Semiconductor devices
pn junction and diode, its application

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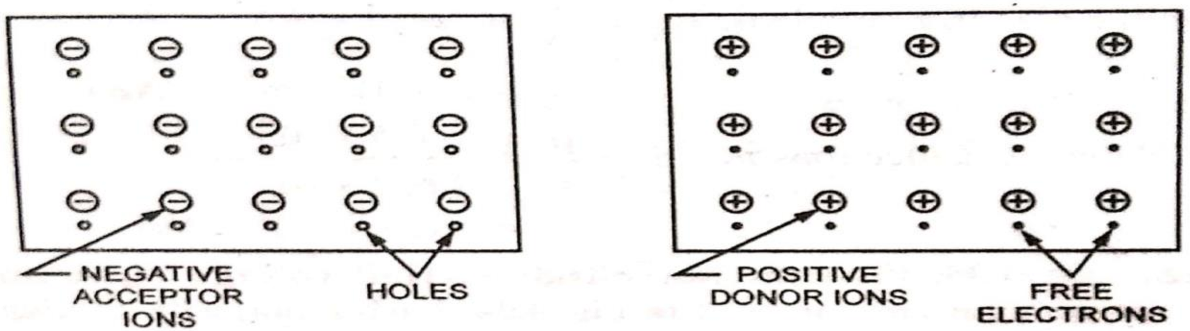
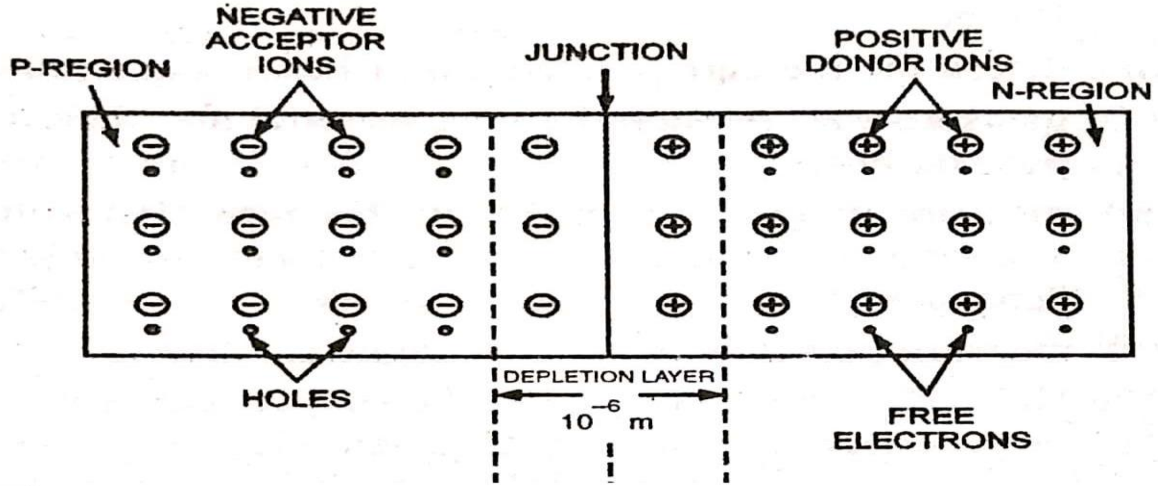
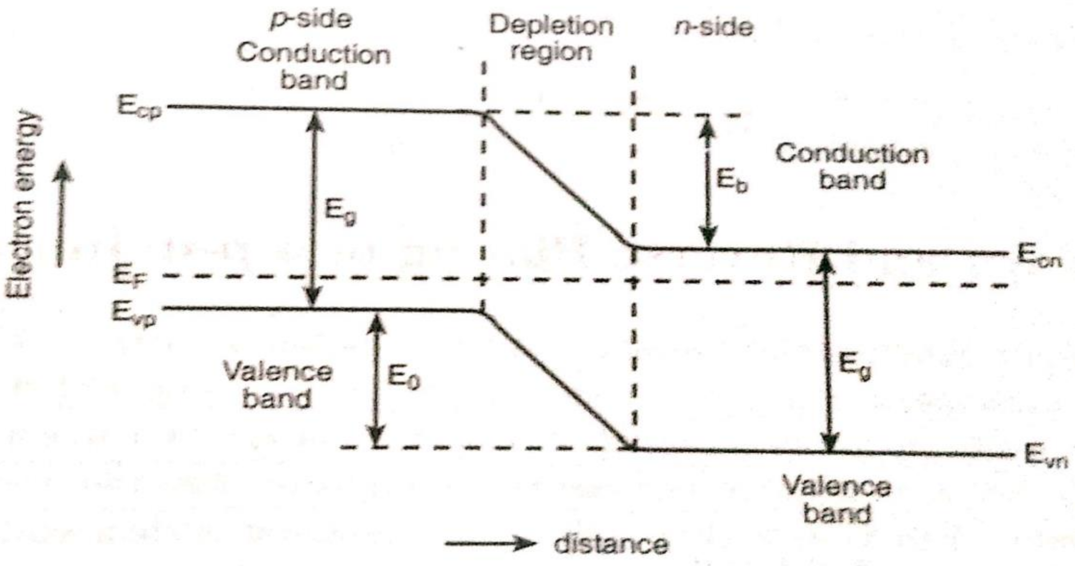
Basic structure of p-n junction:



