SHREE H. N. SHUKLA GROUP OF COLLEGES

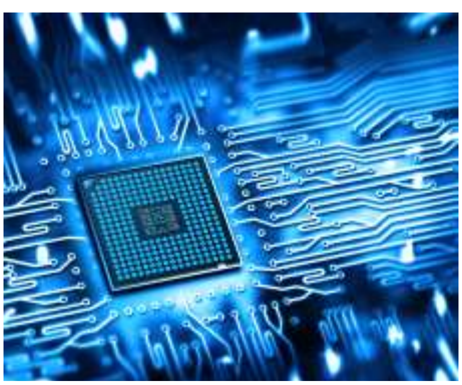
F.Y.B.Sc. SEM – I

Subject: Physics

Paper- 101

Unit -2

SEMICONDUCTOR PHYSICS



- Introduction
- Semiconductor
- Energy band
- Intrinsic semiconductor
- Extrinsic semiconductor
- P –type semiconductor
- N- type semiconductor
- PN junction diode
- Zener diode
- Numerical

❖ TITLE JUSTIFICATION :

We often hear that we are living in the information age. Large amount of information can be obtained via the internet, for example - and can also be obtained quickly over long distance via satellite communication system. This all happens because of semiconductor material. The development in semiconductor physics has lead to these remarkable capabilities. One of the most dramatic examples of IC technology is the **digital computer** - relatively small laptop computer today has more computing capability than the equipment used to send a man to the moon a few years ago.

❖ THEME :

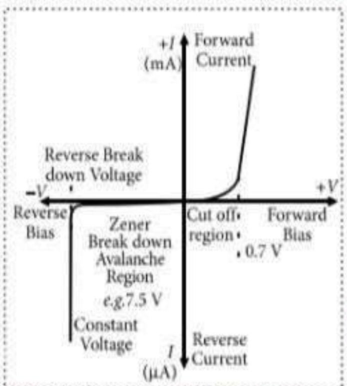
In this chapter the text begins with introductory physics, moves on to the **semiconductor physics** and then the covers the physics of semiconductor device like **Diode** and Transistor. The main purpose of the chapter is to provide a basic understanding of characteristic, operation and limitation of semiconductor device. Since **semiconductor** itself is not sold in stores as electrical appliances, it may to be hard to understand, but in fact it is used in many electric appliances. Many digital consumer products in everyday life such as mobile phones / smartphones, digital cameras, televisions, washing machines, refrigerators and LED bulbs also use semiconductors.

SEMICONDUCTOR PHYSICS

BRAIN MAP

TYPES OF SEMICONDUCTORS

INTRINSIC SEMICONDUCTORS
The pure semiconductors have thermally generated current carriers. Here, $n_e = n_h = n_i$



EXTRINSIC SEMICONDUCTORS
The semiconductor whose conductivity is mainly due to doping of impurity.

***p*-type semiconductor**
- Doped with trivalent atom.
- Here, $n_h >> n_e$

***n*-type semiconductor**
- Doped with pentavalent atom.
- Here, $n_e >> n_h$

SEMICONDUCTOR DIODE
***p–n* junction diode :** A *p*-type semiconductor is brought into contact with an *n*-type semiconductor such that structure remains continuous at boundary.

BIASING CHARACTERSTICS
Forward bias characteristic
- Width of depletion layer decreases
- Effective barrier potential decreases
- Low resistance at junction
- High current flow of the order of mA.

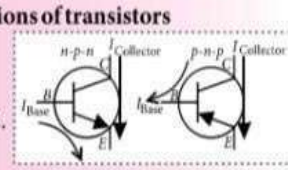
Reverse bias characteristic
- Width of depletion layer increases
- Effective barrier potential increases
- High resistance at the junction
- Low current flow of the order of μA.
- Reverse break down occurs at a high reverse bias voltage.

APPLICATIONS OF DIODE
- **Diode as a rectifier**
  - Half wave rectifier
  - Full wave rectifier
- **Zener diode** as a voltage regulator.
- **Photo diode** for detecting light signals.
- **LED:** light emitting diode.
- **Solar cells:** Generates emf from solar radiations.

JUNCTION TRANSISTOR
A semiconductor device possessing fundamental action of transfer resistor.

Junction transistors are of two types
- ***n-p-n* transistor:** A thin layer of *p*-type semiconductor is sandwiched between two *n*-type semiconductors.
- ***p-n-p* transistor:** A thin layer of *n*-type semiconductor is sandwiched between two *p*-type semiconductors.

There are three configurations of transistors
- CB (Common Base)
- CE (Common Emitter)
- CC (Common Collector).

