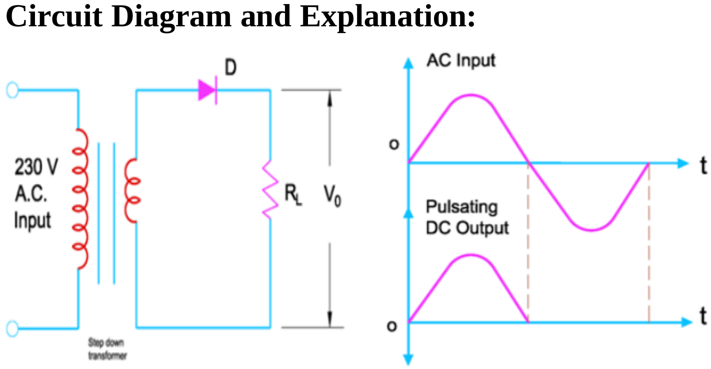


Fig. 1.1.1.1(a) Positive half wave rectifier

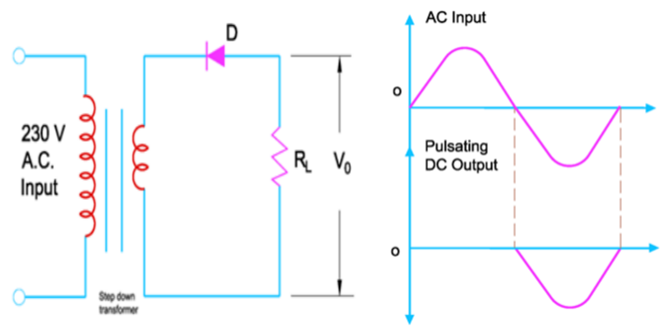


Fig. 1.1.1.1(b) Negative half wave rectifier

Half wave rectifier circuit consists of resistive load, P-N junction diode and A.C. input is applied through suitable step-up or step down transformer. As shown in waveforms of fig 1.1.1.4, the input voltage to the circuit is sinusoidal A.C. voltage having 50Hz supply frequency.

Operation of the circuit:

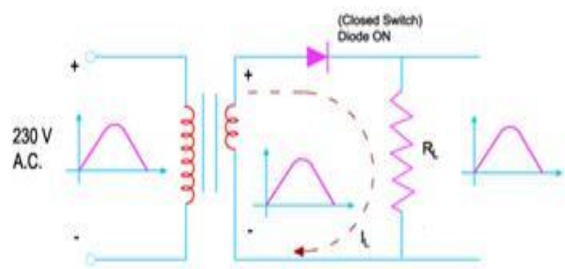


Fig. 1.1.1.2 Positive half cycle

Positive half wave rectifier circuit is as shown in figure 1.1.1.1(a). <u>During the positive half cycle</u> of secondary A.C. Voltage, anode of the diode is positive with respect to cathode as shown in fig. 1.1.1.2. Diode is forward biased and it offers a less forward resistance, acts as a closed switch and current starts to flow in the circuit in clockwise direction. This current flow through a load resistor R_L is known as load current i_L. The output load voltage is the product of i_L and R_L.

<u>During the negative half cycle of</u> secondary A.C. Voltage, anode is negative with respect to cathode and diode becomes reverse biased. Due to reverse biased, diode offers a very high resistance and acts as an open switch and no current flows in the circuit as shown in fig.1.1.1.3.

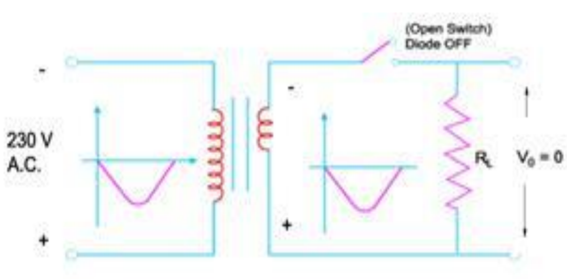


Fig. 1.1.1.3 Negative half cycle

Due to this operation, the circuit current, which is also the load current and load voltage are in the form of half sinusoidal pulses. That is, the power at the input is delivered to the output only during the half cycle. Here, as shown in figure 1.1.1.1 (a) positive part of the input waveform is delivered at the output.

Similarly, as shown in figure 1.1.1.1 (b), diode orientation is changed and hence power is delivered at the output during negative part of the input waveform. This is the circuit of negative half wave rectifier. Waveforms for load current, load voltage and across diode for positive half wave rectifier are shown in detail in figure 1.1.1.4.

Performance Parameters of Half wave Rectifier:
(Analysis)

Finding the performance parameters of HWR is nothing but analysis of HWR.

1. **DC current or average load current (I_{Ldc}):**

We know that, the average value of a periodic function is given by the area under one cycle of the function divided by the base or period. As shown in load current waveform, consider one complete cycle.

$$I_{Ldc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t\, d\omega t = -\frac{I_m}{2\pi}[\cos\pi - \cos 0]\text{----}$$

Here I_m=Peak amplitude of the load current $I_{Ldc} = -\frac{I_m}{2\pi}[-1-1] = \frac{I_m}{\pi}$, Where $I_m = \frac{V_m}{R_s+R_f+R_L}$,

R_s=Transformer secondary Resistance, R_f= Diode forward

resistance, V_m=Maximum or peak secondary voltage.

2. **DC voltage or average load voltage (V_{Ldc}):** For a purely resistive load the average load voltage or dc voltage is given by, $V_{Ldc} = I_{Ldc}\,x\,R_L$, Substituting I_{Ldc} value from above equation, $V_{Ldc} = \frac{I_m}{\pi}\,x\,R_L$, Substituting the value of I_m in above equation, ,$V_{Ldc} = \frac{V_m}{\pi(R_s+R_f+R_L)}\,x\,R_L$, R_s and R_f are very small as compared to R_L, so neglecting $R_s + R_f$ term from above equation,$V_{Ldc} = \frac{V_m}{\pi}$ Where, V_m = Peak or maximum secondary voltage.