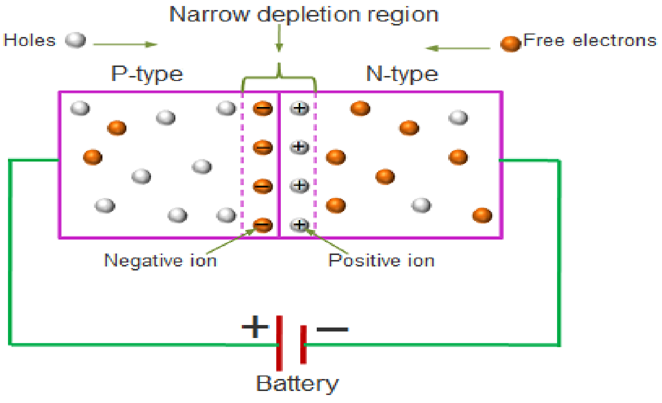
(a) P-Type Semiconductor Material *(b) N-Type Semiconductor Material*



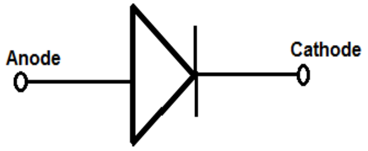
Energy band diagram of an open circuit p-n junction:



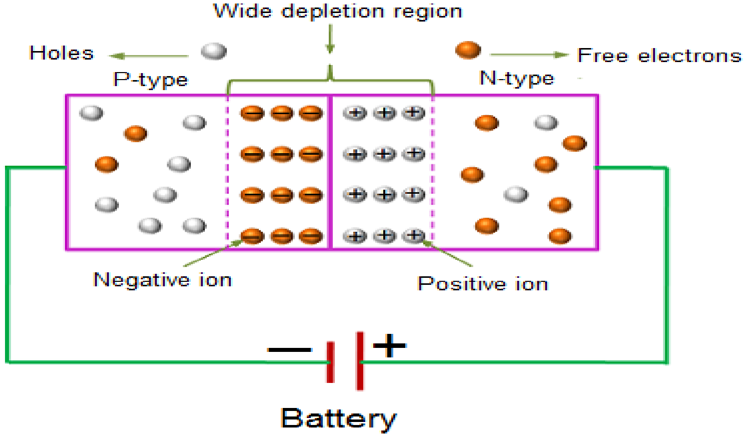
$$E_b = E_{cp} - E_{cn}$$



Forward bias

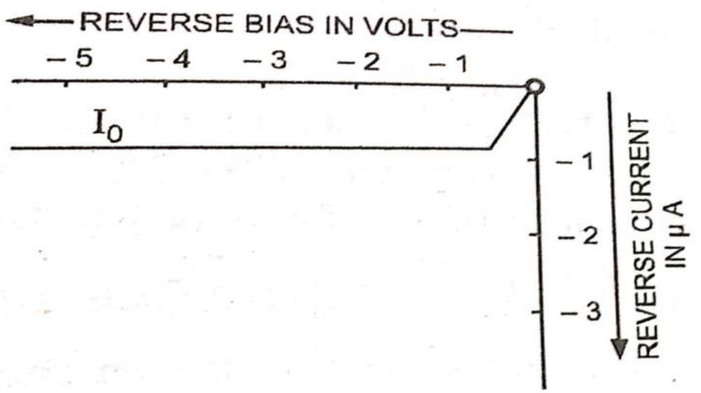


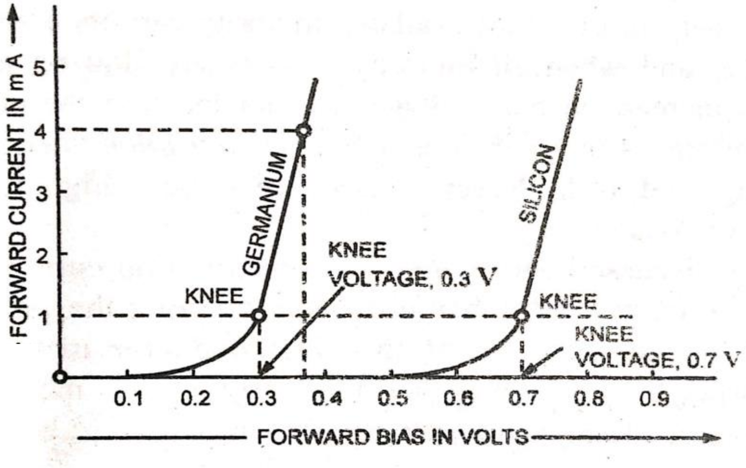
Circuit symbol

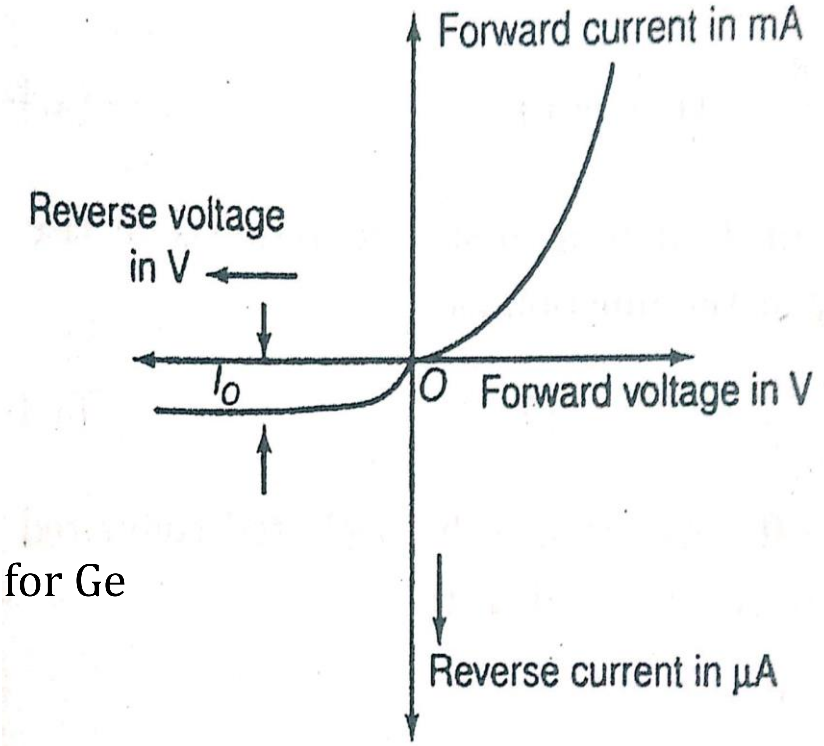


Reverse bias

Volt-Ampere characteristics of P-N junction:







