Semi conductor Divices

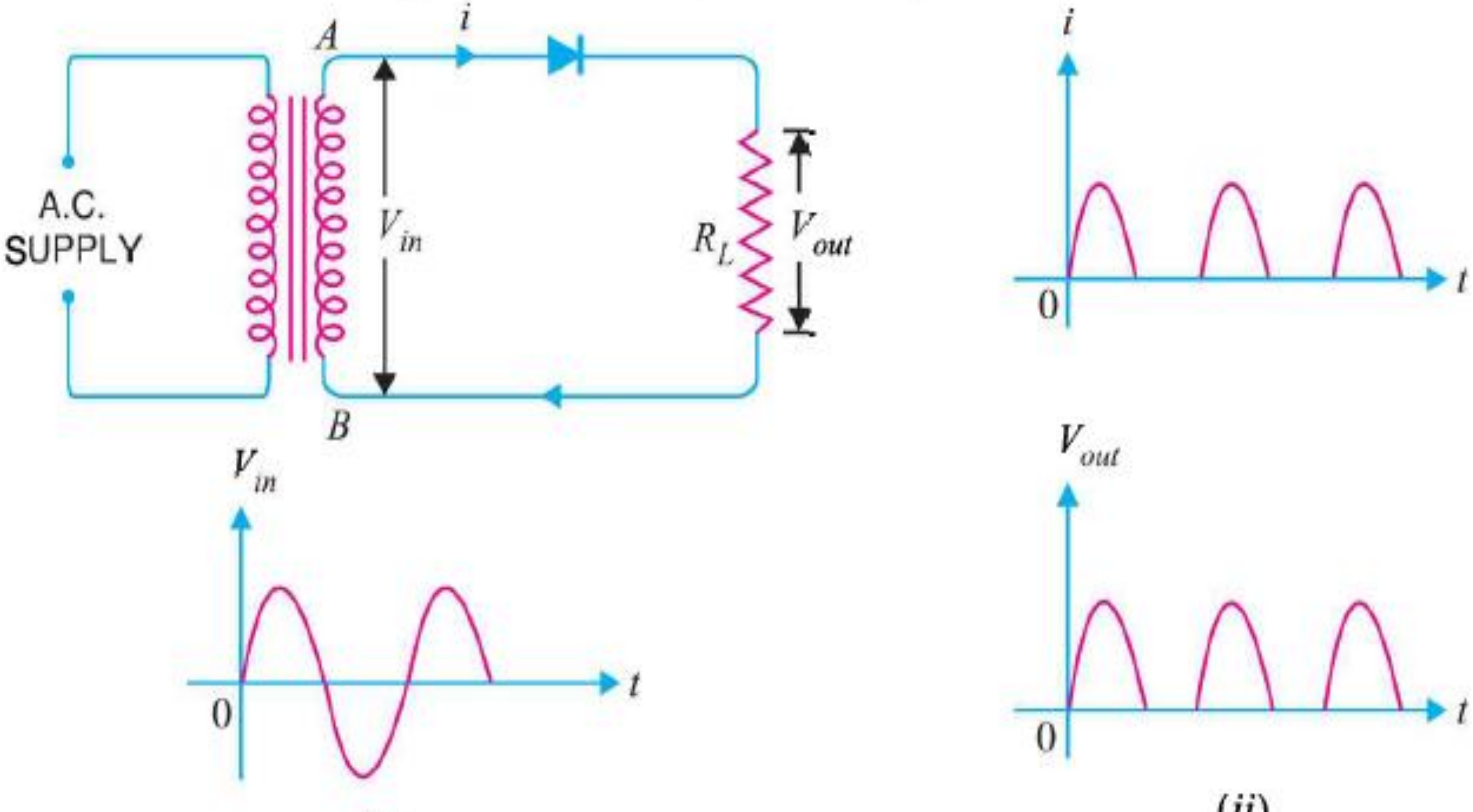
- Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials. Semiconductor devices contain at least one PN Junction. They are classified as two terminal, three terminal or four terminal devices. Two terminal devices include diode Zener diode, tunnel diode, photocell, laser diode solar cell etc. Three terminal devices include BJT, FET, TRIAC Thyristor etc.

Rectifiers

- A pn junction diode can be used as a rectifier which can convert ac to dc. It can function as a halfwave rectifier and full wave rectifier.

Half Wave Rectifiers

- In a half wave rectifier a single PN Junction diode is connected in series with a load resistor . The diode act as a gatekeeper allowing current to flow only when it is forward biassed. During the positive half cycle of ac supply . During the negative half cycle the diode is reverse biassed and hence blocks the current flow. Hence all the negative half cycles of ac supply are suppressed hence current always flows only in one direction through the load creating a pulsating dc voltage. Figure shows the circuit In which a single PN junction diode act as half-wave rectifier.



