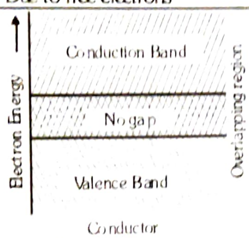
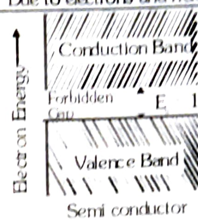
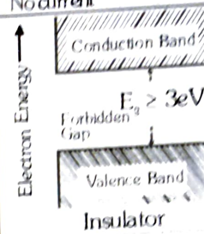
# Semiconductor & Digital Electronics

## COMPARISON BETWEEN CONDUCTOR, SEMICONDUCTOR AND INSULATOR

| Properties | Conductor | Semiconductor | Insulator |
|---|---|---|---|
| Resistivity | $10^{-2}$ – $10^{-8}$ Ωm | $10^{-5}$ – $10^{6}$ Ωm | $10^{11}$ – $10^{19}$ Ωm |
| Conductivity | $10^{2}$ – $10^{8}$ mho/m | $10^{-6}$ – $10^{5}$ mho/m | $10^{-19}$ – $10^{-11}$ mho/m |
| Temp. Coefficient of resistance ($\alpha$) | Positive | Negative | Negative |
| Current | Due to free electrons | Due to electrons and holes | No current |
| Energy band diagram |  |  |  |
| Forbidden energy gap | $\cong 0eV$ | $\cong 1eV$ | $\geq 3eV$ |
| Example | Pt, Al, Cu, Ag | Ge, Si, GaAs, $GaF_2$ | Wood, plastic, Diamond, Mica |







- **Number of electrons reaching from valence band to conduction band :** $n = AT^{3/2}e^{-\frac{\Delta E_g}{2kT}}$
- **CLASSIFICATION OF SEMICONDUCTORS :**

**SEMICONDUCTOR**

- Intrinsic semiconductor → (pure form of Ge, Si) $n_e = n_h = n_i$
- Extrinsic semiconductor (doped semicondutor)
  - N-type: pentavalent impurity (P, As, Sb etc.) donor impurity ($N_D$) $n_e >> n_h$
  - P-type: trivalent impurity (Ga, B, In, Al) acceptor impurity ($N_A$) $n_h >> n_e$

- **MASS-ACTION LAW** : $n_i^2 = n_e \times n_h$
  - ❑ For N-type semiconductor $n_e \cong N_D$
  - ❑ For P-type semiconductor $n_h \cong N_A$

### CONDUCTION IN SEMICONDUCTOR

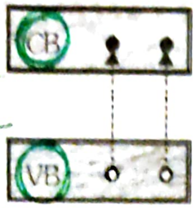
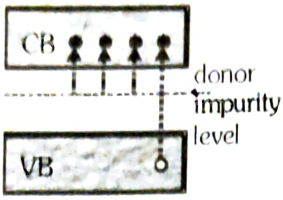
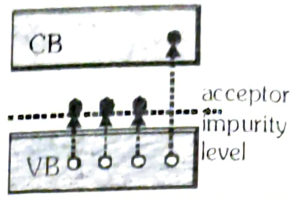
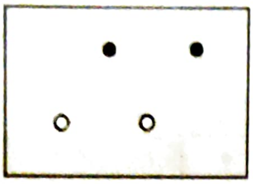
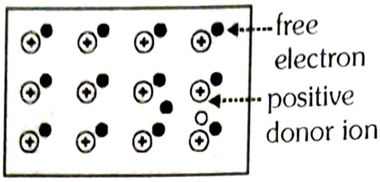
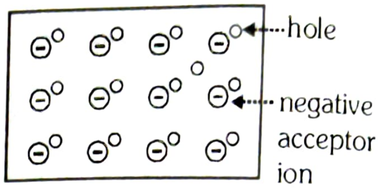
| Intrinsic semiconductor | P - type | N - type |
|---|---|---|
| $n_e = n_h$ | $n_h >> n_e$ | $n_e >> n_h$ |
| $J = ne\,[v_e + v_h]$ (Current density) | $J \cong e\,n_h\,v_h$ | $J \cong e\,n_e\,v_e$ |
| $\sigma = \frac{1}{\rho} = en\,[\mu_e + \mu_h]$ (Conductivity) | $\sigma = \frac{1}{\rho} \cong e\,n_h\,\mu_h$ | $\sigma = \frac{1}{\rho} \cong e\,n_e\,\mu_e$ |