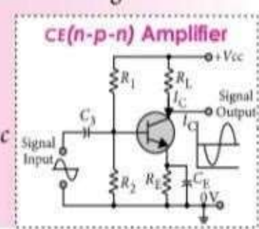


Transistor characteristics
- Input resistance $(r_i)_{(CE)} = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}=\text{constant}}$
- Output resistance $(r_o)_{(CE)} = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B=\text{constant}}$
- Current amplification factor

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}=\text{constant}} \qquad \alpha_{ac} = \left(\frac{\Delta I_C}{\Delta I_E}\right)_{V_{CB}=\text{constant}}$$

APPLICATIONS OF TRANSISTOR
- **Transistor as an Amplifier**
  - Its operating voltage is fix in active region.
  - Voltage gain,

    $A_v = \frac{V_o}{V_i} = -\beta_{ac}\frac{R_{out}}{R_{in}}$
  - Power gain, $A_p = A_v \times \beta_{ac}$
- **Transistor as a Switch**
- **Transistor as an Oscillator**



❖ ENERGY BAND IN SOLID :

Based on Pauli's exclusion principle

In an isolated atom electrons present in energy level but in solid, atoms are not isolated, there is interaction among each other, due to this energy level splitted into different energy levels. Quantity of these different energy levels depends on the quantity of interacting atoms. Splitting of sharp and closely compact energy levels result into energy bands. They are discrete in nature. Order of energy levels in a band is 10^{23} and their energy difference = 10^{-23} eV.

Energy Band

Range of energy possessed by an electron in a solid is known as energy band.

Valence Band (VB)

Range of energies possessed by valence electron is known as valence band.

(a) Have bonded electrons.

(b) No flow of current due to such electrons.

(c) Always fulfill by electrons.

Conduction Band (CB)

Range of energies possessed by free electron is known as conduction band.

(a) It has conducting electrons.

(b) Current flows due to such electrons.

(c) If conduction band is fully empty then current conduction is not possible.

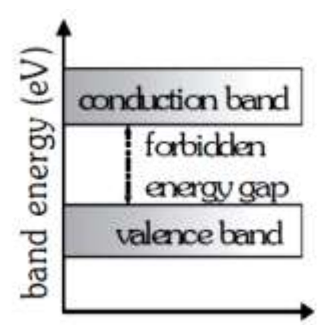
(d) Electrons may exist or not in it.

Forbidden Energy gap (FEG) (ΔEg)

$$\Delta E_g = (C\,B)_{min} - (V\,B)_{max}$$

Energy gap between conduction band and valence band, where no free electron can exist.

- Width of forbidden energy gap depends upon the nature of substance.
- Width is more, then valence electrons are strongly attached with nucleus
- Width of forbidden energy gap is represented in eV.
- As temperature increases forbidden energy gap decreases (very slightly).



❖ CLASSIFICATION OF MATERIAL :

On the basis of the relative values of electrical conductivity and energy bands the solids are broadly classified into three categories

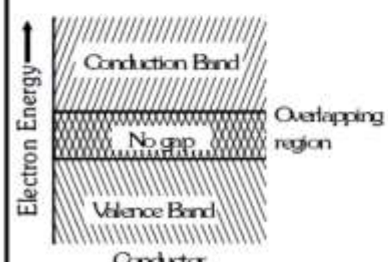
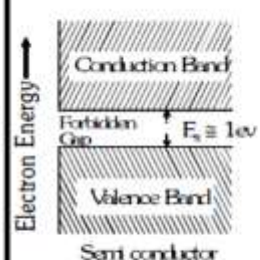
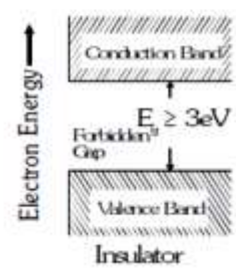
(i) Conductors