(i)
(ii)

- The ac supply to be rectified is applied in series with the diode and load resistance R L.. AC supply is given through a transformer. This transformer can step up or step down the AC input voltage depending on the situation. It can also isolate the rectifier circuit from the power line and thus reduce the risk of electric shock . Output frequency of half wave rectifier is the same as input frequency.

Working

- The ac voltage across the secondary winding AB changes polarities after every half cycle. During the positive half cycle of input AC voltage ,the end A becomes positive with respect end B.This makes the diode forward biased and hence it conducts current. During the negative half cycle, end A is negative with respect to end B. Under this condition the diode is reverse biassed and does not conduct any current. Thus current flows through the diode during the positive half cycle of input AC voltage and during the negative half cycle current is blocked. Current flows through the load RL always in the same direction. Hence a DC voltages is obtained across RL. But the output obtained is a pulsating dc.

- Disadvantages ;
- i) Filtering is required to produce steady direct current .Because the current in the load contains alternating component whose frequency is equal to supply frequency.
- ii) The output power is very low since output is obtained only half of the time.
- Efficiency of halfwave rectifier

Efficiency of a HWR

- Consider a half wave rectifier as shown in the figure. Let rf be the diode resistance and RL be the load resistance and v = Vm sin θ be the alternating voltage that appears across the secondary of the transformer. The diode conducts during positive half cycles and there is no conduction during the negative half cycles.

- The ratio of dc output power to applied ac input power is known as rectifier efficiency.ie, Rectifier efficiency, η = $\frac{dc\ output\ power}{ac\ input\ power}$
- The average dc current is given by I dc = $\frac{1}{2\pi}\int_0^{\pi} i\, d\theta$

- $= \frac{1}{2\pi}\int_0^{\pi} i\, d\theta = \frac{1}{2\pi}\int_0^{\pi} \frac{v_m \sin\theta}{(r_f + R_L)}\, d\theta$
- $= \frac{v_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta\, d\theta$ - $\frac{v_m}{2\pi(r_f + R_L)}(-\cos\theta)_0^{\pi}$
- $= \frac{v_m}{2\pi(r_f + R_L)} \times 2 = \frac{v_m}{\pi(r_f + R_L)} = \frac{I_m}{\pi}$

- dc power $P_{dc} = I_{dc}{}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$

- ac input power $P_{ac} = I^2{}_{rms}(r_f + R_L)$

- For a half wave rectifier $I_{rms} = I_m/2$

- $P_{ac} = \frac{I_m^2}{4}(r_f + R_L)$

- Rectifier efficiency, η = $\frac{dc\ output\ power}{ac\ input\ power}$

- $= I_{dc}{}^2 R_L / I^2_{rms}(r_f + R_L) = \frac{4}{\pi^2}\frac{R_L}{(r_f + R_L)}$ - $\frac{0.406}{1+\frac{r_f}{R_L}}$

  - Efficiency of a half wave rectifier, η = $\frac{0.406}{1+\frac{r_f}{R_L}}$

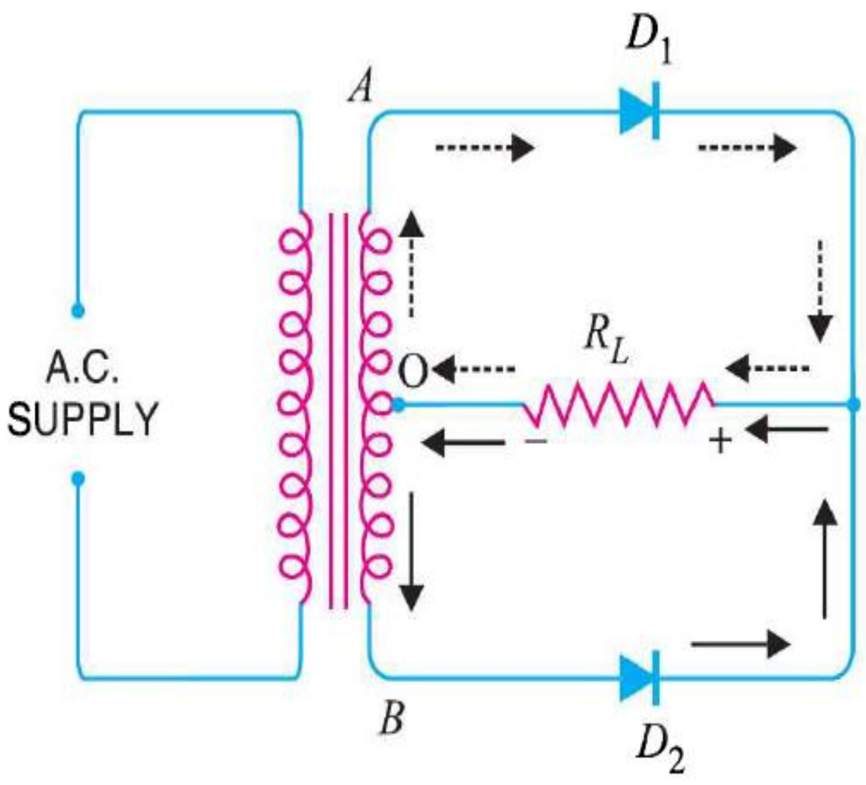
- Where r_f represents diode resistance and R_L represents the load resistance.The efficiency of half wave rectifier will be maximum when r_f negligible when compared to R_L. Maximum rectifier efficiency is 40.6 %. This means that a maximum of 40.6 % of input ac power is converted to dc power.