3. **AC current or RMS load current (I_{Lrms}):** To analyze the root mean square value of load current, write the equation of current accordingly.

$$I_{Lrms} = \left[\frac{1}{2\pi}\int_0^{\pi} {I_m}^2\sin^2\omega t\, d\omega t\right]^{1/2} = \left[\frac{Im^2}{2\pi}\int_0^{\pi}\frac{(1-\cos 2\omega t)}{2}\, d\omega t\right]^{1/2} = \frac{I_m}{2}\left[\frac{1}{\pi}\left(\pi - \frac{1}{2}\sin 2\pi\right)\right]^{1/2} = \frac{I_m}{2}$$

4. **AC voltage or RMS load voltage (V_{Lrms}):** For a purely resistive load the rms load voltage or AC voltage is given by, $V_{Lrms} = I_{Lrms}\,X\,R_L = \frac{I_m}{2}\,x\,R_L = \frac{Vm}{2(R_s+R_f+R_L)}\,x\,R_L$

R_s and R_f are very small as compared to R_L, so neglecting $R_s + R_f$ term from above equation,$V_{Lrms} = \frac{V_m}{2}$

Line regulation is the change in regulated load voltage due to change in line voltage at constant load current. Load regulation is the capability to maintain a constant voltage on output channel of power supply despite changes in supply's load. % voltage regulation $= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$

Where, V_{NL} is average load voltage at no load condition i.e. at zero load current when $R_L = \infty$ so, $V_{NL} = \frac{V_m}{\pi}$

V_{FL} is average load voltage at full load condition i.e. at maximum load current. So, $V_{FL} = \frac{V_m}{\pi} \times \frac{R_L}{R_s+R_f+R_L}$

Substituting these values of V_{NL} and V_{FL} in above equation of voltage regulation and simplifying we will get,

% voltage regulation $= \frac{R_s+R_f}{R_L} \times 100\%$.

Ideally the load regulation should be zero and practically it should be as low as possible.

5. **<u>Ripple factor (r):</u>** It is denoted by a notation r. Rectifier output consist of AC as well as DC components. Ripple factor is used to measure percentage of AC component present at the output of rectifier. Ideally ripple factor should be zero and practically it should be as small as possible.
It can be also defined as the ratio of RMS value of the AC component of output to the DC or average value of the output. $r = \left[\frac{{V_{Lrms}}^2 - {V_{Ldc}}^2}{V_{Ldc}}\right]^{1/2}$ Substituting the approximate values from the above derivations we get,

$$r = \frac{\left[\left(\frac{V_m}{2}\right)^2 - \left(\frac{V_m}{\pi}\right)^2\right]^{1/2}}{\frac{V_m}{\pi}} = \pi \times \left[\frac{1}{4} - \frac{1}{\pi^2}\right]^{1/2}$$

= 1.211 or 121%. This high ripple factor value indicates that output of HWR is not very close to the pure dc voltage. To get this a filter is required. The ripple factor value can be also derived considering the current equations instead of voltage equations. We can get the same ripple factor value using that derivation too.

6. **<u>Voltage regulation:</u>** Ideally the rectifier output voltage should remain constant, but practically it varies as the load current changes. Basically there are two types of regulators namely, line regulation/ source regulation and load regulation.

Line regulation is the change in regulated load voltage due to change in line voltage at constant load current. Load regulation is the capability to maintain a constant voltage on output channel of power supply despite changes in supply's load. % voltage regulation $= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$

Where, V_{NL} is average load voltage at no load condition i.e. at zero load current when $R_L = \infty$ so, $V_{NL} = \frac{V_m}{\pi}$

V_{FL} is average load voltage at full load condition i.e. at maximum load current. So, $V_{FL} = \frac{V_m}{\pi} \times \frac{R_L}{R_s+R_f+R_L}$

Substituting these values of V_{NL} and V_{FL} in above equation of voltage regulation and simplifying we will get,

% voltage regulation $= \frac{R_s+R_f}{R_L} \times 100\%$.

Ideally the load regulation should be zero and practically it should be as low as possible.

7. **<u>Rectification Efficiency (η):</u>** It is also called as power conversion efficiency. It is the ratio of DC output power (P_{Ldc}) to the AC input power (P_{ac}). $\eta = \frac{P_{Ldc}}{P_{ac}}$ Let us first find the formula for DC output power and AC input power. DC output power (P_{Ldc}) $= {I_{Ldc}}^2 \times R_L = \frac{{I_m}^2}{\pi^2} \times R_L = \frac{{V_m}^2}{\pi^2\,(R_s+R_f+R_L)^2} \times R_L$------ after substituting Im value $= \frac{{V_m}^2}{\pi^2\,R_L}$, AC input power ($P_{ac}$) $= {I_{srms}}^2 \times R_L$

Here, I_{srms} is RMS value of secondary current. In HWR, the secondary current is same as load current. Hence RMS value of secondary current is same as the RMS value of load current. $I_{srms} = I_{Lrms} = \frac{I_m}{2}$

Putting this value in above equation of AC input power, $P_{ac} = \frac{{I_m}^2}{4} \times R_L$, Substituting now P_{Ldc} and P_{ac} in $\eta = \frac{P_{Ldc}}{P_{ac}}$ we get, $\eta = \frac{4}{\pi^2} = 0.4$ or 40% ,Efficiency in HWR is 0.4 or 40%. Ideally efficiency should be 100% and practically as high as possible.

8. **Transformer utilization factor (TUF):** TUF indicates utilization of input transformer in the circuit. Ideally it should be utilized 100%. Here we will find its utilization in HWR. TUF is defined as the ratio of DC output power to the AC power rating of the transformer. i.e.

$$\text{TUF} = \frac{\text{DC output power}}{\text{AC power rating of the transformer}} = \frac{V_{Ldc} \times I_{Ldc}}{V_{srms} \times I_{srms}} = \frac{\frac{V_m}{\pi} \times \frac{I_m}{\pi}}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{2}} \text{.....Assuming } (R_s + R_f) << R_L$$

$\text{TUF} = \frac{2\sqrt{2}}{\pi^2} = 0.287$ or 28.7% Practically TUF should be as high as possible but for HWR it is just 28.7%.

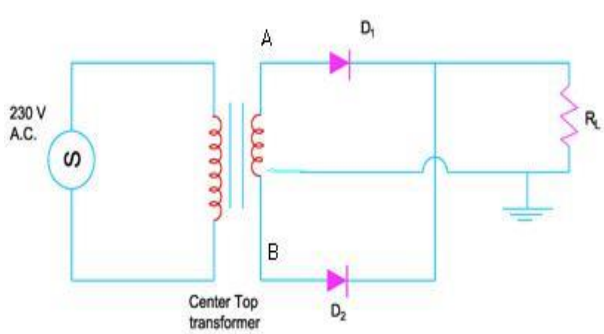
9. **Peak Inverse Voltage (PIV):** It is the maximum negative voltage which diode has to sustain when it will be reverse biased. When diode is reverse biased, the maximum negative voltage across the diode is $-V_m$. As PIV denotes the maximum reverse voltage capability of a diode, selection of diode should be done by considering this parameter as the most important parameter. We must select a diode having PIV rating higher than the maximum negative voltage V_m to ensure safety of the diode otherwise diode may get damaged.