If silicon crystal contains 'N' atoms, their



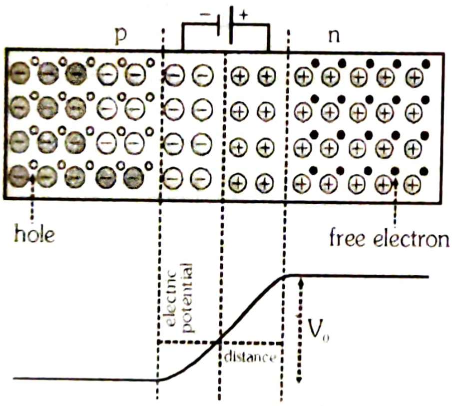
CB → 4N states & zero e⁻

VB → 4N states & 4N e⁻

| Intrinsic Semiconductor | N-type (Pentavalent impurity) | P-type (Trivalent impurity) |
|---|---|---|
|  energy gap |  |  |
|  |  |  |
| Current due to electron and hole | Mainly due to electrons | Mainly due to holes |
| $n_e = n_h = n$ | $n_h << n_e$ $(N_D \approx n_e)$ | $n_h >> n_e$ $(N_A \approx n_h)$ |
| $I = I_e + I_h$ | $I \approx I_e$ | $I \approx I_h$ |
| Entirely neutral | Entirely neutral | Entirely neutral |
| Quantity of electrons and holes are equal | Majority Electrons<br>Minority Holes | Majority Holes<br>Minority - Electrons |



## P-N JUNCTION
### (At equilibrium condition)



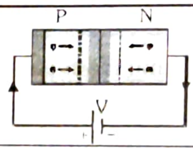
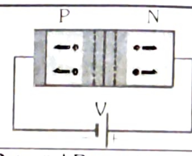
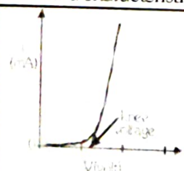
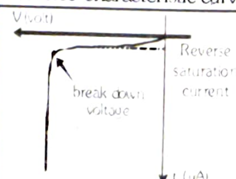

Direction of diffusion current : P to N side

and drift current : N to P side

If there is no biasing then diffusion current = drift current. So total current is zero

In junction N side is at high potential relative to the P side. This potential difference tends to prevent the movement of electron from the N region into the P region. This potential difference called a **barrier potential**.

## COMPARISON BETWEEN FORWARD BIAS AND REVERSE BIAS

| | Forward Bias | | Reverse Bias |
|---|---|---|---|
| |  | |  |
| 1 | Potential Barrier reduces | 1 | Potential Barrier increases. |
| 2 | Width of depletion layer decreases | 2 | Width of depletion layer increases. |
| 3 | P-N jn. provide very small resistance | 3 | P-N jn. provide high resistance |
| 4 | Forward current flows in the circuit | 4 | Very small current flows. |
| 5 | Order of forward current is milli ampere. | 5 | Order of current is micro ampere for Ge or Nano ampere for Si. |
| 6 | Current flows mainly due to majority carriers. | 6 | Current flows mainly due to minority carriers. |
| 7 | Forward characteristic curves. | 7 | Reverse characteristic curve |
| |  | |  |
| 8 | Forward Resistance : $R_f = \frac{\Delta V}{\Delta I} \approx 100\,\Omega$ | 8 | Reverse Resistance $R_r = \frac{\Delta V}{\Delta I} \approx 10^6\,\Omega$ |
| 9 | Order of knee or cut in voltage | 9 | Breakdown voltage |
| | Ge → 0.3 V | | Ge → 25 V |
| | Si → 0.7 V | | Si → 35 V |
| | Special point : Generally $\frac{R_r}{R_f} = 10^4 : 1$ for Ge | | $\frac{R_r}{R_f} = 10^4 : 1$ for Si |

## BREAKDOWN ARE OF TWO TYPES

**Zener Break down**

Where covalent bonds of depletion layer, itself break, due to high electric field of very high Reverse bias voltage.

This phenomena take place in

(i) P – N junction having "High doping"

(ii) P – N junction having thin depletion layer

Here P – N junction does not damage permanently

"In D.C voltage stabilizer zener phenomena is used".

**Avalanche Break down**

Here covalent bonds of depletion layers are broken by collision of "Minorities" which aquire high kinetic energy from high electric field of very-very high reverse bias voltage.

This phenomena takes place in

(i) P – N junction having "Low doping"

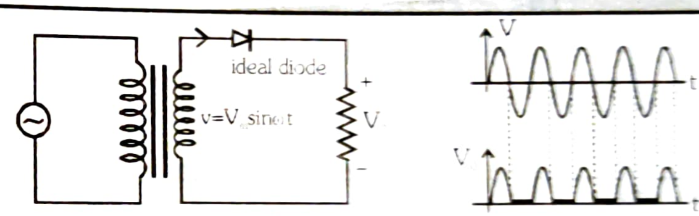
(ii) P – N junction having thick depletion layer

Here P – N junction damages permanentaly due to abruptly increment of minorities during repeatative collisions.

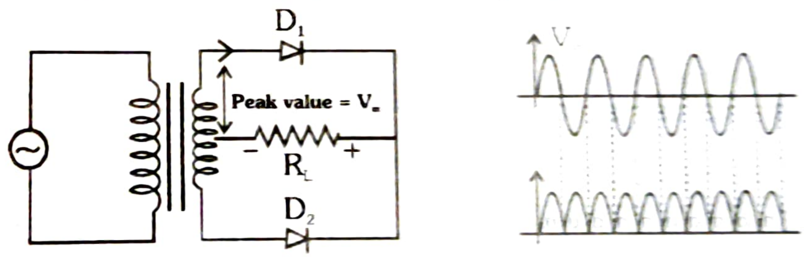
## APPLICATION OF DIODE

- **Zener diode** : It is highly doped p-n junction diode used as a voltage regulator.
- **Photo diode** : A p-n junction diode use to detect light signals operated in reverse bias.
- **LED** : A p-n junction device that emits optical radiation under forward bias conditions
- **Solar cell** : Generates emf of its own due to the effect of sun radiations.

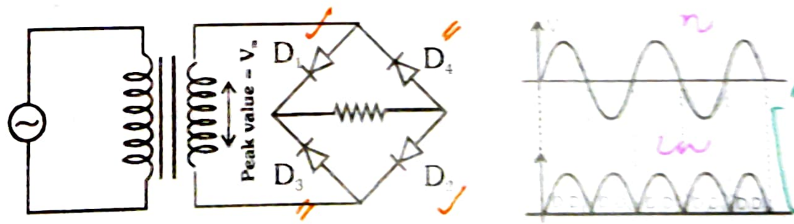
**HALF WAVE RECTIFIER**

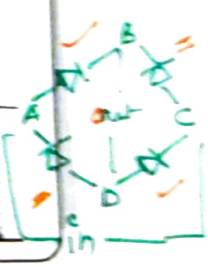



**CENTRE – TAP FULL WAVE RECTIFIER**




**FULL WAVE BRIDGE REACTIFIER**




**RIPPLE FACTOR :** $r = \frac{I_{ac}}{I_{dc}}$

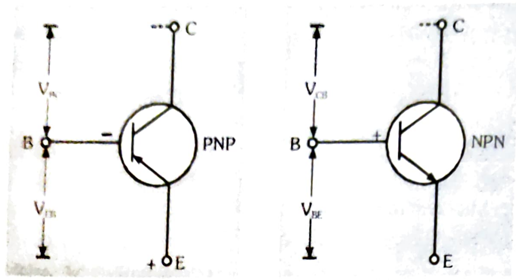
- For HWR $r = 1.21$
- For FWR $r = 0.48$

**RECTIFIER EFFICIENCY:** $\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_L)}$

For HWR : $\eta\% = \frac{40.6}{1 + \frac{R_f}{R_L}}$ & FWR $\eta\% = \frac{81.2}{1 + \frac{R_f}{R_L}}$

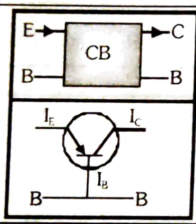
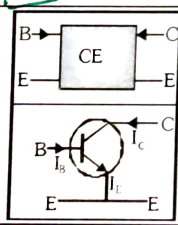
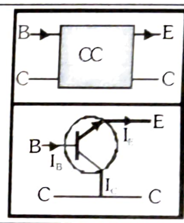
**FOR TRANSISTOR**

$I_E = I_B + I_C$




**COMPARATIVE STUDY OF TRANSISTOR CONFIGURATIONS**

1. Common Base **(CB)** 2. Common Emitter **(CE)** 3. Common Collector **(CC)**

| | CB | CE | CC |
|---|---|---|---|
| |  |  |  |
| **Input Resistance** | Low (100 Ω) | High (750 Ω) | Very High ≅ 750 kΩ |
| **Output resistance** | Very High | High | Low |
| **Current Gain** | ($A_I$ or α) | ($A_I$ or β) | ($A_I$ or γ) |
| | $\alpha = \frac{I_C}{I_E} < 1$ | $\boxed{\beta = \frac{I_C}{I_B} > 1}$ jo missing hai | $\gamma = \frac{I_E}{I_B} > 1$ |
| **Voltage Gain** | $A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_E R_i}$ | $A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_B R_i}$ | $A_V = \frac{V_o}{V_i} = \frac{I_E R_L}{I_B R}$ |
| | $A_v = \alpha \frac{R_L}{R_i} \cong 150$ | $A_v = \beta \frac{R_L}{R_i} \cong \boxed{500}$ load input highest | $A_v = \gamma \frac{R_L}{R} < 1$ |
| **Power Gain** | $A_p = \frac{P_o}{P_i} = \alpha^2 \frac{R_L}{R_i}$ | $A_p = \frac{P_o}{P_i} = \beta^2 \frac{R_L}{R_i}$ | $A_p = \frac{P_o}{P} = \gamma^2 \frac{R_L}{R}$ |
| **Phase difference (between output and input)** | same phase | opposite phase | same phase |
| **Application** | For High Frequency | For Audible frequency | For Impedance Matching |

## TRANSISTOR CHARACTERISTICS

- Input resistance ($r_i$) $\left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE\text{-constant}}}$
- Output resistance ($r_0$) $\left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_{B\text{-constant}}}$
- **Relation between α and β :** $\beta = \frac{\alpha}{1-\alpha}$ **&** $\alpha = \frac{\beta}{1+\beta}$
- **Current amplification factor**
  - **For CE(n-p-n)** $\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE\text{-constant}}}$
  - **For CB (p-n-p)** $\alpha_{ac} = \left(\frac{\Delta I_C}{\Delta I_E}\right)_{V_{CB\text{-constant}}}$

## CB CE APPLICATIONS OF TRANSISTORS

**There are three regions of transistor operation:**

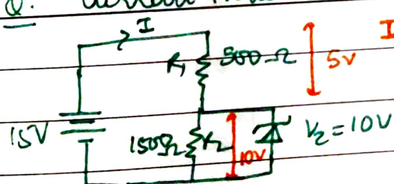
- **Cut off region * Active region * Saturation region**
- **Transistor as Voltage amplifier**
  - To operate it as an amplifer we need to fix its operating voltage somewhere in active region where it increases the strength of input ac signal and produces an amplified output signal.
  - Voltage gain $A_V = \frac{V_0}{V_i} = -\beta_{ac}\frac{R_{out}}{R_{in}}$
  - Power gain $A_P = A_V \times \beta_{ac}$
- **Transistor as a Switch**
  A transistor can be used as a switch if it is operated in its cutoff and saturation states only.
- **Transisot as an Oscillator**
  An oscillator is a generator of an ac signal using positive feedback

  Frequency of oscillations if $f = \frac{1}{2\pi\sqrt{LC}}$
- **Relation between α, β and γ :**

  $\beta = \frac{\alpha}{1-\alpha}$, $\gamma = 1+\beta$, $\gamma = \frac{1}{1-\alpha}$

## IMPORTANT NOTES

Q. Current thru Zener diode




$I = \frac{5}{500} = \frac{1}{100}$

$I = I_2 + I_Z$

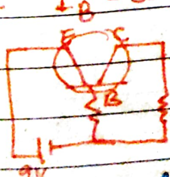
$I_Z = I - I_2$

$I_2 = \frac{10}{1500} = \frac{1}{150}$

$= \frac{1}{100} - \frac{1}{150}$

$\boxed{I_Z = \frac{1}{300}}$

Q. $I_B = 35mA$ find $R_B$ = ?




$I_B = 35mA$

$V_B = I_B \cdot R_B$

$9 = 35 \cdot R_B \times 10^{-3}$