Full wave rectifier

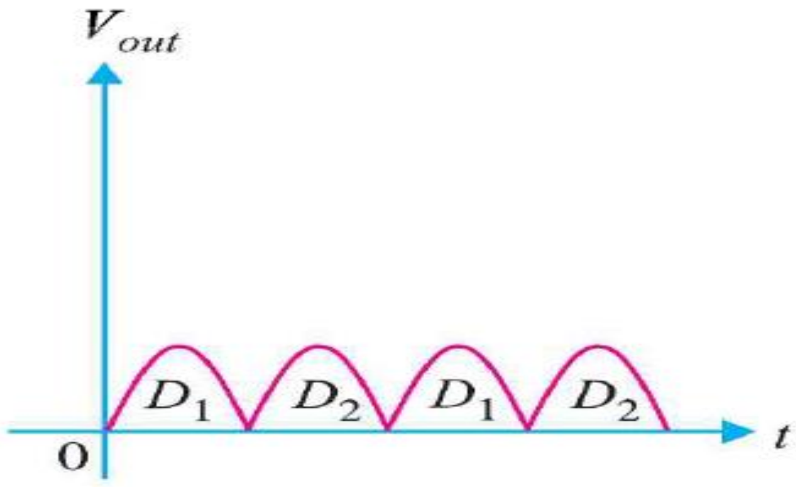
- In a full wave rectifier current flows through the load in the same direction for both half cycles of input ac voltage. For this purpose two diodes which works alternately are used. For the positive half cycle of input voltage, one diode supplies current to the load and for the negative half cycle the other diode supplies current. Hence in a full wave rectifier dc output is obtained for both half cycles of input ac voltage. Two commonly used full wave rectifiers are centre tap full wave rectifier and full wave bridge rectifier.

- In a centre tap full wave rectifier Two diodes D1 and D2 are used. A centre tapped transformer AB is used . The diode D1 utilises ac voltage appearing across the upper half of secondary winding for rectification and D2 uses the lower half of winding OB.
- During the positive half cycle of secondary voltage the end A of secondary winding becomes positive and end B becomes negative. Hence the diode D1 is forward biased and D2 is reversed biased. Therefore D1 conducts and D2 does not

- The conventional current flows through the diode D1, load resistor RL and upper half of the secondary winding. During the negative half cycle, end A of the secondary winding becomes negative and B becomes positive. Hence, D2 conducts and D1 does not. The conventional current flow is through the diode D2, load R¬L and lower half of the winding. The current in the load resistance R¬L is in the same direction for both half cycles of AC input voltage. Thus, DC is obtained across the load RL.