10. **Ripple Frequency:** Ripple frequency is the frequency of the pulsating load voltage waveform. It indicates how often ripple occurs. For half wave rectifier it is same as AC mains i.e. 50Hz.

Disadvantages of Half wave Rectifier:

1. The output of HWR is a pulsating DC which contains AC component so filtration is needed to get steady direct current.
2. Input power is delivered to the output only half the time so output is low.
3. Ripple factor is very high.
4. It has very low rectification efficiency.
5. Its transformer utilization factor is very low, just 28.7%.
6. Possibility of transformer core saturation due to unidirectional flow of current.

1.1.2. Full wave Rectifier with center tapped transformer (FWR):



Disadvantages of HWR are resolved at maximum level in FWR with center tapped transformer. In full wave rectifier with center tapped transformer two diodes are used. The name full wave rectifier indicates that the input power is delivered to the output for the full input cycle.

The special transformer used is a center tapped transformer having two secondary windings and the output at each half of the secondary is equal in magnitude. The winding resistance

Fig.1.1.2.1 FWR with center tap transformer

of the two secondary is same in magnitude. The two diodes are connected in the circuit in such a way that input power is delivered to the output for the complete input AC signal.

Operation of the circuit:

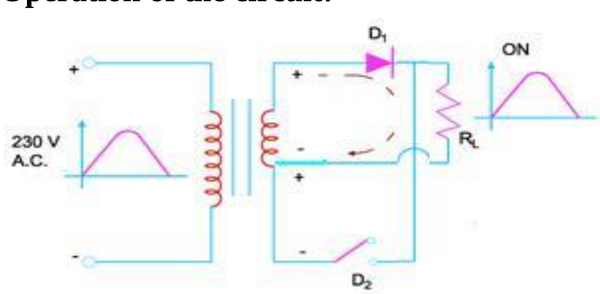


Fig.1.1.2.2 Equivalent circuit for positive half cycle

During positive half cycle: Due to use of center tapped transformer during positive half cycle equal amount of secondary voltage is obtained across the first and second half of the secondary. Due to this positive polarity at diode D1, diode D1 is forward biased and due to negative at the anode of diode D2, it is reverse biased. D1 allows the flow of current in the circuit as shown in fig.1.1.2.2. Due to this flow of current, output voltage is produced across load resistance R_L because of diode D1.

During Negative half cycle: During negative half cycle of the input, opposite polarity occurs at the secondary of the transformer as compared to positive half cycle. This polarity makes diode D1 reverse biased and diode D2 forward biased. Diode D2 allows the flow of current in the same direction as that of diode D1 as shown in fig. 1.1.2.3. This flow of current generates the output voltage as shown.

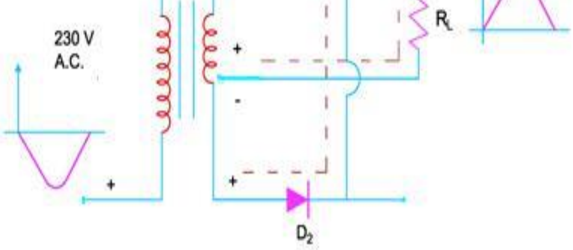
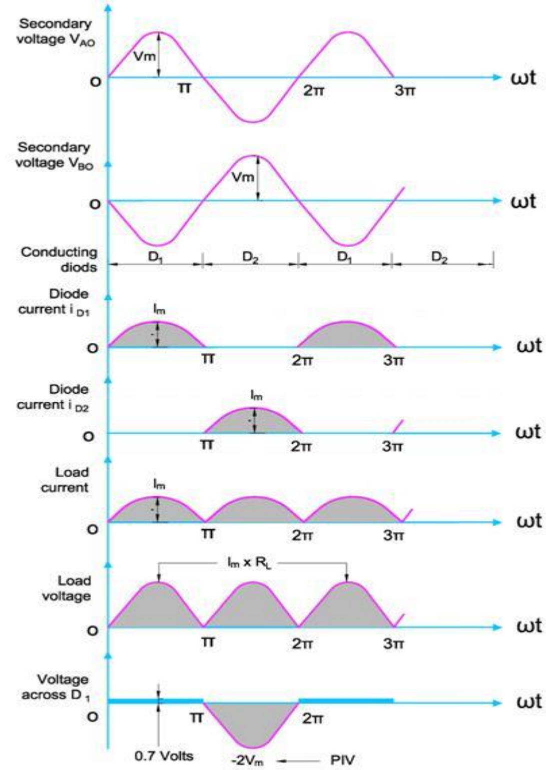


Fig.1.1.2.3 Equivalent circuit for negative half cycle

In this way FWR delivers output for both, positive and negative half cycle. Direction of load current for both cycles is same and continuous to be positive.

Voltage and current waveforms for full wave center tapped rectifier are shown in figure 1.1.2.4. Waveform for voltage across diode D1 is shown at the last. Learner can try to draw the waveform across diode D2 exactly in the same way.



1.1.3. Bridge Rectifier (BR):

Disadvantages of FWR with center tapped transformer are resolved here in bridge rectifier. Bridge rectifier uses four diodes which are connected to form a bridge. Bridge rectifier is a type of full wave rectifier.

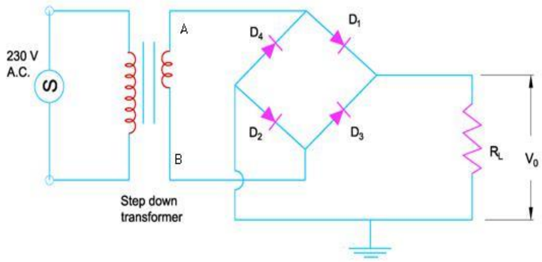


Fig.1.1.3.1 Bridge rectifier circuit

Here, step down transformer is used instead of center tapped transformer.

Operation of the circuit:

Input 230V A.C. signal is applied to the step down transformer as shown in the figure 1.1.3.1. Four diodes D1, D2, D3, D4 are connected to form a bridge.

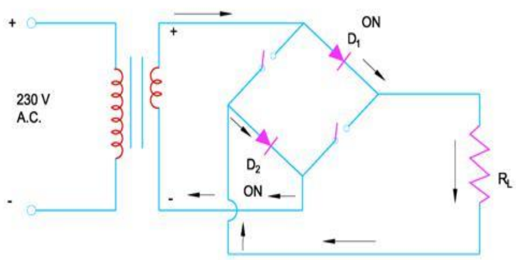


Fig.1.1.3.2 Flow of current during positive half cycle

<u>During positive half cycle:</u>

During positive half cycle of the ac supply the secondary voltage is positive. This polarity makes diode D1 and D2 forward biased whereas D3 and D4 reverse biased. Diode D1 and D2 allows the flow of current in the circuit as shown in fig 1.1.3.2 and output voltage is positive as shown in the waveforms in figure 1.1.3.4.