(ii) Semiconductors

(iii) Insulator

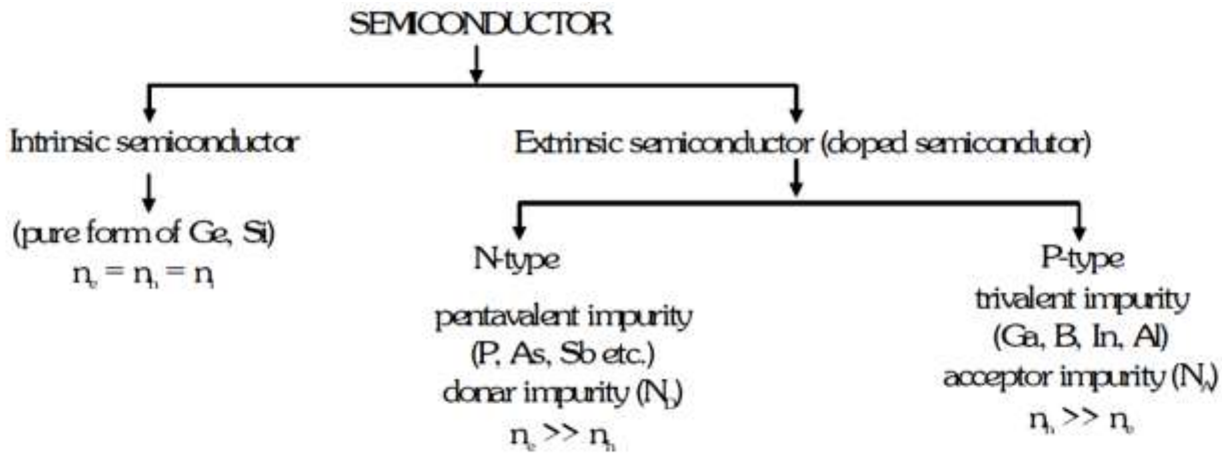
Comparison between conductor, semiconductor and insulator :

Scan here for video

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^{5} – 10^{-6} mho/m	10^{-11} – 10^{-19} mho/m
Temp. Coefficient of resistance (α)	Positive	Negative	Negative (Very slightly)
Current	Due to free electrons	Due to electrons and holes	No current
Energy band diagram			
Forbidden energy gap	≅ 0eV	≅ 1eV	≥ 3eV
Example :	Pt, Al, Cu, Ag	Ge, Si, GaAs, GaF_2	Wood, plastic, Diamond, Mica

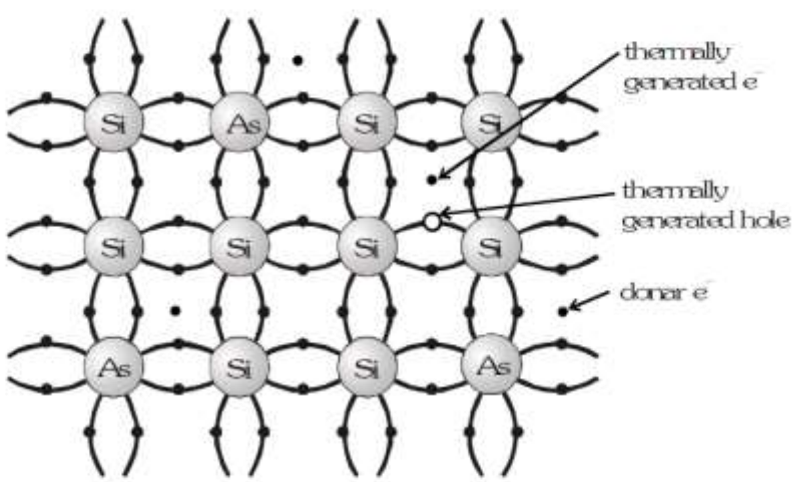
SRNO	QUESTION	ANSWER
1	Range of energy possessed by an electron is known as a _____________ .	Energy band
2	Range of energy possessed by an valance electron is known as a _____________ .	Valence band
3	Range of energy possessed by an free electron is known as a _____________.	Conduction band
4	Energy gap between conduction band and valence band is known as _____.	Forbidden gap
5	Forbidden energy gap represent as unit in __________.	Electrovolt (ev)
6	On the basis of energy band solid classified in _________ groups.	3
7	On the basis of energy band solid classified in three category , name them.	Conductor , Semiconductor Insulator
8	Temperature co efficient of resistance of conductor material is ___________.	Positive
9	Temperature co efficient of resistance of semiconductor material is _____ .	Negative
10	Current will be flow in conductor due to ___________.	Free electron
11	Current will be flow in semiconductor due to ___________.	Electron & hole
12	Give the example of conductor material.	Al, Cu, Ag
13	Give the example of semiconductor material.	Ge, Si
14	Give the example of insulator material.	Wood, plastic.
15	Write the forbidden gap value for conductor material.	0 ev

❖ CLASSIFICATION OF SEMICONDUCTOR :

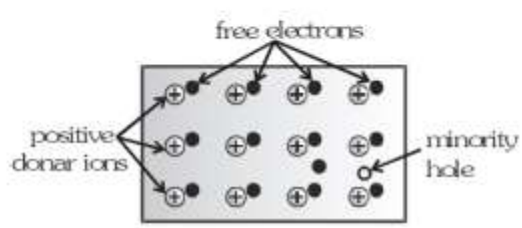


❖ N - TYPE SEMICONDUCTOR :

When a pure semiconductor (Si or Ge) is doped by pentavalent impurity (P, As, Sb, Bi) then four electrons out of the five valence electrons of impurity take part, in covalent bonding, with four silicon atoms surrounding it and the fifth electron is set free. These impurity atoms which donate free e^- for conduction are called as Donar impurity (N_D). Due to donar impurity free e^- increases very much so it is called as "N" type semiconductor. By donating e^- impurity atoms get positive charge and hence known as "Immobile Donar positive Ion". In N-type semiconductor free e^- are called as "majority" charge carriers and "holes" are called as "minority" charge carriers.