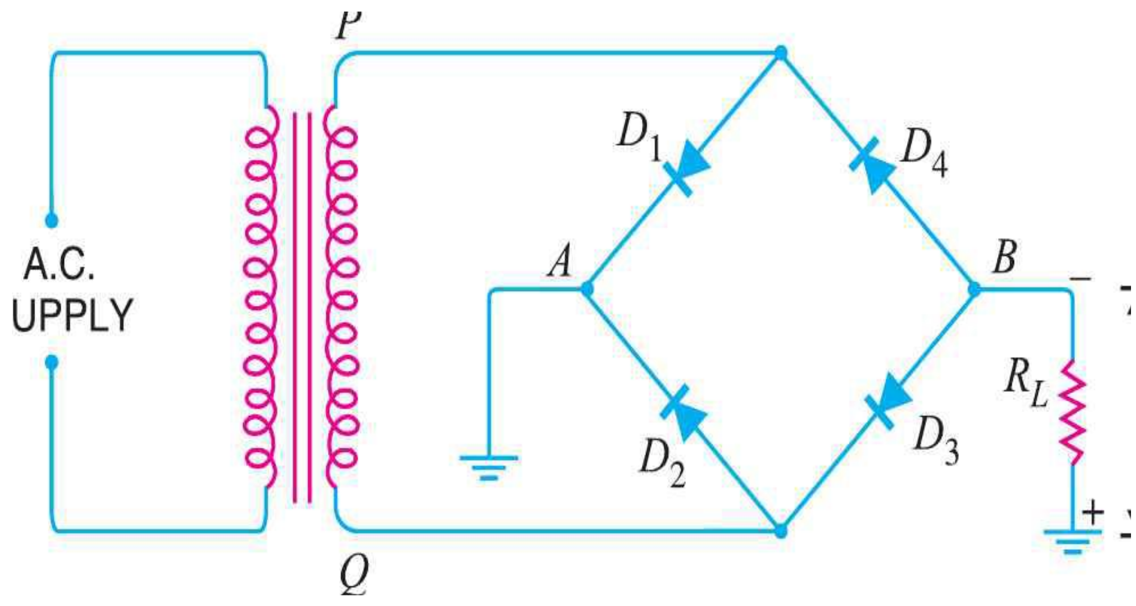
D_1
A
A.C.
SUPPLY
O
R_L
−
+
B
D_2

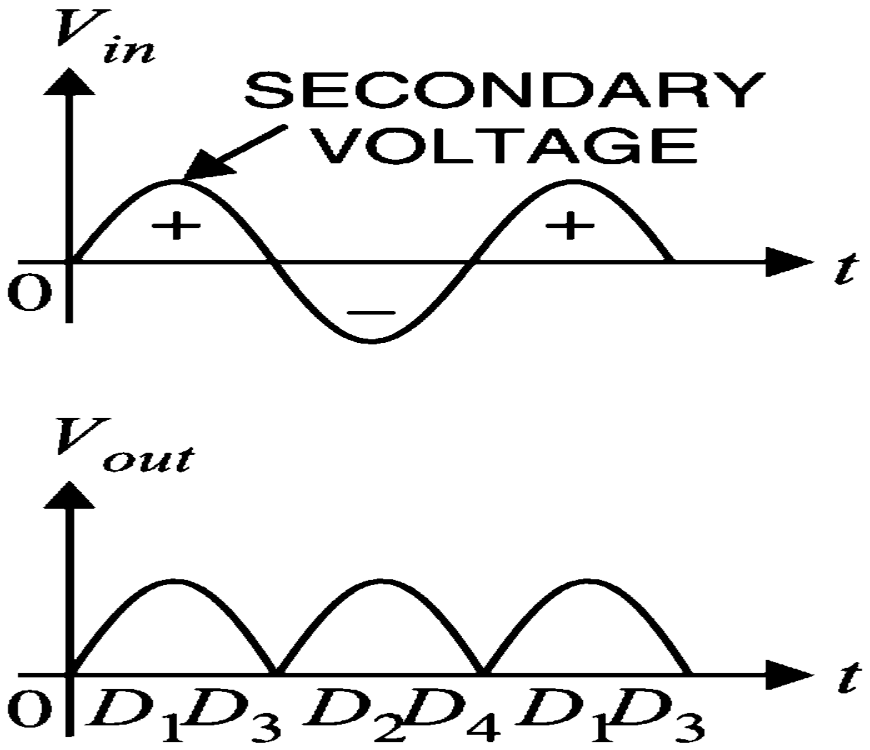


V_{out}
D_1
D_2
D_1
D_2
O
t

Full wave bridge rectifier

- In a full wave rectifier 4 diodes D1, D2, D3 and D4 are used. They are connected to form a bridge. Hence the need for a centre tapped power transformer is eliminated in bridge rectifier. The ac supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between the other two ends of the bridge the load resistance R L is connected.


P
A.C.
UPPLY
Q
D_1
D_4
D_2
D_3
A
B
R_L
–
+


V_{in}
SECONDARY VOLTAGE
+
–
+
O
t
V_{out}
O
D_1D_3 D_2D_4 D_1D_3
t

- During the positive half cycle of secondary voltage, the end P of secondary winding becomes positive and end Q becomes negative. Hence D1 and D3 are forward biassed while D2 and D4 are reverse biassed. Therefore D1 and D3 conduct and these two diodes will be in series through the load RL. Hence current flows from A to B through the load resistance RL .During the negative half cycle of secondary voltage the end P becomes negative and end Q becomes positive

- This makes the diodes D2 and D4 forward biassed and while D1 and D3 are reverse biased. Therefore D2 and D4 conducts through the load resistance RL. Hence current flows from A to B through the load resistance which is in the same direction as for the positive half cycle. Therefore a DC output is obtained across RL

Efficiency of a full wave rectifier

- The instantaneous current through a full rectifier
- $\text{i} = \frac{v}{r_{f+R_L}} = \frac{V_m}{r_{f+R_L}} \sin\theta$
- $I_{dc} = \frac{2Im}{\pi}$
- P dc $= I_{dc}^2\ R_L$ **= (** $\frac{2Im}{\pi}$) ^{2} R_L
- $I_{rms} = I\ m/\surd 2$

- P $_{ac}$ =(I m/✓2) $^2(r_f + R_L)$
- $\eta = \frac{P_{dc}}{P_{ac}} = \frac{\left({}^{2Im}/_{\Pi}\right)^2 R_L}{\left({}^{Im}/_{\sqrt{2}}\right)^2 (\gamma_f + R_L)}$
- $= \frac{8}{\pi^2} \times \frac{R_L}{(\gamma_f + R_L)} = \frac{0.812}{1+\frac{\gamma_f}{R_L}}$

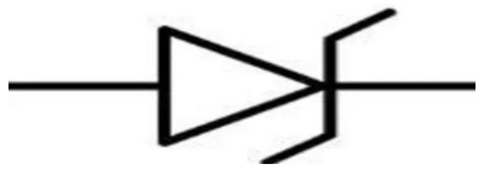
- The efficiency will be maximum when rf is negligible compared to RL. Therefore the maximum efficiency is 81. 2%. Since the efficiency of full wave rectifier is double the efficiency of half a rectifier it is more efficient compared to half wave rectifier.

- The ratio of rms value of ac component to the dc component in the rectifier output is known as ripple factor. Smaller the ripple factor, the lesser the effective ac component and hence the rectifier will be more effective
- For half wave rectifier, ripple factor = 1.21
- For full wave rectifier ripple factor = 0.48

- Ripple Factor= Iac/Idc
- Iac =

Zener diode

- Zener diode is a heavily doped PN Junction diode which is designed to operate in the reverse breakdown region, The breakdown voltage of a zener diode is carefully set by controlling the doping level during manufacture. Zener diode if the diode is heavily doped, the depletion region will be very thin and the breakdown of the junction will occur at a lower reverse voltage.



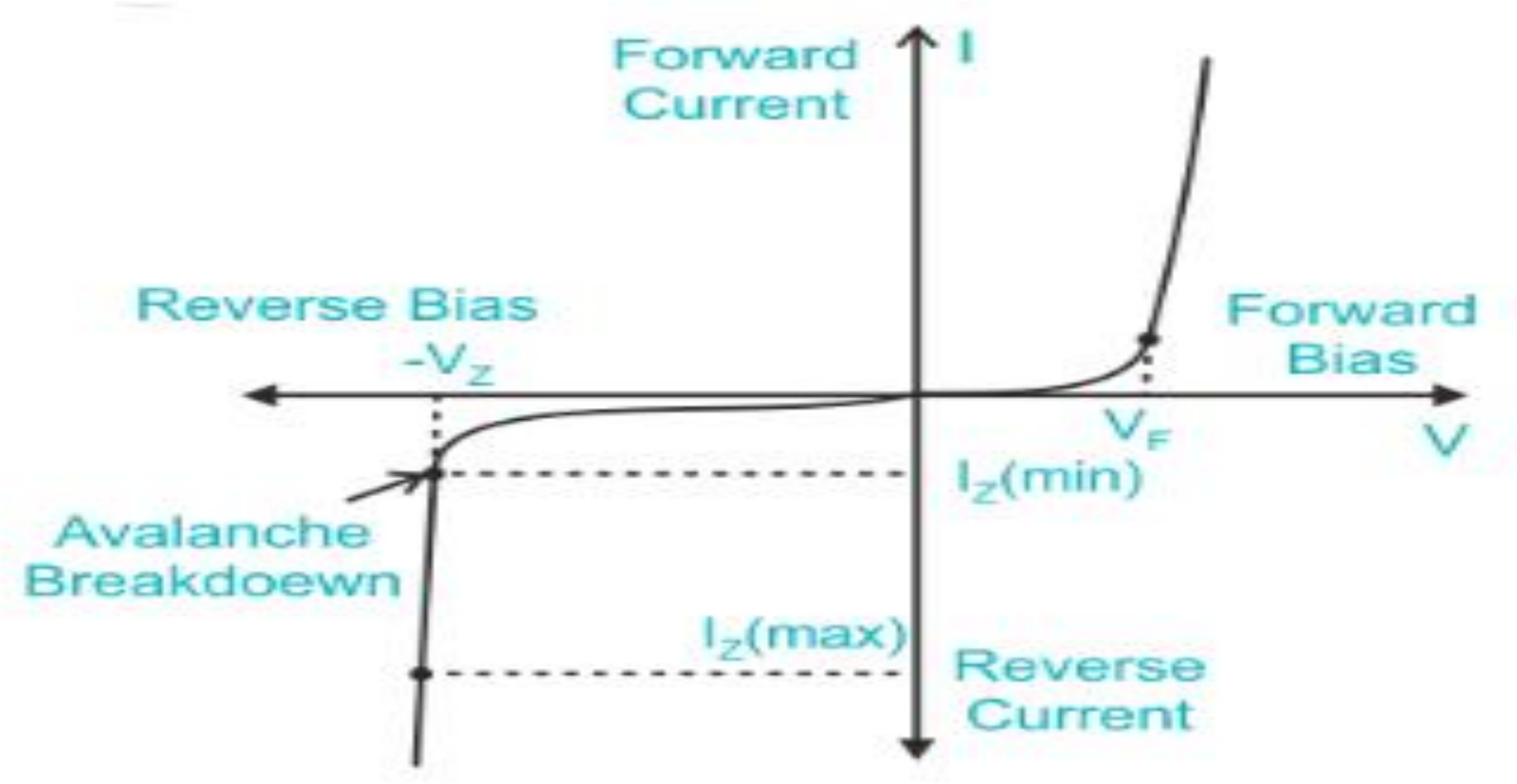
Working of Zener diode

- When zener diodes forward biased, it acts as an ordinary diode. But when it is reverse biassed small leakage current flows through the diode and when the reverse voltage increases and reaches the breakdown voltage the current increases abruptly. The voltage at which sudden increase in reverse current occurs is shown as zener breakdown voltage or zener voltage.

- The forward bias characteristics of zener diode is similar to normal pn junction diode.
- When it is reversed biassed, a small reverse saturation current flows across the diode. This current is due to thermally generated minority carriers present in the diode. The reverse bias voltage sets up a strong electric field across the narrow depletion layer. This field is strong enough to break the covalent bonds of atoms.

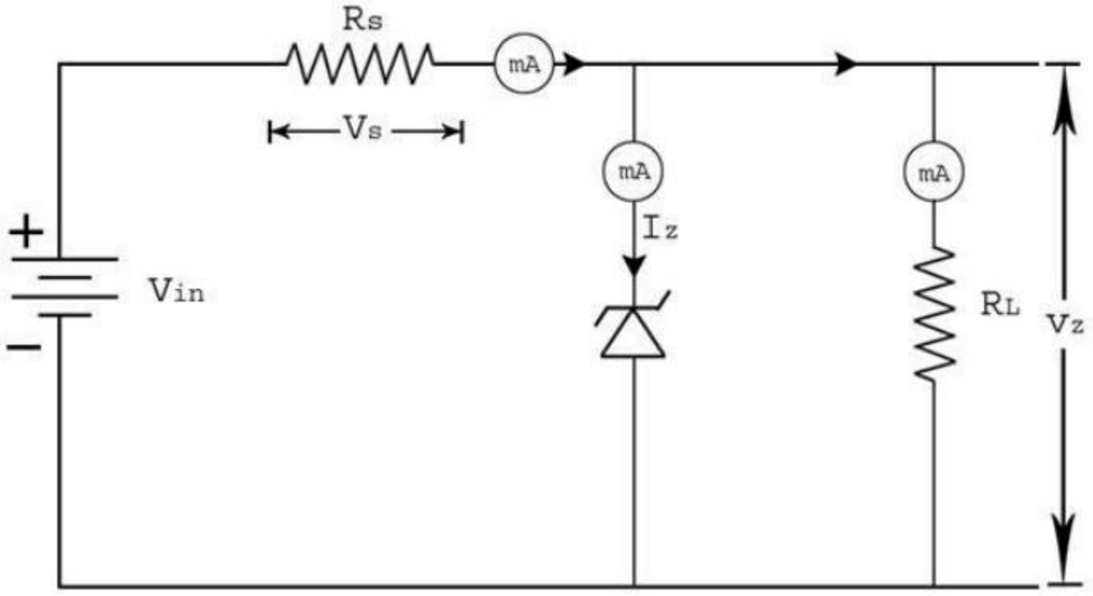
- Therefore, there is a generation of a large number of electron-hole pairs, leading to a sharp increase in the reverse current. When reverse bias is increased, upto a certain voltage called as breakdown voltage, the diode starts conducting heavily and the reverse current increases sharply. This voltage is called zener breakdown voltage(Vz). Zener diode maintains a constant voltage across its terminals when the reverse bias voltage exceeds the breakdown voltage.

VI characteristics of a Zener diode



- 1. A Zener diode is a properly doped pn junction diode with a sharp breakdown voltage.
- 2. It is always reverse biased.
- 3. The sharp breakdown voltage is called Zener voltage VZ .
- 4. In forward biased condition it behaves like an ordinary diode.
- 5. Zener diode is not immediately burnt just because it has entered the breakdown region.

Zener Diode as Voltage Regulator



- Zener diodes can be used as voltage regulators to maintain a constant voltage across a load regardless of variations in the applied input voltage and variations in the load currents. They are connected in parallel with the load, in reverse bias. The resistor is selected so that when the input voltage is at VIN(min) and the load current is at IL(max) that the current through the zener diode is at least Iz(min). Then for all other combinations of input voltage and load current the zener diode conducts the excess current, thus maintaining a constant voltage across the load. The zener conducts the least current when the load current is the highest and it conducts the most current when the load current is the lowest
- 2. Zener Diode can be used for Over-Voltage Protection.
- 3. .Zener Diode is used in Clipping Circuits.

Zener breakdown and Avalanche breakdown

- In a pn Junction diode width of depletion region depends on the biasing voltage and doping level. The width of depletion region decreases with increase in bias voltage in the case of forward bias and it increases with increase in bias voltage the case of reverse bias. The width of the depletion region is more for a lightly doped material compared to heavily doped material. When the reverse voltage is greater than breakdown voltage the kinetic energy of minority charge carriers increases and these fast-moving electrons collide with other atoms and knockout more electrons from the atoms.

- These released electrons can release much more electrons from the atoms by breaking the covalent bonds. This process continues as an avalanche process and causes carrier multiplication leading to considerable increase in current and the associated breakdown is known as avalanche breakdown. Avalanche breakdown voltage increases with increase in junction temperature and hence it has positive temperature coefficient. Avalanche breakdown occurs in a pn junction diode which is reasonably doped and have thick depletion region.

- When high reverse voltages are applied across the diode the electric field also increases which causes a force on electrons and make them free from a covalent bond. These free moving electrons collide with neighbouring atoms and hence generate more free electrons and this drifting of electrons causes increase in net current across the junction.

- Zener breakdown occurs in pn junction diodes having narrow depletion region. When the reverse bias voltage increases the depletion region starts generating strong electric field and when it reaches to Zener voltage the electric field becomes strong to pull electrons from their valance band. These valance electrons break bonding with the parent atom and becomes free electrons and they carry electric current from one place to another. Electron becomes free it leaves a hole in the atom. When Zener voltage is reached large number of free charge carriers are generated and a large current is flowing through the diode.

Zener Breakdown	Avalanche Breakdown
This is observed in diodes having a breakdown voltage V_z of 5 to 8 volts.	This is observed in diode having a breakdown v V_z greater than 8 volts.
The valence electrons are pulled into conduction band due to the high electric field in the narrow depletion region.	The valence electrons are pushed to conduction the energy imparted by accelerated electrons, w gain their velocity due to their collision with ot atoms.
The increase in temperature decreases the breakdown voltage.	The increase in temperature increases the break voltage.
The VI characteristics of a Zener breakdown has a sharp curve.	The VI characteristic curve of the avalanche breakdown is not as sharp as the Zener breakdc
It occurs in diodes that are highly doped.	It occurs in diodes that are lightly doped.
The depletion region is thin.	The depletion region is thick.
The doping concentration is high at the junction.	The doping at the junction is minimum.
It occurs because of the high electric field.	It occurs because of the collision of free electro
The production of electrons takes place.	The production of a pair of electrons and holes place.

Tunnel diode

- Tunnel diode is a pn junction diode which exhibits negative resistance region between peak point voltage and valley point voltage in forward biased condition. A conventional diode exhibits positive resistance in forward bias and reversed biased condition. When a semiconductor pn Junction diode is heavily doped with impurities it exhibits negative resistance in some regions in forward biased condition. Such a diodes known as tunnel diode.

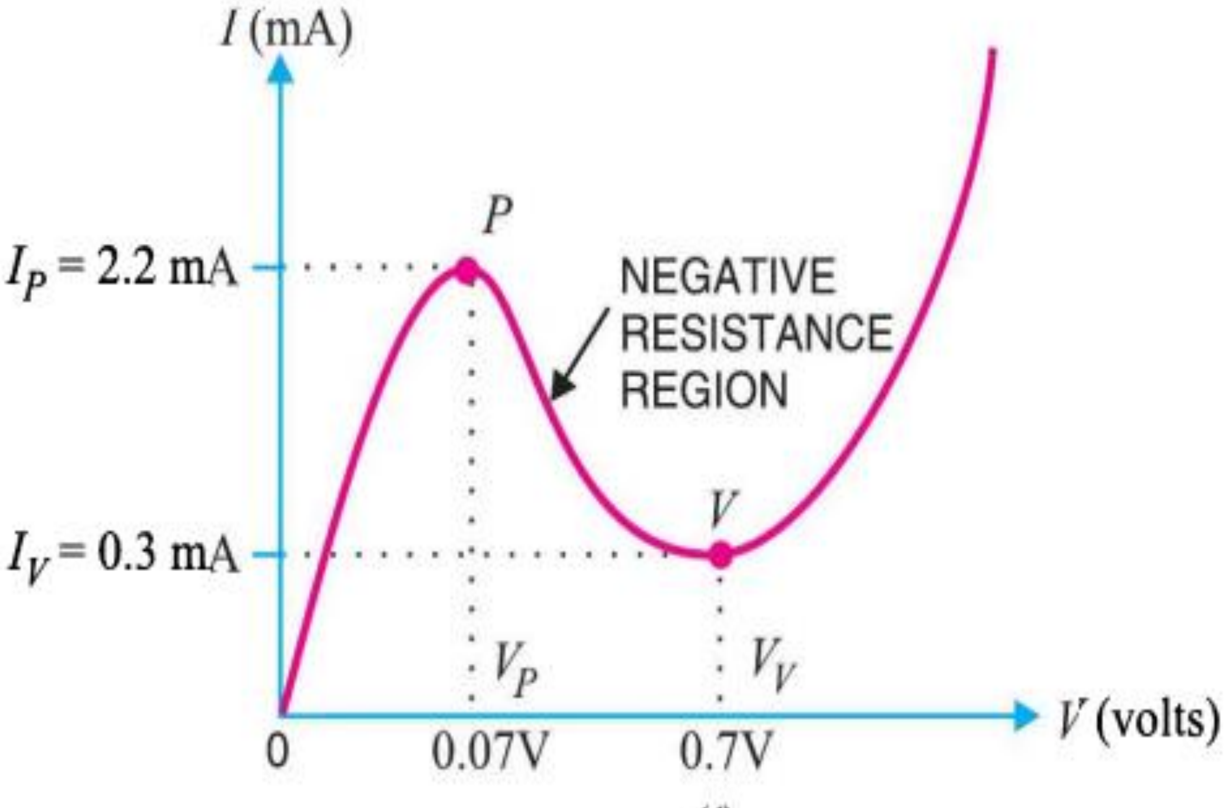
Working

- A tunnel diode is basically a heavily doped pn junction approximately 1000 times as heavily as a conventional diode. Due to this heavy doping, there will be large number of majority carriers. Because of this large number of majority carriers most of them are not used during initial recombination which produces depletion layer. Hence depletion layer will be very narrow. The working principle of tunnel diode is tunnelling effect and hence the name.

- Since there are large number of majority carriers there is much drift activity in p and n regions. This causes many valence electrons to have their energy levels raised closer to the conduction region. Therefore, only small forward voltage is required to start conduction. The movement of valence electrons from valence energy band to the conduction band with little or no forward bias voltage is called tunnelling.

- Hence valence electrons seem to tunnel through the forbidden energy gap. When the forward bias voltage is increased, initially the diode current increases rapidly due to tunnelling effect. Suddenly the tunnelling effect is reduced and then the current starts to decrease as the forward voltage across the diode is increased. This voltage at which current starts to decrease is known as peak point. This is the region where the tunnel diode exhibits negative resistance region. As the voltage is further increased effect of tunnelling will be less and less until valley point is reached. After valley Point tunnel diode behaves like an ordinary diode that means current increases with increase in forward voltage.

V-I Characteristics



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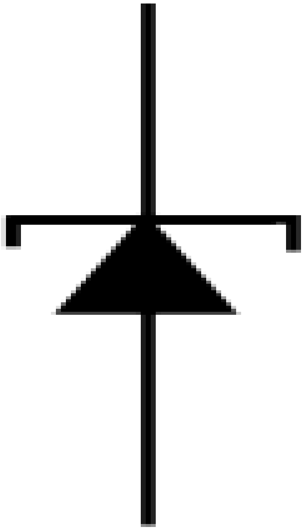

- 1. Initially when the forward bias voltage across the tunnel diode increased, the electrons from n region tunnel through the potential barrier to p region. So as the forward voltage increases the diode current also increases until the peak point P is reached.

- 2. When the voltage is increased beyond peak Point VP, the tunnelling action decreases and hence the diode current decreases as the forward voltage is increased. This continues until valley point voltage VV is reached. In the region between peak point and valley point the diode exhibits negative resistance. That is as the forward voltage increases, the current through the diode decreases. This is a negative resistance region of tunnel diode. When operated in negative resistance region tunnel diode can be used as an oscillator or a switch.

- 3. If the forward bias voltage is in increased beyond valley point voltage the tunnel diode act as a normal diode. That means as the forward voltage increases the current also increases and hence the diode exhibits positive resistance region once again.

Applications

- It is used as an ultra- high speed switch due to tunnelling (which essentially takes place at speed of light). It has switching time of nanoseconds or picoseconds.

- Used as logic memory storage device.

- In satellite communication equipment, they are widely used.

- Due to its feature of negative resistance, it is used in relaxation oscillator circuits.