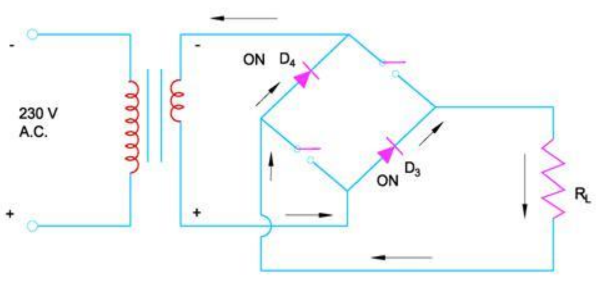


Fig.1.1.3.3 Flow of current during negative half cycle

<u>During Negative half cycle:</u>

During negative half cycle of the ac supply the secondary voltage is negative. This polarity makes diode D1 and D2 reverse biased whereas D3 and D4 forward biased. Diode D3 and D4 allows the flow of current in the circuit as shown in fig 1.1.3.3. Output voltage is positive as shown in the waveforms in figure 1.1.3.4.

Here, in bridge rectifier at a time two diodes conduct. If the diodes are non ideal diodes, the drop across two diodes is more as compared to HWR and FWR with center tapped transformer.

The waveforms observed in bridge rectifier for various parameters are same as that of full wave rectifier with center tapped transformer. The only difference in the waveforms is, instead of naming a single diode in the waveforms of FWR with center tapped transformer two diodes are to be indicated. The waveforms for bridge rectifier are indicated in figure 1.1.3.4.

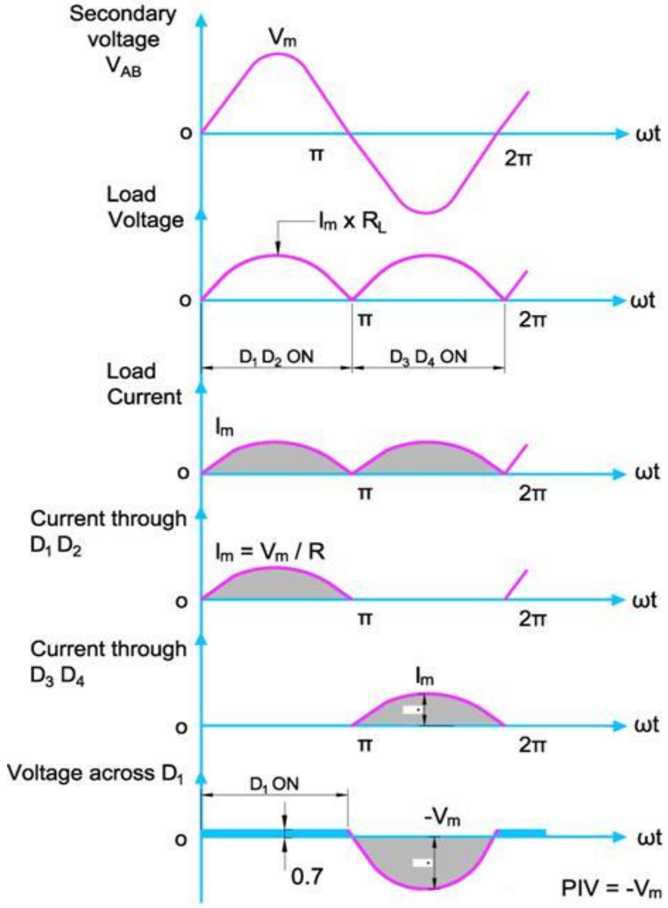


Fig.1.1.3.4 Waveforms for bridge rectifier

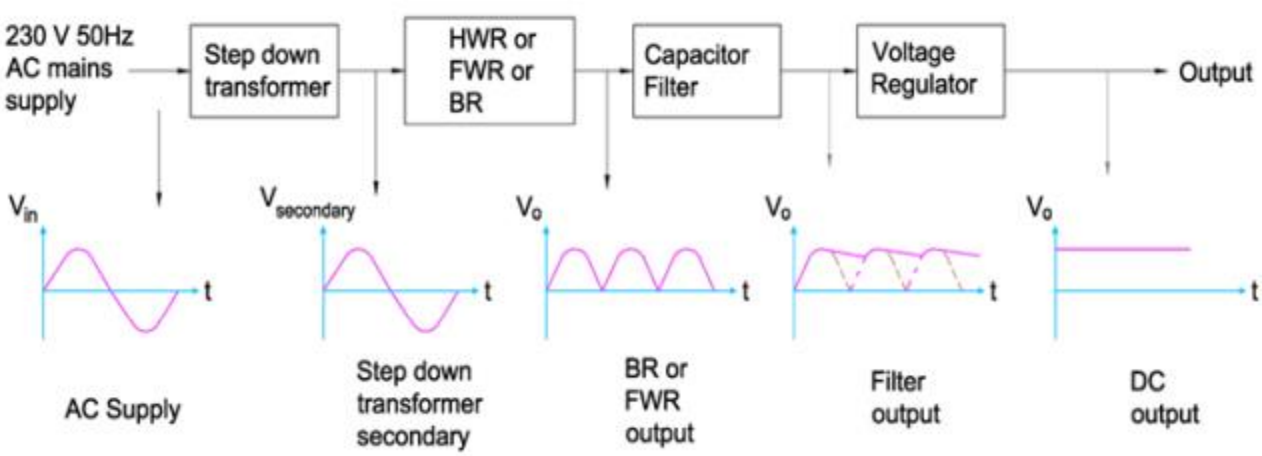
Disadvantages of Bridge Rectifier:

1. The number of diodes required is four.
2. Two diodes conduct simultaneously so the voltage drop across them increases and ultimately reduces the output voltage.