V_γ =cutin voltage=0.2 V for Ge and 0.6 V for Ge

$$I = I_0(exp^{eV/\eta K_B T} - 1)$$

I_0= reverse saturation current

e=charge of electron=$1.6 \times 10^{-19} C$

K_B=Boltzmann constant=1.38×10^{-23} J/K

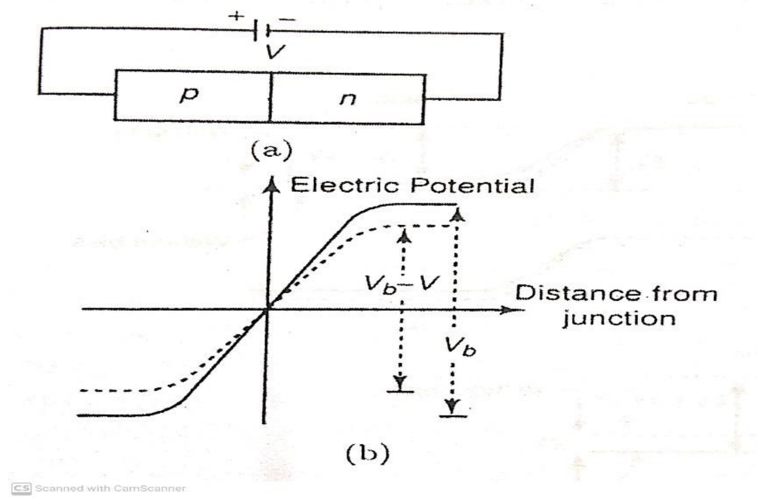
T=300K

V=applied voltage

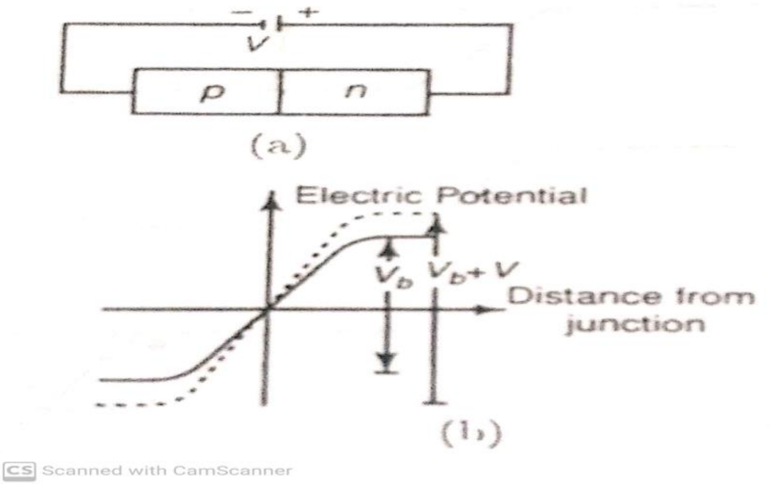
H=Dimensionless number=1 for Si and 2 for Ge

Diode resistance: $r_{dc} = \frac{V}{I}$,ratio between the voltage across the junction and the current I flowing through the junction is called static or the dc resistance.

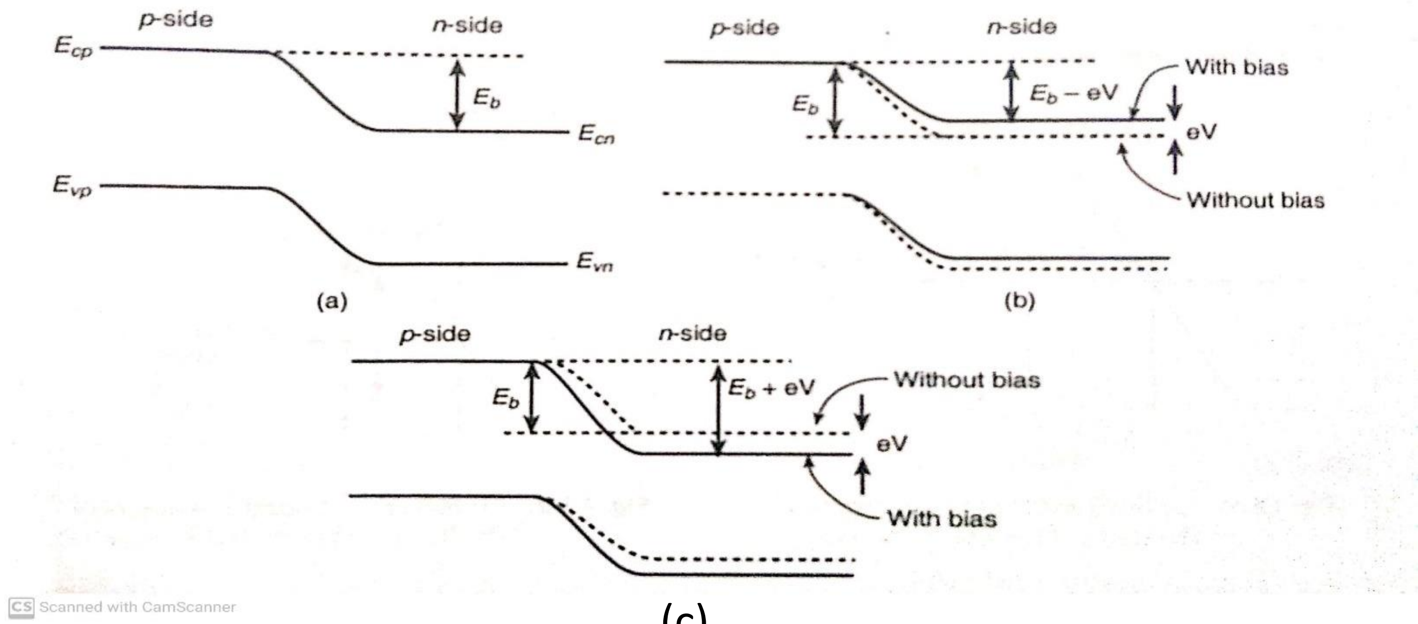
$r_{ac} = \frac{dV}{dI}$, the inverse of the slope of the volt-ampere characteristics pf the p-n diode defines the dynamic or ac resistance.



- ❑ **Reduced potential barrier for forward bias**



- ❑ **Increased potential barrier for reverse bias**

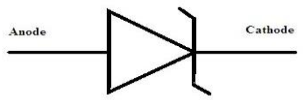


(c)

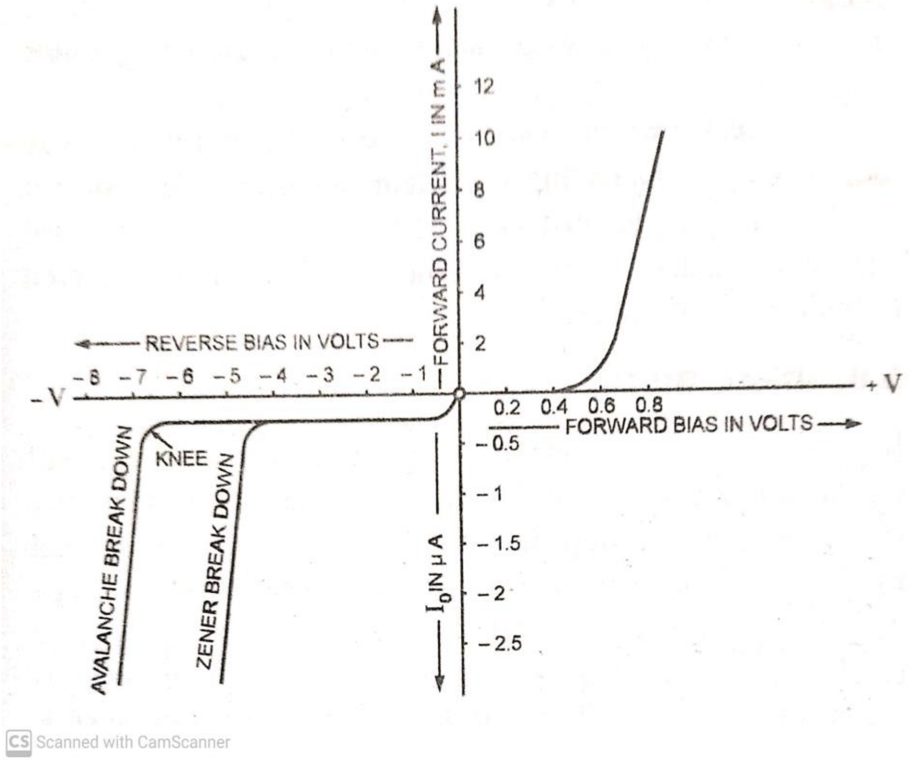
a)Energy band diagram when unbiased,
b)Energy barrier is lower to the value $(E_b - eV)$ when forward biased
c)Energy barrier is raised to the value $(E_b + eV)$ when reverse biased

Junction breakdown:

- If the reverse biased increased, a point is reached when the junction breaks down and the reverse current increases abruptly.
- The critical value at which breakdown occurs is called breakdown voltage.
- There are two mechanism by which breakdown occur: avalanche breakdown and zener breakdown.



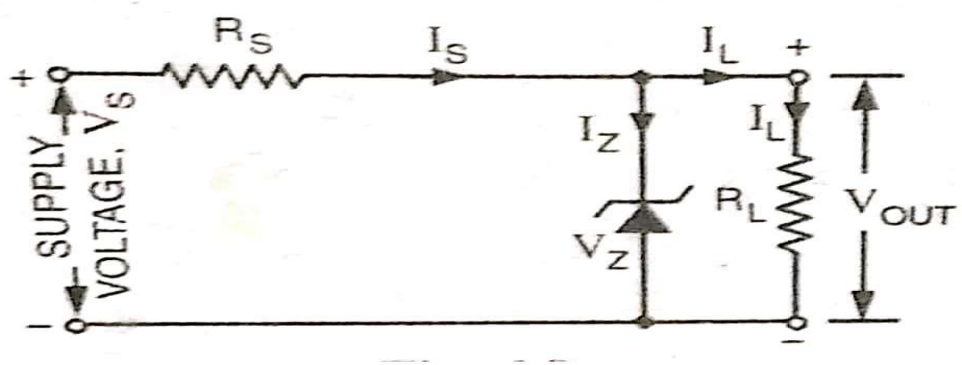
Zener diode circuit symbol



- Zener break down occurs in heavily doped junction which produce narrow depletion layers. Avalanche breakdown occurs in lightly doped junctions which produce wide depletion layers.
- Breakdown voltage require higher for avalanche breakdown then zener.
- Zener diode have a negative temperature coefficient which avalanche diode have a positive temperature coefficient.

Zener diode applications:
Zener diode voltage regulations:

- Voltage regulator is a measure of a circuit's ability to maintain a constant output voltage when either input voltage or load current varies.



Calculation of Rs:

R_S=current limiting resistance

V_Z = zener voltage

I_Z=zener current

Current through resistor R_S, $I_S = \frac{V_S - V_Z}{R_S}$

$I_S = I_Z + I_L$ ....(1)

$$I_{S\,min} = \frac{V_{S\,min} - V_Z}{R_{S\,max}}$$

Or, $R_{S\,max} = \frac{V_{S\,min} - V_Z}{I_{S\,min}}$ ....(2)

From eq (1), $I_Z = I_S - I_L$, In worst case, this may be written as

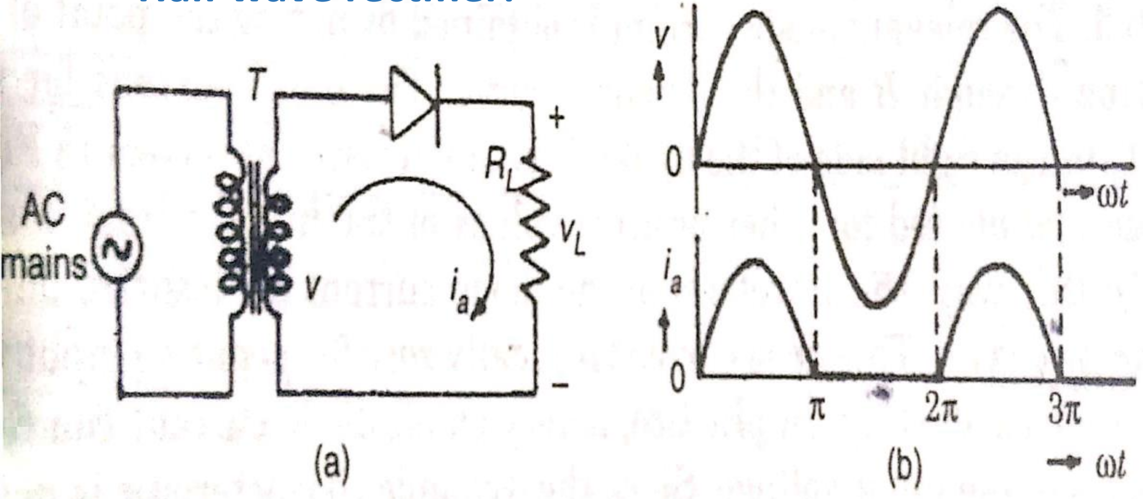
$$I_{Z\,min} = I_{S\,min} - I_{L\,max}$$

The critical point occurs when $I_{L\,max}$=$I_{S\,min}$. At this point, the zener current, I_Z reduce to zero and regulation is lost.

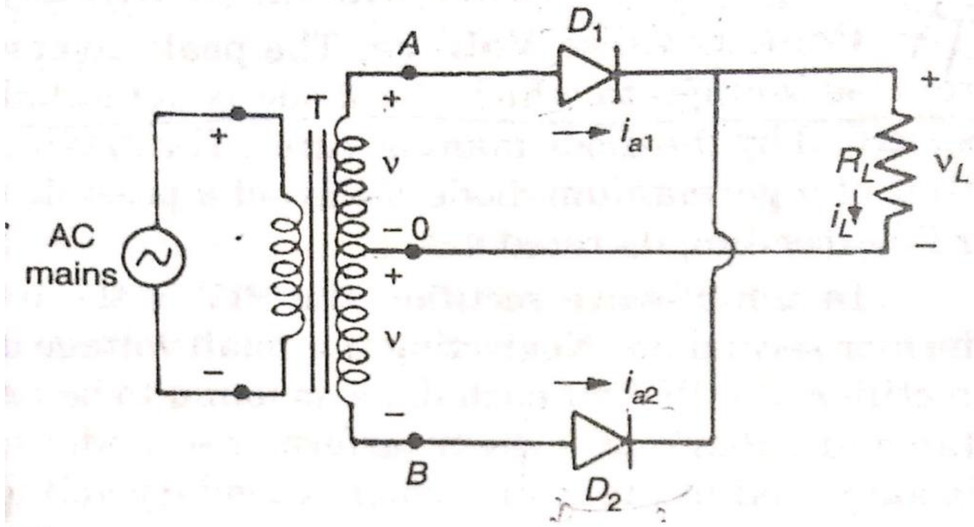
From eq (2), $R_{S\,max} = \frac{V_{S\,min} - V_Z}{I_{L\,max}}$

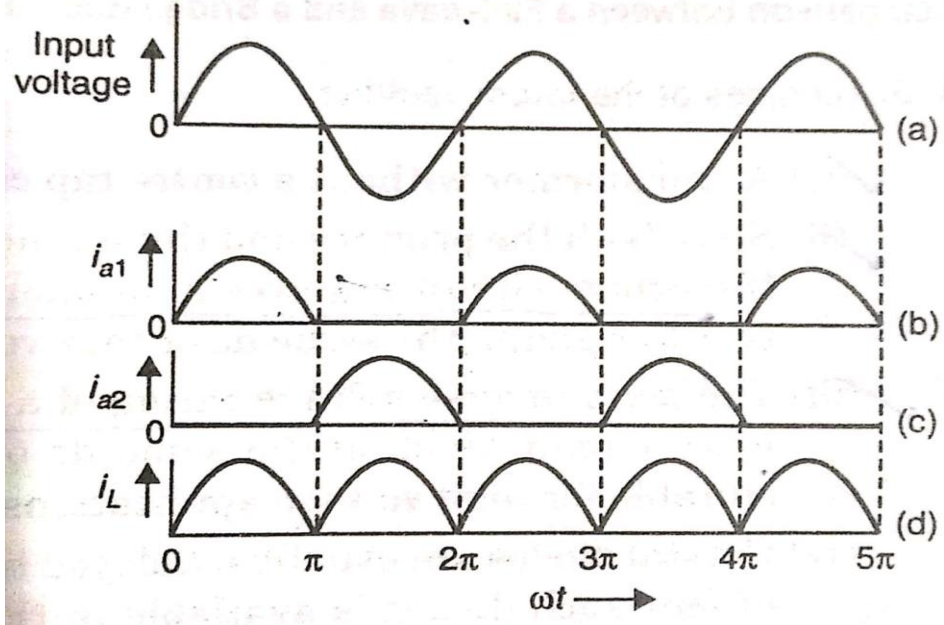
- The critical resistance, $R_{S\,max}$ is the maximum allowable series resistance. The series resistance R_S must always be less than the critical value, otherwise; breakdown operation is lost and the regulator stops its operation.

Half wave rectifier:

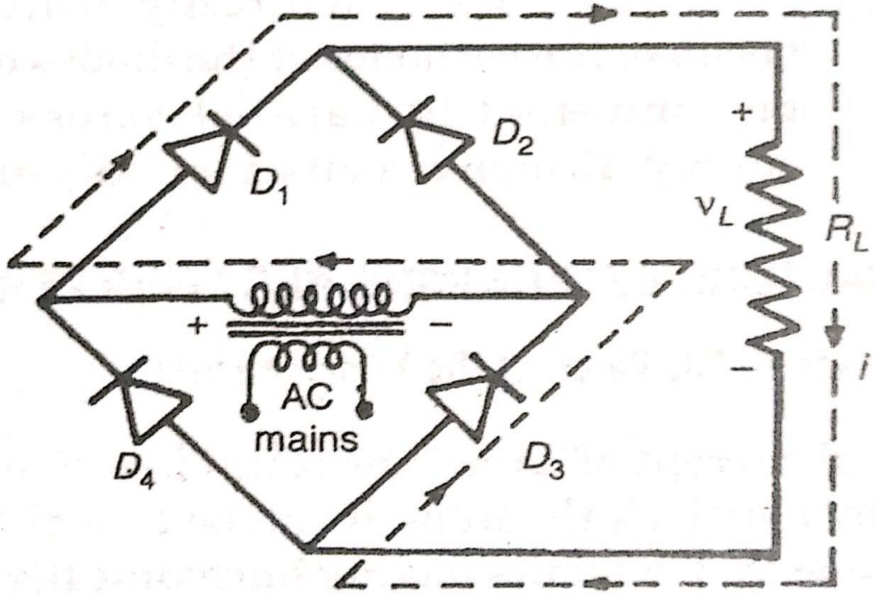


Full wave rectifier:





Bridge rectifier:



Factors determining rectifier performance:

Average or DC value of the load current:

$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)$

Ripple factor (γ) : it gives a measure of this imperfection or of the fluctuating components.

$\gamma = \frac{I_{rms}}{I_{dc}} = \frac{V_{rms}}{V_{dc}}$

$=\frac{(I_{rms}{}^2 - I_{dc}{}^2)^{1/2}}{I_{dc}{}^2} = \frac{(V_{rms}{}^2 - V_{dc}{}^2)^{1/2}}{V_{dc}{}^2}$

$=\left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1\right]^{1/2}$

Rectification efficiency: the efficiency of rectification is defined to be the ratio of the dc output power to the ac input power of the rectifier.

$$\eta = \left(\frac{I_{dc}}{I_{rms}}\right)^2 \frac{1}{1+\frac{R_f}{R_L}} \times 100\ \%$$

For half wave rectifier:

Load current $i_L = I_m \sin \omega t$ if $0 \le \omega t \le \pi$

$i_L = 0$ if $\pi \le \omega t \le 2\pi$

$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin \omega t \, d(\omega t) = \frac{1}{2\pi} I_m \times 2 = \frac{I_m}{\pi}$

$I_{rms} = [\frac{1}{2\pi}\int_0^{2\pi} I_m{}^2 sin^2\omega t \, d(\omega t)]^{1/2} = [\frac{1}{2\pi}\frac{1}{2}\int_0^{\pi} I_m{}^2 2sin^2\omega t \, d(\omega t)]^{1/2}$

$= [\frac{1}{2\pi}\frac{1}{2}\int_0^{\pi} I_m{}^2 \, (1 - cos2\omega t \, d(\omega t)]^{1/2}$

$= [\frac{1}{4\pi} I_m{}^2 \pi]^{1/2} = \frac{I_m}{2}$

$$\gamma = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{\frac{I_m}{2}}{\frac{I_m}{\pi}}\right)^2 - 1\right]^{1/2} = \mathbf{1.21}$$

$$\eta = \left(\frac{\frac{I_m}{\pi}}{\frac{I_m}{2}}\right)^2 \frac{1}{1+\frac{R_f}{R_L}} \times 100\ \% = \frac{0.406}{1+\frac{R_f}{R_L}} \times 100\ \% = \frac{\mathbf{40.6}}{\mathbf{1+\frac{R_f}{R_L}}}\ \%$$

Full wave rectifier:

Load current $i_L = I_m \sin \omega t \qquad \text{if } 0 \le \omega t \le \pi$

$$\mathrm{I}_{dc} = \frac{1}{2\pi}\int_0^{\pi} 2I_m \sin \omega t\, d(\omega t) = 2\times \frac{1}{2\pi} I_m \times 2 = \frac{2I_m}{\pi}$$

$$I_{rms} = [\frac{1}{2\pi} 2 \times \int_0^{\pi} {I_m}^2 sin^2\omega t\, d(\omega t)]^{1/2} = [2 \times \frac{1}{2\pi}\frac{1}{2}\int_0^{2\pi} {I_m}^2 2sin^2\omega t\, d(\omega t)]^{1/2}$$

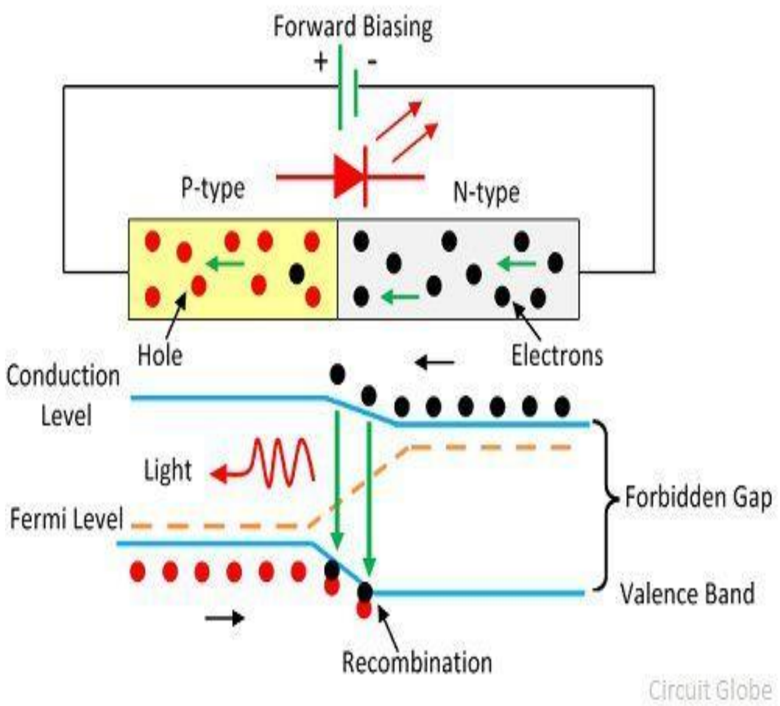
$$= [2 \times \frac{1}{2}\int_0^{2\pi} {I_m}^2 \ (1 - cos2\omega t\, d(\omega t)]^{1/2}$$

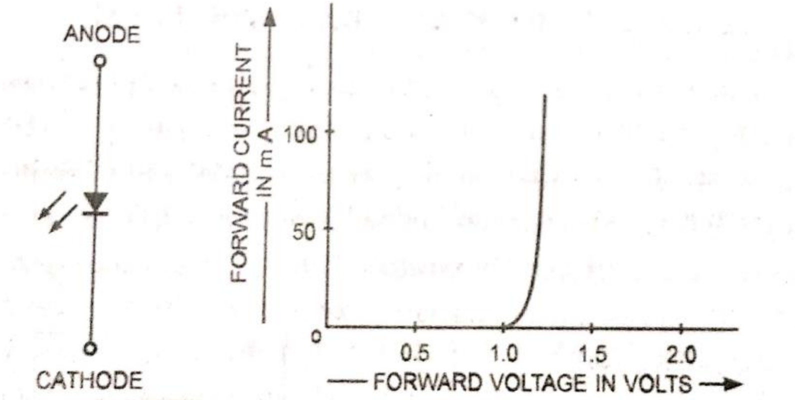
$$= [2 \times \frac{1}{4\pi} {I_m}^2 \pi]^{1/2} = \frac{I_m}{\sqrt{2}}$$

$$\gamma = \left[\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right]^{1/2} = \left[\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}}\right)^2 - 1\right]^{1/2} = \mathbf{0.482}$$

$$\eta = \left(\frac{\frac{2I_m}{\pi}}{\frac{I_m}{\sqrt{2}}}\right)^2 \frac{1}{1+\frac{R_f}{R_L}} \times 100\ \% = \frac{0.812}{1+\frac{R_f}{R_L}} \times 100\ \% = \frac{\mathbf{81.2}}{\mathbf{1+\frac{R_f}{R_L}}}\ \%$$

Light emitting diode:

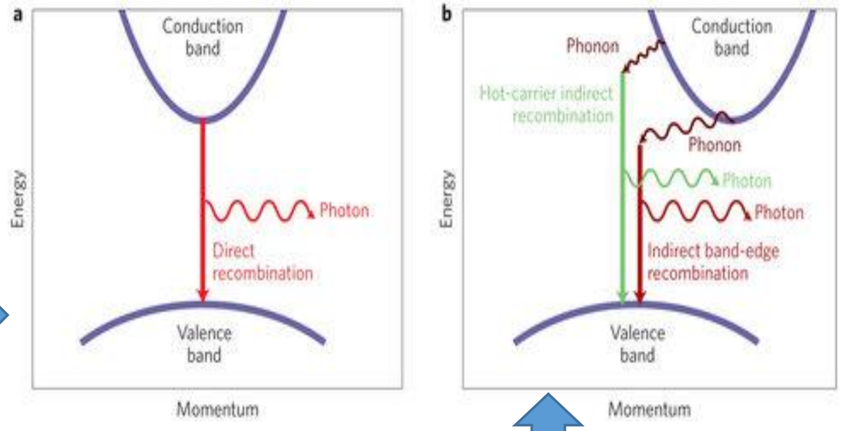




(a) (b) *Forward Bias V-I Curve*

- Photon are generated by the process of injection luminescence or electroluminescence.
- LED emits light by spontaneous emission.
- Group III-V compounds (direct band gap semiconductor) are used for LED.
- LED uses in signal lamp, optical communication etc.

The minimum of conduction band and maximum of valance band are at same point in wave vector space. Hence electron may jump from minimum of conduction band to maximum of valance band without change vector. There is direct recombination of electrons and holes and the excess energy is emitted in the form of photon.



The minimum of conduction band and maximum of valance band do not occur at same point in wave vector space. Hence electron may jump from minimum of conduction band to maximum of valance band involves change in energy as well as momentum. There is no direct recombination of electrons and holes. As a result energy is liberated goes to heat the crystal.

colour	Construction
blue	GaN
Green or red	GaP
yellow	GaAsP
red	GaAsP
white	GaN
yellow	AlInGaP

Thank you