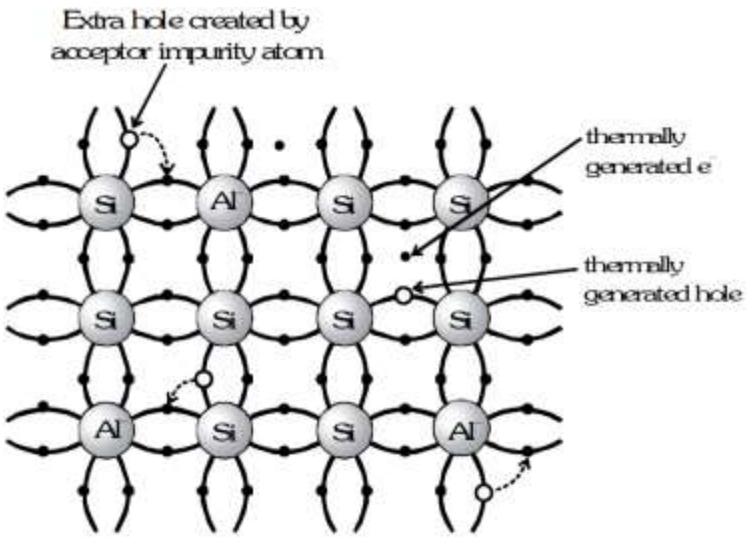
N-type semiconducting crystal



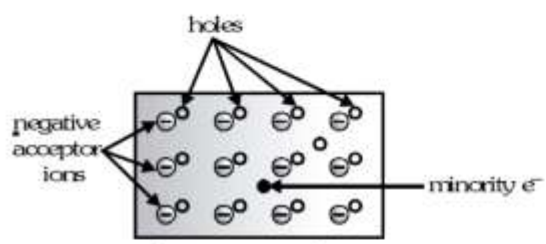
N-type semiconductor

❖ P - TYPE SEMICONDUCTOR :

When a pure semiconductor (Si or Ge) is doped by trivalent impurity (B, Al, In, Ga) then outer most three electrons of the valence band of impurity take part, in covalent bonding with four silicon atoms surrounding it and except one electron from semiconductor and make hole in semiconductor. These impurity atoms which accept bonded e^- from valance band are called as Acceptor impurity (N_A). Here holes increases very much so it is called as "P" type semiconductor and impurity ions known as "Immobile Acceptor negative Ion". In P-type semiconductor free e^- are called as minority charge carries and holes are called as majority charge carriers.



P-type semiconducting crystal

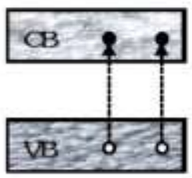
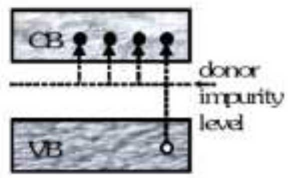
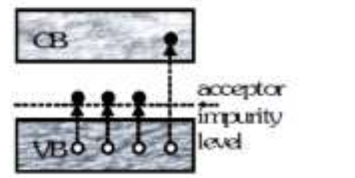
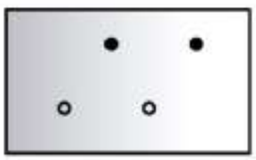
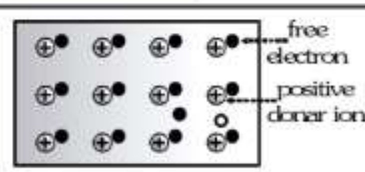
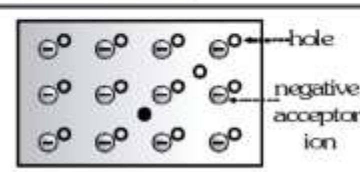


P-type semiconductor

❖ INTRINSIC SEMICONDUCTOR :

A perfect semiconductor crystal with no impurities or lattice defects is called an intrinsic semiconductor. In such material there are no charge carriers at 0*K*, since the valence band is filled with electrons and the conduction band is empty. At higher temperatures electron-hole pairs are generated as valence band electrons are excited thermally across the band gap to the conduction band. These EHPs are the only charge carriers in intrinsic material.

❖ KEY POINT:

Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type(Trivalent impurity)
1. 		
2. 		
3. Current due to electron and hole	Mainly due to electrons	Mainly due to holes
4. $n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n_h$)
5. $I = I_e + I_h$	$I \simeq I_e$	$I \simeq I_h$
6. Entirely neutral	Entirely neutral	Entirely neutral
7. Quantity of electrons and holes are equal	Majority - Electrons Minority - Holes	Majority - Holes Minority - Electrons

SR NO	QUESTION	ANSWER
1	How many types of semiconductor?	2
2	Pure semiconductor is known as __________.	Intrinsic semiconductor
3	Impurity doped semiconductor is known as ____________.	Extrinsic semiconductor
4	How many types of extrinsic semiconductor?	P type semiconductor N type semiconductor
5	Which impurity added to a P type semiconductor?	Trivalent (B, Al)
6	Which impurity added to a N type semiconductor?	Pentavalent (Sb, As)
7	In N type semiconductor majority charge carrier is _________.	Electron
8	In P type semiconductor majority charge carrier is _________.	Holes

❖ Numerical :

Ex.1 The energy of a photon of sodium light (λ = 589 nm) equals the band gap of a semiconducting material. Find :

(a) the minimum energy E required to create a hole-electron pair.

(b) the value of $\frac{E}{kT}$ at a temperature of 300 K.

Sol. (a) $E = \frac{hc}{e\lambda}$ (in eV) so $E = \frac{12400}{\lambda}$ (E is in eV and λ is in Å) λ = 5890 Å

so $E = \frac{12400}{5890} = 2.1\text{eV}$ (b) $\frac{E}{kT} = \frac{2.1 \times 1.6 \times 10^{-19} \text{J}}{1.38 \times 10^{-23} \times 300} = 81$

Ex.2 A P type semiconductor has acceptor level 57 meV above the valence band. What is maximum wavelength of light required to create a hole ?

Sol. $E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{57 \times 10^{-3} \times 1.6 \times 10^{-19}} =$ 217100 Å

Ex.3 A silicon specimen is made into a p-type semiconductor by doping on an average one indium atom per 5 10^7 silicon atoms. If the number density of atoms in the silicon specimen is 5 10^{28} atoms/m^3; find the number of acceptor atoms in silicon per cubic centimeter.

Sol. The doping of one indium atom in silicon semiconductor will produce one acceptor atom in p-type semiconductor. Since one indium atom has been dopped per 5 10^7 silicon atoms, so number density of acceptor atoms in silicon $= \frac{5 \times 10^{28}}{5 \times 10^{7}} = 10^{21}$ atom/m^3 = = 10^{15} atoms/cm^3

Ex.4 A pure Ge specimen is doped with $A\ell$. The number density of acceptor atoms is approximately 10^{21} m^{-3}. If density of electron holes pair in an intrinsuc semiconductor is approximately 10^{19}m^{-3}, the number density of electrons in the specimen is :

Sol. In pure semiconductor electron-hole pair $n_i = 10^{19}$ m^{-3}

acceptor impurity $N_A = 10^{21}$ m^{-3}

Holes concentration $n_h = 10^{21}$ m^{-3}

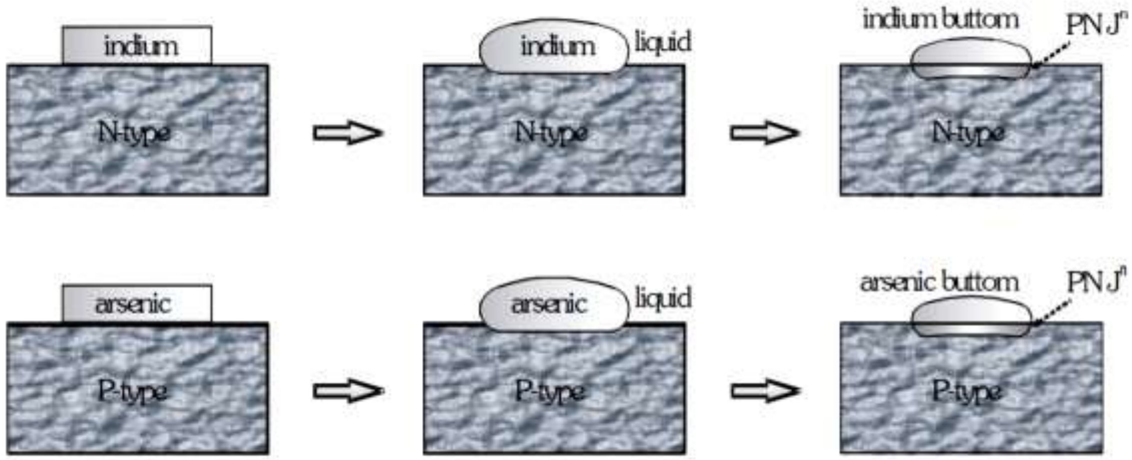
electrons concentration $= n_e = \frac{n_i^2}{n_h} = \frac{(10^{19})^2}{10^{21}} = 10^{17}$ m^{-3}

❖ PN junction Diode :

Techniques for making P-N junction

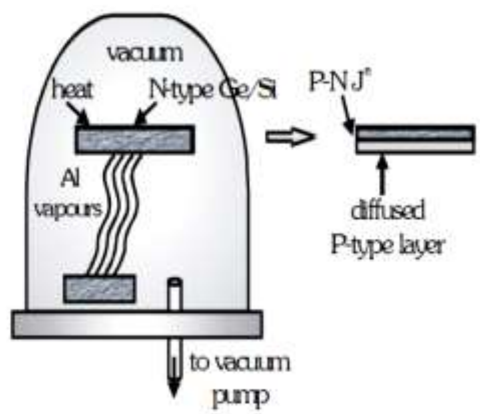
(i) Alloy Method or Alloy Junction

Here a small piece of III group impurity like indium is placed over n-Ge or n-Si and melted as shown in figure ultimetely P – N junction form.



(ii) Diffusion Junction

A heated P-type semiconductor is kept in pentavalent impurity vapours which diffuse into P-type semiconductor as shown and make P-N junction.



(iii) Vapour deposited junction or epitaxial junction

If we want to grow a layer of n-Si or p-Si then p-Si wafer is kept in an atmosphere of Silane (a silicon compound which dissociates into Si at high temperatures) plus phosphorous vapours. On craking of silane at high temperature a fresh layer on n-Si grows on p-Si giving the "P-N junction". Since this junction growth is layer by so it is also referred as layer growth or epitaxial junction formation of P-N junction.

Description of P-N Junction without applied voltage or bias

Given diagram shows a P–N junction immediately after it is formed.

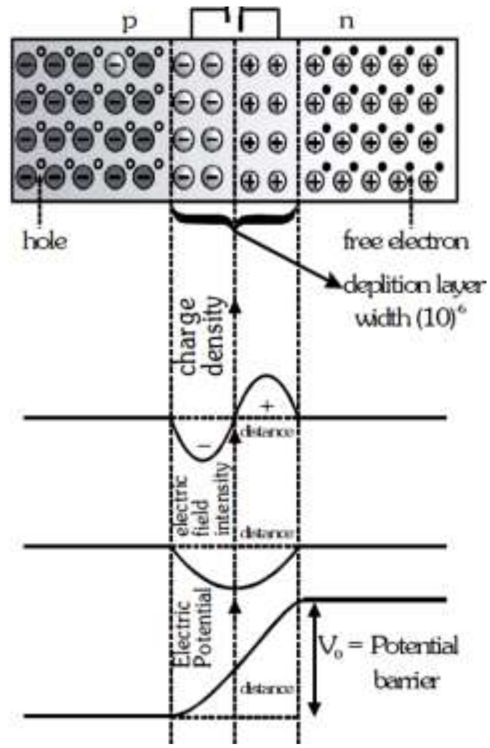
P region has mobile majority holes and immobile negatively charged impurity ions.

N region has mobile majority free electrons and immobile positively charged impurity ions.

Due to concentration difference diffusion of holes starts from P to N side and diffusion of e^- s starts N to P side.

Due to this a layer of only positive (in N side) and negative (in P–side) started to form which generate an electric field (N to P side) which oppose diffusion process, during diffusion magnitude of electric field increases due to this diffusion it gradually decreased and ultimately stopes.

The layer of immobile positive and negative ions, which have no free electrons and holes called as **depletion layer** as shown in diagram.



❖ Diffusion and drift current :

(1) Diffusion current – P to N side (2) Drift current – N to P side

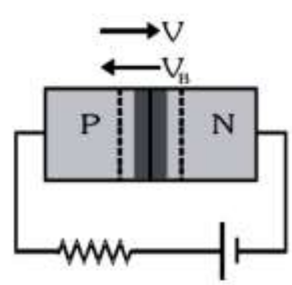
If there is no biasing diffusion current = drift current

So total current is zero

❖ Biasing of PN junction diode :

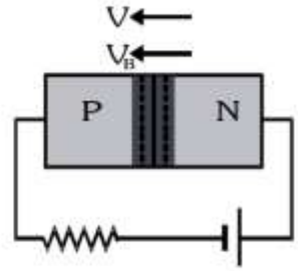
Forward Bias

If we apply a voltage "V" such that P–side is positive and N–side is negative as shown in diagram.



The applied voltage is opposite to the junction barrier potential.Due to this effective potential barrier decreases, junction width also decreases, so more majority carriers will be allowed to flow across junction. It means the current flow in principally due to majority charge carriers and it is in the order of mA called as forward Bias.

Reverse Bias

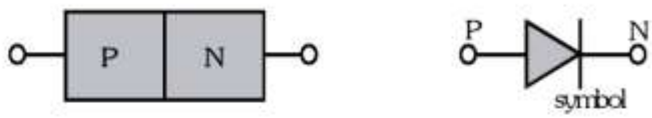


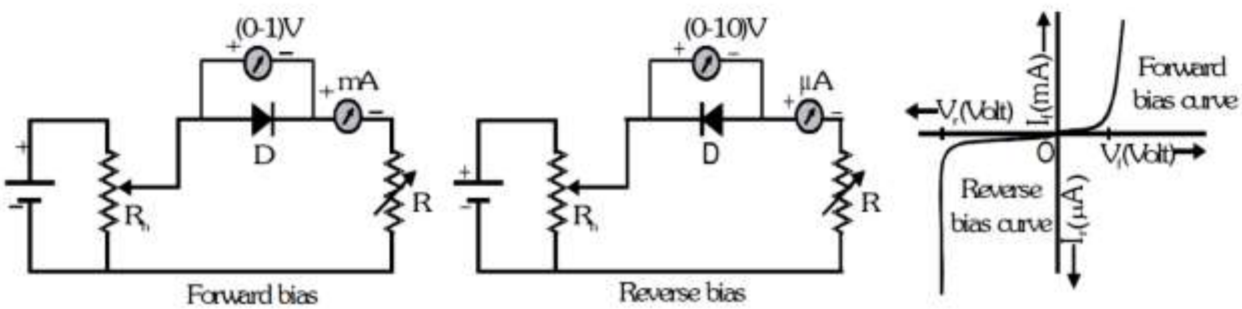
If we apply a voltage "V" such that P–side is negative and N–side is positive as shown in diagram.

The applied voltage is in same direction as the junction barrier potential. Due to this effective potential barrier increase junction, width also increases, so no majority carriers will be allowed to flow across junction.

Only minority carriers will drifted. It means the current flow in principally due to minority charge carriers and is very small (in the order of μA). This bias is called as reversed Bias.

CHARACTERISTIC CURVE OF P-N JUNCTION DIODE

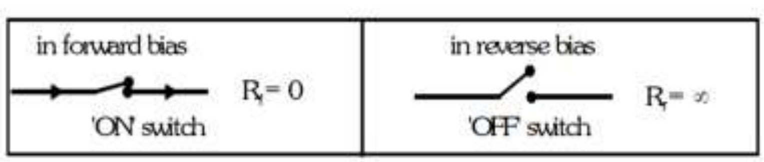




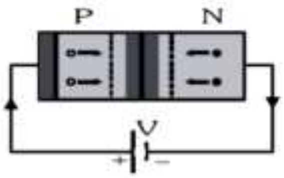
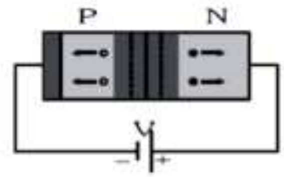
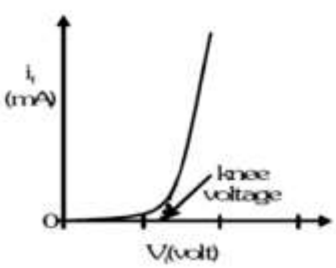
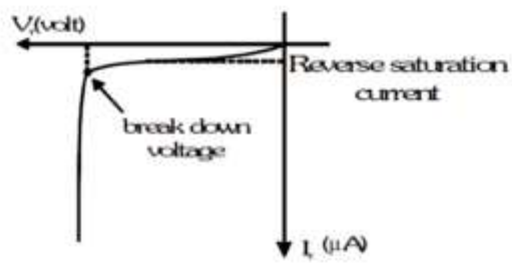
In forward bias when voltage is increased from 0V is steps and corresponding value of current is measured, the curve comes as OB of figure. We may note that current increase very sharply after a certain voltage knee voltage. At this voltage, barrier potential is completely eliminated and diode offers a low resistance.

In reverse bias a microammeter has been used as current is very very small. When reverse voltage is increased from 0V and corresponding values of current measured the plot comes as OCD. We may note that reverse current is almost constant hence called reverse saturation current. It implies that diode resistance is very high. As reverse voltage reaches value V_B, called breakdown voltage, current increases very sharply.

For Ideal Diode



Comparison between Forward Bias and Reverse Bias

Forward Bias	Reverse Bias
P → positive N → negative	P → negative N → positive
	
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 Neno 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 $R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$	8. Reverse resistance $R_r = \frac{\Delta V_r}{\Delta I_r} \cong 10^6\Omega$
9. Order of knee or cut in voltage Ge → 0.3 V Si → 0.7 V	9. Breakdown voltage Ge → 25 V Si → 35 V
Special point : Generally $\frac{R_r}{R_f} = 10^3 : 1$ for Ge	$\frac{R_r}{R_f} = 10^4 : 1$ for Si

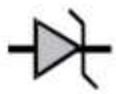
❖ ZENER DIODE :

A specifically doped crystal diode which can work in break down region is known as Zener diode.

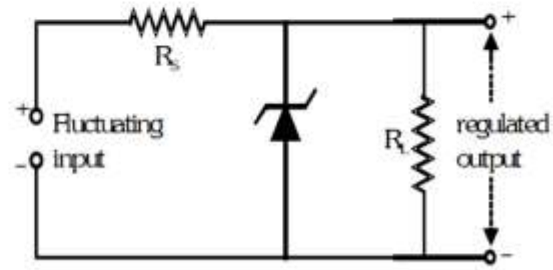
It is always connected in reverse biased condition manner.

Used as a voltage regulator

Symbol of Zener diode

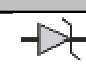


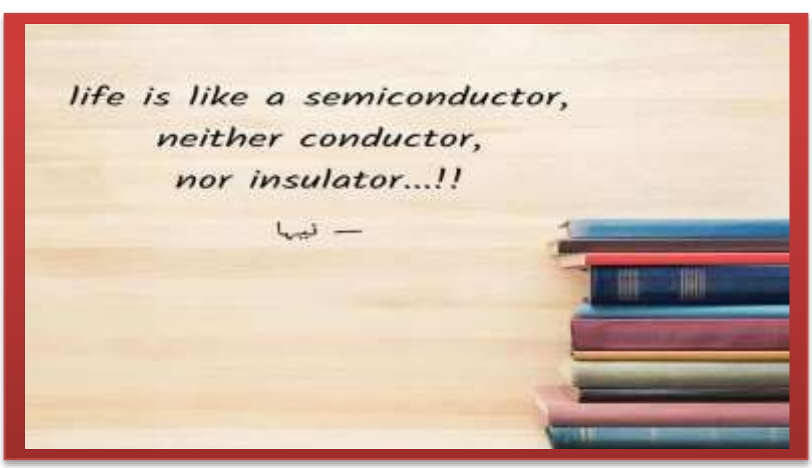
In forward biased it works as a simple diode.



Voltage regulating circuit of Zener diode

Zener Break down	Avalanche Break down
Where covalent bonds of depletion layer, its self break, due to high electric field of very high Reverse bias voltage.	Here covalent bonds of depletion layers are bro ken by collision of "Minorities" which aquire high kinetic energy from high electric field of very-very high reverse bias voltage.
This phenomena predominant	This phenomena predominant
(i) At lower voltage after "break down"	(i) At high voltage after breakdown
(ii) In P – N having "High doping"	(ii) In P – N having "Low doping"
(iii) P – N Jn. having thin depletion layer	(iii) P – N Jn. having thick depletion layer
Here P – N not demage paramanently	Here P – N damage peramanentaly due to
"In D.C voltage stablizer zener phenomenan is used".	"Heating effect" due to abruptly increament of minorities during repeatative collisoins.

SRNO	QUESTION	ANSWER
1	Give the name of techniques for formation of PN junction diode.	Alloy junction, Diffusion junction, Epitaxial junction
2	What is diffusion current direction?	P to N side
3	What is drift current direction?	N to P side
4	In PN junction diode in forward bias condition P type is connected to __________ and N type is connected to __________.	Positive , Negative
5	In PN junction diode in reverse bias condition P type is connected to __________ and N type is connected to __________.	Negative , Positive
6	Give the symbol of Zener diode.	
7	In forward bias condition of P-N diode the width of depletion layer __________.	Decreases
8	In forward bias condition of P-N Diode the width of depletion layer __________.	Increases
9	In forward bias condition of P-N junction diode current will flow due to ____________.	Decreases
10	A doped crystal diode which can work in break down region is known as _____________.	Zener diode



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