1.3 Comparison of Rectifiers:

Sr. No.	Parameter	HWR	FWR	BR
1	Number of diodes used	1	2	4
2	Is center tap transformer required	Not required	Required	Not required
3	Construction	Simple	Complicated	Simple
4	Transformer core saturation	Possible	Not Possible	Not Possible
5	DC current or average load current (I_{Ldc})	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
6	DC voltage or average load voltage (V_{Ldc})	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
7	AC current or RMS load current (I_{Lrms})	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
8	AC voltage or RMS load voltage (V_{Lrms})	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
9	Ripple factor (r)	1.21 or 121%	0.48 or 48%	0.48 or 48%
10	DC load power P_{dc}	$\frac{{I_m}^2}{\pi^2}$ RL	$\frac{4{I_m}^2}{\pi^2}$ RL	$\frac{4{I_m}^2}{\pi^2}$ RL
11	Rectification Efficiency (η)	40%	81.2%	81.2%
12	Transformer utilization factor (TUF)	28.7%	69.3%	81.2%
13	Ripple Frequency	$50H_Z$	$100H_Z$	$100H_Z$
14	Peak Inverse Voltage(PIV)	V_m	$2V_m$	V_m
15	Expression for peak load current	$I_m = \frac{V_m}{RS + Rf + RL}$	$I_m = \frac{V_m}{RS + Rf + RL}$	$I_m = \frac{V_m}{RS + 2Rf + RL}$
16	Relation between ripple factor & capacitor filter	$r = \frac{1}{2\sqrt{3}fC\,R_L}$	$r = \frac{1}{4\sqrt{3}fC\,R_L}$	$r = \frac{1}{4\sqrt{3}fC\,R_L}$
17	Ripple voltage V_{rrms}	$Vr(rms) = \frac{Idc}{2\sqrt{3}fC}$	$Vr(rms) = \frac{Idc}{4\sqrt{3}fC}$	$Vr(rms) = \frac{Idc}{4\sqrt{3}fC}$
18	DC output voltage from a capacitor filter	$V_m - Idc[\frac{1}{2fC}]$	$V_m - Idc[\frac{1}{4fC}]$	$V_m - Idc[\frac{1}{4fC}]$

1.4 Power supply block diagram



Power supply is an electronic instrument used to provide regulated DC supply. It uses rectifiers along with capacitor filter to get pure ripple free dc voltage. Let us understand the blocks in power supply as shown in fig. 1.4.1. and their use to get regulated dc power supply at the output if ac mains supply is applied at the input. Block diagram of power supply consist of following blocks:

1. **Transformer:** Transformer is also called as AC to AC converters. They are basically used to transform the signal from primary side (AC) to secondary side (AC) of the transformer. Depending upon the type of transformer used either it increases the voltage level or decreases it at the secondary side. If the input supply of 230V, 50Hz AC signal is applied to the step down transformer, it gives the secondary voltage less than 230V signal. Frequency remains same at the primary and secondary side of the transformer. Usually step up transformers are used when high ac supply range is needed. Here we have shown the step down transformer.
2. **Rectifier:** Rectifier using diode circuit is used to convert A.C. supply into pulsating dc. Here, we have shown bridge rectifier in the circuit diagram. The output of step down transformer is given as input to the bridge rectifier. The pulsating dc is obtained from bridge rectifier. The associated output waveform at each block is also shown in the block diagram.
3. **Filter:** Filter circuit is used to remove the AC component from the output of bridge rectifier to get pure dc output. The filter circuitry is nothing but a capacitor connected in shunt between rectifier and the load. Usually electrolytic capacitors are used to remove ripple content successfully. The RC time constant should be very high and for this value of capacitor must be high. The waveform is shown at the output of filter capacitor.
4. **Voltage Regulator:** The output of filter is an unregulated dc voltage. In order to get pure or regulated dc supply voltage regulator is needed. Zener diode is a device used as a voltage regulator. It is connected in shunt between filter and the load. Zener diode is always used in reverse biased. It tries to maintain the output dc voltage constant.

Zener diode and its Applications:

Introduction: Zener diode is a special type of p-n junction semiconductor diode. Its construction is similar to that of a conventional p-n junction diode. However in constructing the zener diodes, the reverse breakdown voltage is adjusted between 3V to 200V. Most of its applications are based on this principle and so it is also called as a breakdown diode. In order to achieve the precise value of reverse breakdown voltage, the doping level of the impurity to be added to manufacture the zener diode is controlled

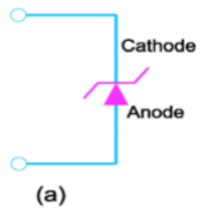


Fig.1.8.1.1.(a) Symbol of zener diode

Zener diode can be operated in forward biased or reverse biased. Its operation in the forward biased mode is same as that of a p-n junction diode but its operation in reverse biased mode is substantially different.

Zener diode is a two terminal device having anode and cathode terminals as shown in Fig.1.8.1.1 (a). Arrowhead in the symbol indicates the conventional direction of current through the zener diode, when it is forward biased.

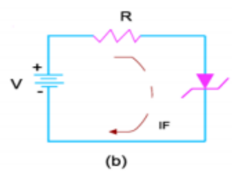


Fig.1.8.1.1.(b) Forward Biased zener diode

Forward biasing of zener diode:

When the anode of zener diode is connected to the positive terminal of the dc source and the cathode is connected to the negative terminal, the zener diode is said to be forward biased. It behaves like a forward biased p-n junction diode. The forward (b) biasing of the diode is shown in Fig.1.8.1.1 (b). Zener diode is generally not used in the forward biased condition.

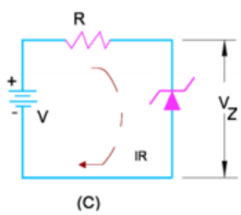


Fig.1.8.1.1 (c) Reverse Biased zener diode

Reverse biasing of zener diode:

When the anode of zener diode is connected to the negative terminal of the dc source and the cathode is connected to the positive terminal, the zener diode is said to be reverse biased. It behaves differently in reverse biased as compared to p-n junction diode. The reverse biasing of the diode is shown in Fig.1.8.1.1 (c). Zener diode is generally used as a voltage regulator in the reverse biased condition.

1.8.2 V-I characteristics of a Zener diode:

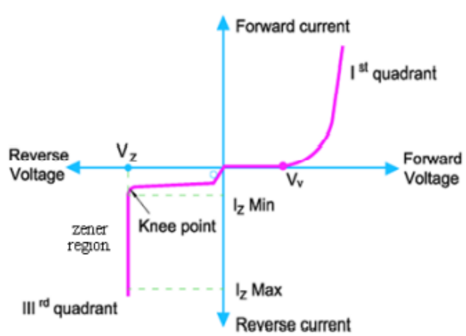


Fig.1.8.2.1. VI characteristics of zener diode

VI characteristics of zener diode are divided into two parts namely, forward characteristics and reverse characteristics.

Forward characteristics of zener diode are almost identical to the forward characteristics of a p-n junction diode and are shown in the first quadrant of Fig.1.8.2.1.

Reverse characteristics are different from that of p-n junction diode and are shown in the third quadrant of the Fig.1.8.2.1. When reverse voltage is increased, initially a very small reverse saturation current I_o will flow. This current is due to thermally generated minority carriers and is in µA range. At a certain value of reverse voltage, the reverse current will increase suddenly and sharply and this indicates that breakdown has occurred. This breakdown voltage is known as zener breakdown voltage or zener voltage and is denoted by a notationVZ. The value of VZ can be controlled by controlling doping levels of p and n regions during manufacturing. After breakdown, the voltage across zener diode remains constant and is equal toVZ. Any further increase in source voltage result in the increase in reverse zener current and it can be controlled by connecting a resistor R in series with the zener diode as shown in Fig.1.8.1.1 (c). This resistor avoids any damage to the device due to excessive heating. As shown in the characteristics, after reverse breakdown, the zener diode operates in a region called zener region. In this region, the voltage across zener diode remains constant but current changes depending on the supply voltage. Zener diode is used as a voltage regulator in this region.

1.8.3 Breakdown Mechanism in Zener diode:

The two breakdown mechanisms in zener diode are zener breakdown and avalanche breakdown.

<u>Zener breakdown:</u>

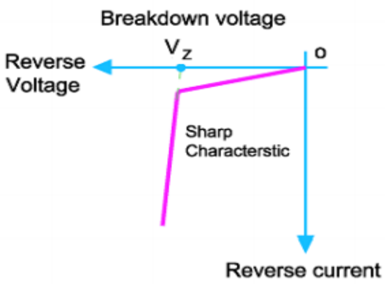


Fig.1.8.3.1 Zener breakdown

Zener breakdown is observed in the zener diodes having V_Z less than 5V or between 5 to 8V. When such a reverse voltage is applied to a zener diode it causes a very intense electric field to appear across a narrow depletion region. This intense electric field is strong enough to pull some of the valence electrons into conduction band by breaking their covalent bonds. These electrons are become free and available for conduction. A large number of free electrons will constitute a large reverse current through the zener diode and breakdown is said to have occurred due to the zener effect. Here, the breakdown voltage depends on the temperature of p-n junction. As the junction temperature increases the breakdown voltage decreases. The VI characteristics are shown in Fig.1.8.3.1, which shows that the characteristics are very sharp, almost vertical.

<u>Avalanche breakdown:</u>

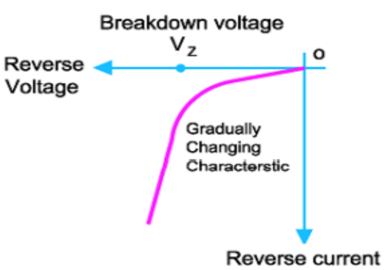


Fig.1.8.3.2 Avalanche breakdown

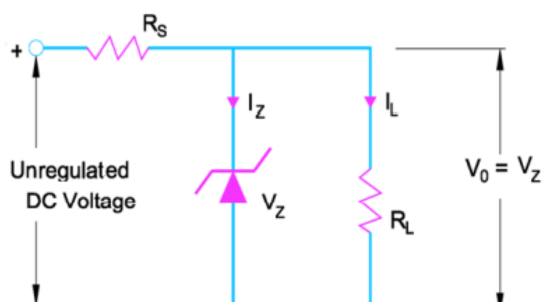
Avalanche breakdown is observed in the zener diodes having $V_Z$greater than 8V. When we increase the reverse voltage applied to the zener diode, minority carriers tend to accelerate and so the kinetic energy associated with them increases. These accelerated minority carriers will collide with the stationary atoms and impart some of the kinetic energy to the valence electrons present in the covalent bonds. Due to this, valence electrons will break their covalent bonds and jump into conduction band to become free for conduction. These newly generated free electrons will get accelerated and knock out some more valence electrons by means of collision. This phenomenon is known as "carrier multiplication". Shortly, a very large number of free minority electrons and holes will be available for conduction and the process becomes self sustained. This self sustained multiplication is called "Avalanche Effect". A large reverse current flow through zener diode and avalanche breakdown is said to have occurred.

Here, as the junction temperature increases the breakdown voltage increases. The VI characteristics are shown in Fig.1.8.3.2 which shows that the characteristic has a gradually increasing nature.

Some of the important specifications of zener diode are:

1. <u>Temperature coefficient:</u> It specifies the percentage change in zener voltage for each ^{0}C change in temperature. For example, a 12V zener diode with a positive temperature coefficient of 0.01%/^{0}C will show a 1.2mV increase in V_Z when the junction temperature increases by 1^{0}C.
2. <u>Zener voltage :(V_Z)</u>: It is the cathode to anode voltage across a zener diode, when it is operating in zener region. It is denoted by V_Z. As long as zener operates in the zener region, V_Z remains constant. To get a particular constant output voltage, V_Z should be selected properly. The typical values of V_Z are 3.1V, 4.7V, 5.1V, 9.1V, 12V, 15V, 18V etc.
3. <u>Break over current or knee current (I_{Zk}) or minimum zener current(I_{Zmin})</u>: This is the current flowing through the zener diode when reverse breakdown has occurred. It is the beginning of the zener region. The reverse current through a zener diode should be higher than the break over current, so as to operate it in the zener region. It usually specified in the range of mA. The knee current is indicated in the VI characteristics of zener diode.
4. <u>Maximum reverse current(I_{Zmax})</u>: It is defined as the maximum reverse current that can flow through a zener diode without damaging it due to overheating. It is denoted by I_{Zmax} and is the end of the zener region as shown in VI characteristics of zener diode. It is of the order of few tens or hundreds of mA.
5. <u>Power dissipation:</u> We know that power is the product of voltage and current. So, for a zener diode the expression for power dissipation is; $P_Z = V_Z \text{ x } I_Z$................where V_Z is the zener voltage and I_Z is the reverse zener current.
6. <u>Maximum power dissipation:</u> $P_{D(max)}$: It is the product of $V_Z$and I_{Zmin}i.e. maximum zener current. It can be indicated as $P_{D(max)} = V_Z\text{x } I_{Zmax}$. In order to not to exceed $P_{D(max)}$, maximum zener current should be below I_{Zmax} otherwise zener diode may get damaged.

7. <u>Dynamic resistance:</u> r_Z: It is defined as the reciprocal of the slope of the zener reverse characteristics in the zener region. Mathematically, $r_Z = \frac{\Delta V_Z}{\Delta I_Z}$. Ideally r_Z is zero and practically it should be as small as possible.
8. <u>Test current (I_{ZT})</u>: It is the current at which various parameters such as dynamic resistance of a zener diode are specified. Its value depends on the zener used. This is the current at which nominal zener breakdown voltage is specified.



1.8.7 Zener diode as a Voltage Regulator:

When zener diode is operated in the zener region of the reverse characteristics then the voltage across a zener diode remains constant i.e. V_Z. This fact is utilized in the application of the zener diode as a voltage regulator.

A voltage regulator circuit should keep the load voltage constant in spite of changes in its input voltage or load current and temperature. The series resistance R_s is connected to limit the total current drawn from the unregulated dc supply as shown in Fig. 1.8.7.1. The zener diode regulator is a shunt type voltage regulator because the control element i.e. zener diode is connected in parallel with the load resistance. The input voltage V_{in} is an unregulated dc voltage which is obtained from a rectifier filter combination. R_L is the load resistor. To use zener as a voltage regulator, the input voltage V_{in} must be higher than the breakdown voltageV_Z , zener current I_Z must be between I_{Zmin} and I_{Zmax}. If this criteria is satisfied voltage across the zener will remain constant = V_Z irrespective of any changes in V_{in} and I_L. As the output voltage is constant and = V_Z, we get a regulated output voltage. As shown in the circuit diagram, the zener diode is reverse biased and operates in the zener region of the reverse characteristics.

Fig.1.8.7.1. Circuit diagram

The regulator should keep the load voltage constant in spite of changes in input voltage and load current. We will see how zener regulator achieves it considering two cases.

1. <u>Regulating action with a varying input voltage (Constant I_L):</u>

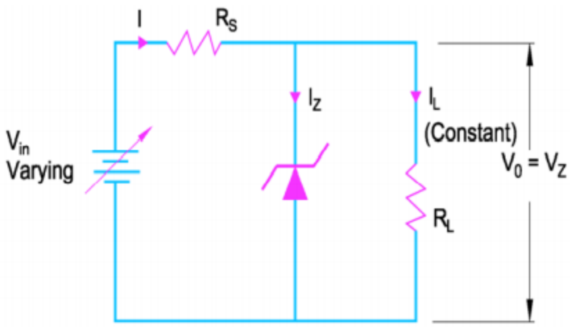


Fig.1.8.7.2. Regulation action with a varying input voltage

Here, we will see how zener diode maintains the output voltage constant with a varying input voltage by keeping load resistance R_L constant as shown in Fig. 1.8.7.2. As load resistance R_L is constant, I_L is also constant. But supply current, I, keeps on changing due to change in V_{in}. We can write equations for I_L *and* I as,

$I_L = \frac{V_Z}{R_L}$ and $I = \frac{V_{in}-V_Z}{R_s}$, Also, by referring the above circuit diagram$I = I_Z + I_L$. Consider following cases of V_{in}.

If V_{in} is increased then supply current, I will increase. This will increase the zener currentI_Z. This will continue to flow as long as I_Z is less thanI_{Zmax} in order to satisfy the equation $I = I_Z + I_L$, because R_L is constant and thus the load current I_L will remain constant.

If V_{in} is decreased then supply current, I will decrease. This will decrease the zener currentI_Z. This will continue to flow as long as I_Z is higher thanI_{Zmin} in order to satisfy the equation$I = I_Z + I_L$, because R_L is constant and thus the load current I_L will remain constant.

This indicates that the output voltage V_o will remain constant as long as the zener current is maintained between I_{Zmin} *and* I_{Zmax}. This is very important condition for getting output voltage constant or else it can't be maintained constant.

2. <u>Regulating action with a varying load</u> (Constant V_{in}):

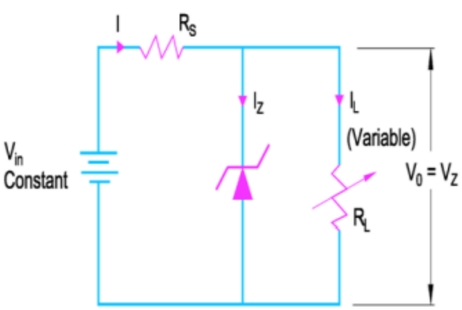


Fig.1.8.7.3. Regulation action with a varying load resistance

Here, assume that the input voltage is constant and load resistance R_L is varying as shown in Fig. 1.8.7.3.

If load resistance R_L is increasing, I_L will decrease but supply current, I, is constant therefore zener current I_Z will increase. This current can continue without damaging the zener diode as long as I_Z is less than I_{Zmax} and output voltage will remain constant. If load resistance R_L is decreases, I_L will increase but supply current,

I, is constant therefore zener current I_Z will decrease. As long as I_Z is higher than I_{Zmin} output voltage will

remain constant. This indicates that the output voltage V_o will remain constant as long as the zener current is maintained between I_{Zmin} *and* I_{Zmax}.

1.9 Light Emitting Diodes (LED):

1.9.1 Introduction:

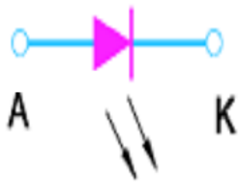


Fig.1.9.1.1 (a) LED symbol

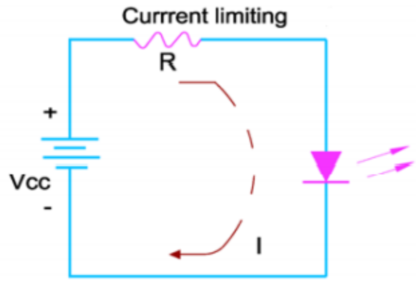


Fig.1.9.1.1 (b) LED Biasing

LED is a two terminal device namely, anode and cathode. A PN junction is formed between anode (A) and cathode (K) so basically this is a PN junction diode. Its symbol is same as that of a PN junction diode with two arrows in outward direction indicating that it emits light. LED is always operated in forward biased mode. LED is also called as a transducer (Converts one form of energy into another form) as it converts electrical signal input into light output. The symbol and LED biasing is as shown in Fig. 1.9.1.1(a) and (b) respectively.

Construction and principle of operation:

Construction:

LED is constructed by depositing three semiconductor layers on the substrate as shown in the Fig. 1.9.1.2(a). In between P and N region there exist active region. The light emerges from this active region in all the directions when recombination of electrons and holes takes place. In order to get light focus in the desired direction instead of all directions, the basic structure is placed in a cup type structure. This cup type structure is called a cup type construction and is shown in Fig. 1.9.1.2(b)

Fig.1.9.1.2 (a) Construction of LED

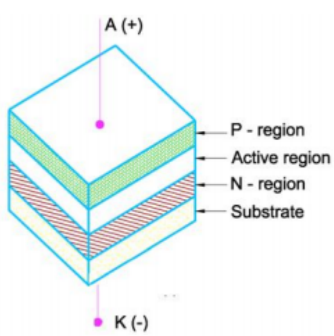
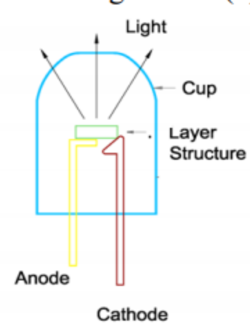


Fig.1.9.1.2 (b) Cup Type Structure



Silicon and Germanium semiconductors are not used to construct LEDs because they are heat producing materials. They are very poor in producing light. LEDs are made up of Gallium Arsenide (GaAs), Gallium Arsenide Phosphide (GaAsP) and Gallium Phosphide (GaP).

Principle of LED operation:

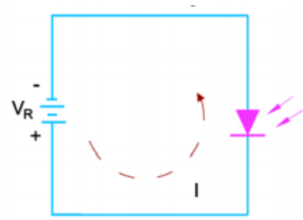
When the LED is forward biased, the electron in the N region will cross the junction and recombines with the holes in the P type region. These free electrons reside in the conduction band and hence are at higher energy level than holes in the valence band. Once the recombination is over, electrons return back to the valence band. While returning back, the recombining electrons give away the excess energy in the form of light. This process of emission of light by the application of electrical signal is called as electroluminescence.

The colour of the emitted light is decided by its wavelength, wavelength in turn depends on the value of the forbidden gap and forbidden gap depends on the material used. Hence the colour of the emitted light is dependent on the material used. Various materials emit light with various colours. For Example,

GaAs ………….Infrared Light GaAsP………..Red or Yellow Gap…………….Red or Green

1.10 Photodiode:

1.10.1 Introduction:



Photodiode is a two terminal device namely, anode and cathode. A PN junction is formed between anode (A) and cathode (K) so basically this is a PN junction diode. Its symbol is same as that of a PN junction diode with two arrows in inward direction indicating that it detects light.

Fig.1.10.1.1 (a) Symbol of Photodiode   Fig. 1.10.1.1(b) Photodiode Biasing

Photodiode is always operated in reverse biased mode. Photodiode is also called as a transducer as it converts light input into electrical output signal. The symbol and photodiode biasing is as shown in Fig. 1.10.1.1(a) and Fig. 1.10.1.1(b) respectively.

1.10.2 Construction and principle of operation:

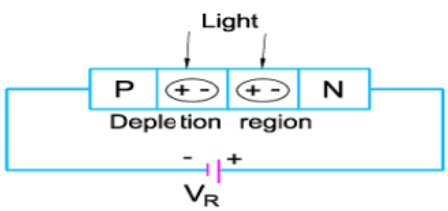


Fig. 1.10.2.1 Construction of Photodiode

Photodiode is constructed by connecting P and N regions together. It is operated in reverse biased mode. The light is allowed to fall through a glass lens on the junction of the photodiode. As the photodiode is reverse biased, the depletion region is wider and gets penetrated on both sides of the junction as shown in Fig.1.10.2.1

1.10.2 Construction and principle of operation:

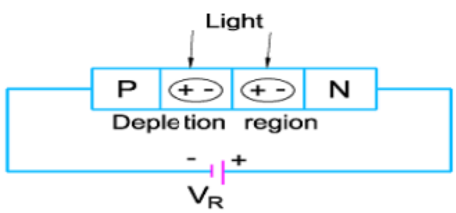


Fig. 1.10.2.1 Construction of Photodiode

Photodiode is constructed by connecting P and N regions together. It is operated in reverse biased mode. The light is allowed to fall through a glass lens on the junction of the photodiode. As the photodiode is reverse biased, the depletion region is wider and gets penetrated on both sides of the junction as shown in Fig.1.10.2.1

<u>Principle of LED operation:</u>

Once the photons incident on the depletion region, it will impart their energy to the ions present there and generate electron hole pair. The number of electron hole pairs will be dependent on the intensity of light i.e. as the light intensity increases, more number of electron hole pairs is generated and the photon current increases. Thus the photocurrent is proportional to the light intensity.

1.10.3 Photodiode characteristics

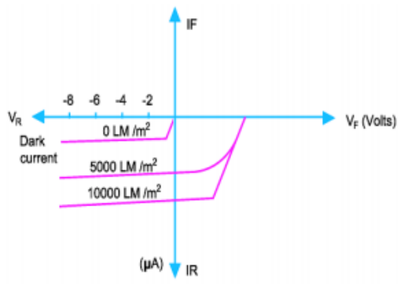


Fig.1.10.3.1 (a) VI characteristics of photodiode

The VI characteristics of photodiode are as shown in Fig.1.10.3.1 (a). The variation of photocurrent with the light intensity falling is also shown in Fig.1.10.3.1 (b). When no light is falling on to the device, then ideally zero current flows through the device. But practically a very small amount of current flows through the device due to thermally generated minority carriers and is known as dark current. The dark current is indicated in the characteristics. Dark current is temperature dependent and increases with increase in temperature.

The reverse current I_λ or photocurrent depends only on the intensity of light incident on the junction. It is not dependent on reverse voltage, as shown in Fig.1.10.3.1 (a).

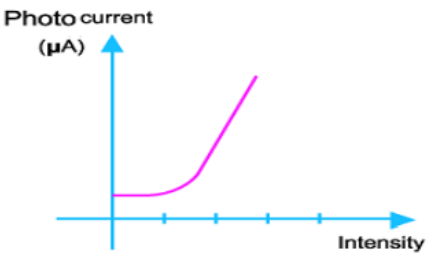
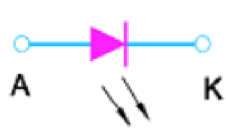


Fig.1.10.3.1(b) variation of photocurrent with light intensity

Photodiode is operated in reverse biased mode because in reverse biased mode the only current flowing through the diode is the reverse saturation current and is very small in magnitude. Hence the change in diode current due to the light falling on to it is significant in reverse biased mode only. In forward bias mode there is no effect of current flow due to light intensity falling on to it. This is the reason; photodiode is operated in reverse biased mode.

Sr.No	LED	Photodiode
1	It is also called as Light emitter.	It is also called as Light detector
2	It is operated in forward biased mode.	It is operated in reverse biased mode.
3	It uses materials like gallium, arsenide phosphide and gallium phosphide.	It uses materials like Silicon and germanium.
4	Application: Seven segment display, optocouplers and alphanumeric display.	In counting system, in light intensity meters, in cameras.
5	Symbol: 	Symbol: