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RRB - JE

ELECTRONICS

Railway Recruitment Board

Volume - 2

Electronic Devices and Circuits

SIERRA INNOVATIONS

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SEMI CONDUCTOR PHYSICS

THEORY

1.1 INTRODUCTION

As a matter of fact, solids are the most important materials handled by man for the designs, development and in day to day life.

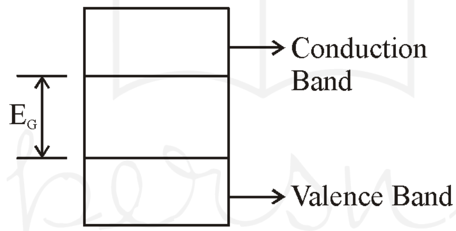
Solids may be classified into three categories with respect to energy band gap.

(1) Insulators

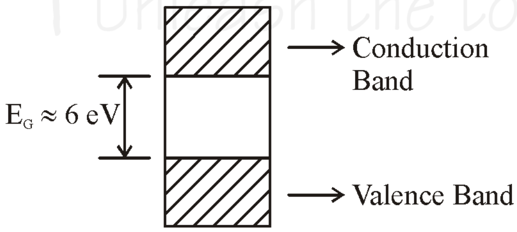
(2) Semiconductors

(3) Conductors

Note : Energy Gap (E_G) or Band Gap : The minimum energy required to detach an electron from valance band to conductor band is equal to it's Energy Gap (E_G).



(1) Insulators : E_G is very large $\approx$ 6 eV

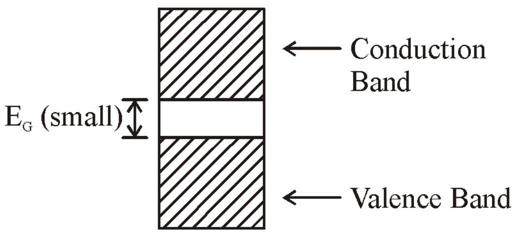


Due to large energy gap between valence and conduction band at room temperature, none of the e^- is in conduction band. Hence no conduction of electricity.

Example : Diamond, Glass.

(2) Semiconductors :

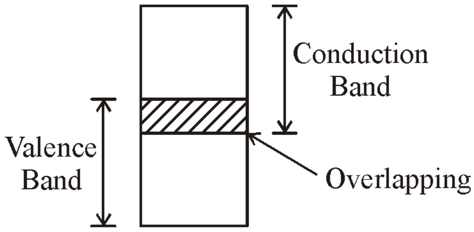
- E_G is small.
- It has the conductivity between metal and insulators.



At 0 K the valence band is completely filled and the conduction band is empty. As temperature increases the electrons in valence band acquire enough energy to cross the small energy gap and move to conduction band. Hence the conductivity of semiconductors increases with temperature.

Example : For Ge $E_G \approx 0.7$ eV and for Si $E_G \approx 1.1$ eV.

(3) Conductors or Metals : Valence band and conduction band are overlapped.



Example : Sodium, lithium, Beryllium.

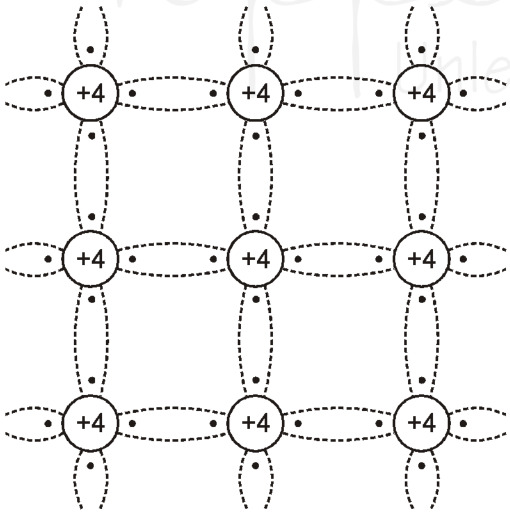
1.2 INTRINSIC AND EXTRINSIC SEMICONDUCTORS

The semiconductors may be classified into two categories :

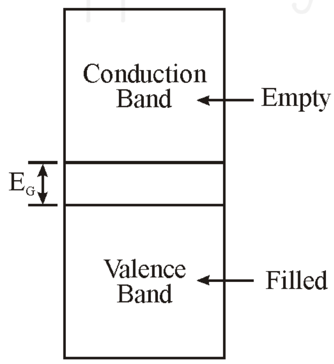
1. Intrinsic semiconductor
2. Extrinsic semiconductor

1.2.1 Intrinsic semiconductors

- Also called pure semiconductor (or) non-degenerative semiconductor (as basic properties are not changed). Degenerate means change of basic properties by adding impurity. Hence extrinsic semiconductor is known as degenerate semiconductor.
- Valence band can accommodate a maximum of 8 electrons. When intrinsic semiconductor at 0 K is placed under electron microscope, it shows crystalline (regular 3D arrangement) structure.

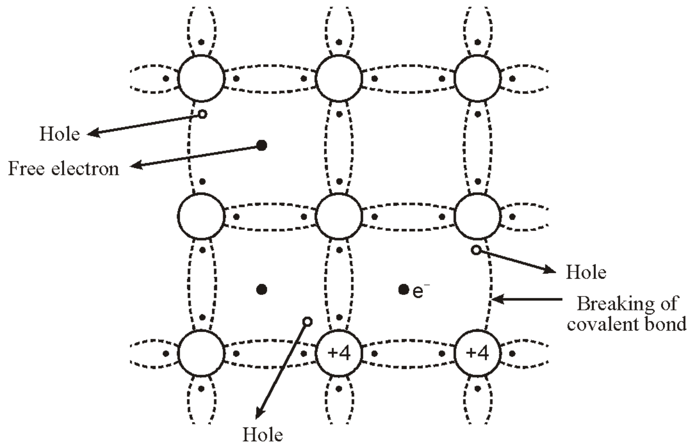


Instrinsic SC at T = 0 K

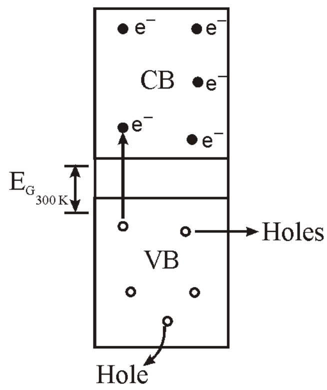


Energy band diagram of intrinsic SC at 0 K

- Intrinsic semiconductor behaves as a perfect insulator at 0 K.
- The sharing of electrons with neighbouring atom is called covalent bonding.
- At 0 K all valence electrons are in perfect covalent bonding.
- Intrinsic semiconductor at 0 K is a perfect insulator.



at T = 300 K



at T = 300 K

- When a covalent bond is broken, it will create one e^- and one hole.
- The electron will jump from VB to CB and become a free electron and hole will remain in VB.
- Hole is defined as deficiency of electron in the broken covalent bond.
- Hole is a carrier of current with a +ve charge of $+1.6 \times 10^{-19}$C.
- The process of breaking of covalent bond and creating electrons and holes is called "generation of electron-hole pair" or ionization.

Condition for intrinsic semiconductor is

$$n = p = n_i$$

Conductivity of intrinsic semiconductors is $\sigma_i = nq\mu_n + pq\mu_p$ ℧/cm

But $n = p = n_i$

$$\sigma_i = n_i q(\mu_n + \mu_p) \text{℧/cm}$$

$$\sigma_i \propto n_i$$

But $n_i \propto T^{3/2}$

$$\sigma_i \uparrow \text{ with } T$$

In intrinsic semiconductor, conductivity increases with temperature.

Resistivity of intrinsic semi-conductor

$$\rho_i = \frac{1}{\sigma_i}$$

$$\rho_i = \frac{1}{n_i q(\mu_n + \mu_p)}$$

Disadvantage of intrinsic semiconductor

- Conductivity is very less (As conductivity is very less, intrinsic semiconductor never used in fabrication i.e. no practical application).
- Only one device in which intrinsic semiconductor used is PIN DIODE (a micro wave diode).

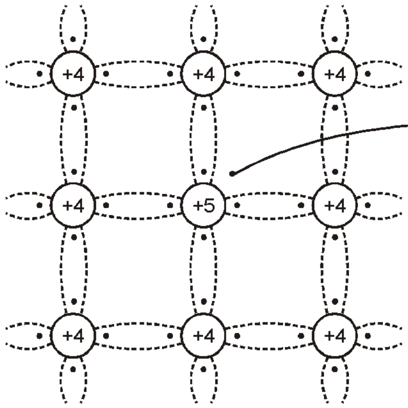
1.2.2 Extrinsic Semiconductors

It is also called impurity semiconductor (or) doped semiconductors (or) artificial semiconductors (or) degenerate semiconductor or compensated semiconductor.

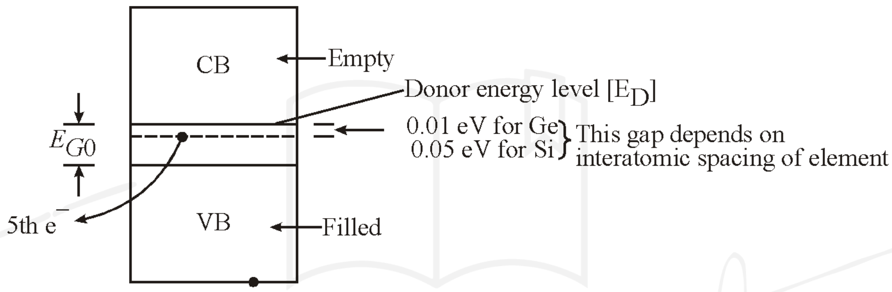
Types of extrinsic semiconductor

1. **N-type semiconductor or Donors**

- Pentavalent impurities are added.

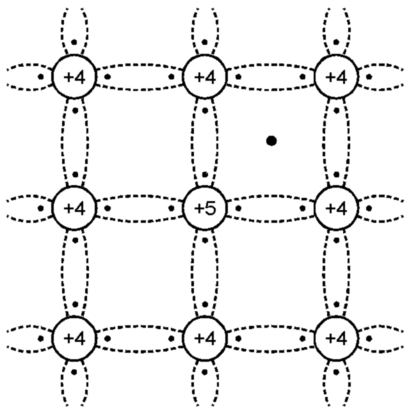


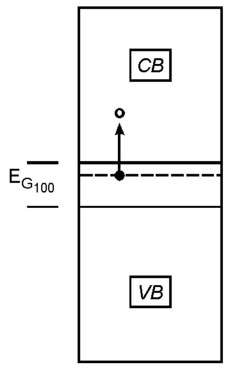
at T = 0° K



Energy band diagram of N-type semiconductor at T = 0 K

- Energy band diagram of N-type of semiconductor at T = 0 K (Because of addition of impurity there is disturbance in energy level. So a new discrete energy level is created below the conduction band known as donor energy level [E_D]).
- Donor energy level is a discrete energy level created just below conduction band.
- Donor energy level denotes energy level of all pentavalent atom added to the pure semiconductor.
- At 0 K the 5th electron of the impurity atoms will be existing in the donor energy level.
- The additional energy required to detach 5th electron from its orbit is equal 0.01 V for Ge and 0.050 V for Si.
- The minimum energy required to conduction in N-type Ge is 0.01 eV.
- The minimum energy required for conduction in N-type Si is 0.05 eV.
- N-type semiconductor at 0 K is a perfect insulator.



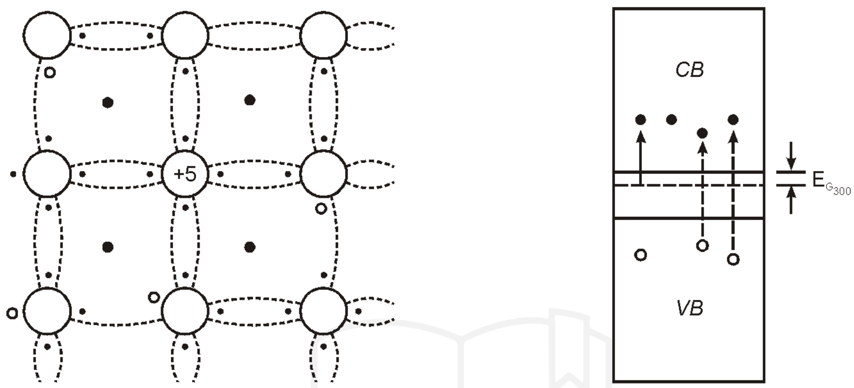


At $T = 100$ K

$$\text{No. of atoms} = 5 \times 10^{22} \times \frac{1}{10^7}$$

$$\text{Impurity added} = 5 \times 10^{15} \text{ atoms/cm}^3$$

- As temperature increases from 100 K to 300 K, covalent bond breaks creating electron hole pair.
- If 1 covalent bond breaks 1 e^- and 1 hole will be created and there is extra 1 e^- due to impurity means electrons are more as compared to hole i.e., e^- are majority charge carrier.



at T = 300 K

Silicon (Si) $\rightarrow$ 1 : 10^7 pentavalent impurity 5×10^{15} atoms/cm^3

Because of temperature $\rightarrow$ 10^4 covalent bond break

$\rightarrow$ 10^4 e^- created

$\rightarrow$ 10^4 holes created

$\rightarrow$ e^- goes to CB holes remain in VB.

Total no. of e^- $\rightarrow$ $5 \times 10^{15} + 10^4 \simeq 5 \times 10^{15}$

- Donor level ionization means exciting the electrons from donor energy level into conduction band.
- Every impurity atom will be donating one electron into the conduction band. (hence N-type is called donor).
- Donor level ionization increases with temperature.
- At 300 K, donor level ionization is completed i.e., the 5th e^- of all the impurity atoms will be moving from donor energy level into the conduction band.
- Above 300 K, there is no donor level ionization.
- Majority carriers are electrons.
- Minority carriers are holes.
- The condition for N-type semiconductor $n > n_i$, $p < n_i$.
- As temperature increases because of thermal energy, a large number of covalent bonds will be broken creating equal number of electrons and holes and these electrons will be moving, into the conduction band and due to donor level ionization a large number of electrons are entering into the conduction band such that electron concentration in the conduction band is far greater than hole concentration in valance band.
- Hence electrons are majority charge carrier and holes are minority carrier.

According to the law of electrical neutrality

$$N_D + p = N_A + n$$

In N-type semiconductor

$$N_A = 0$$

$$n = N_D + p$$

Since $\quad n >> p$

$$n \simeq N_D$$

In N-type semiconductor, the free electron concentration is almost equal to donor concentration.

N_D is the donor concentration and it denotes no. of pentavalent atom added to pure semiconductor.

$$N_D = \frac{\text{Total no. of atoms}}{\text{Volume}} \times \text{Impurity ratio}$$

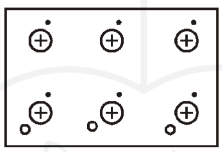
The conductivity of N-type semiconductor is

$$\sigma_N = nq\mu_n + pq\mu_p \ \mho/\text{cm} \ ; \ \simeq nq\mu_n \ \mho/\text{cm} \simeq N_D q\mu_n \ \mho/\text{cm}$$

i.e., $\quad \sigma_N \propto N_D$

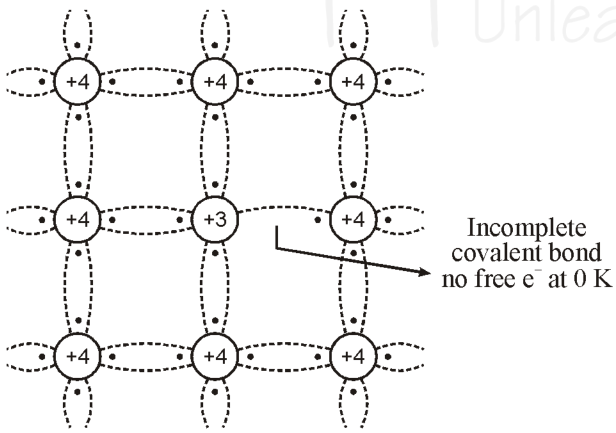
$\Rightarrow \quad \sigma_N \uparrow$ with doping

- **Representation for N-type semiconductor :** The one impurity atom will donate one electron and after donating, it will become positive ion.

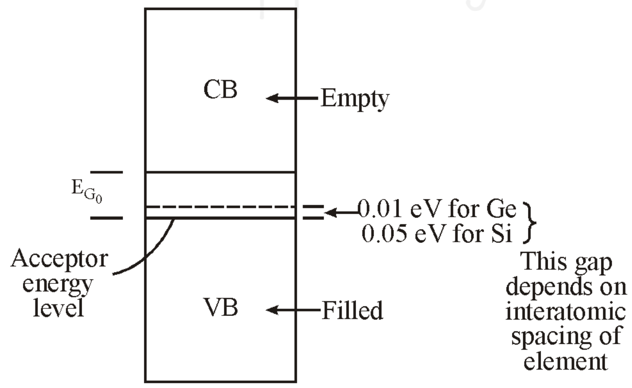


2. P-type semiconductor or Acceptors

- The impurity is trivalent.

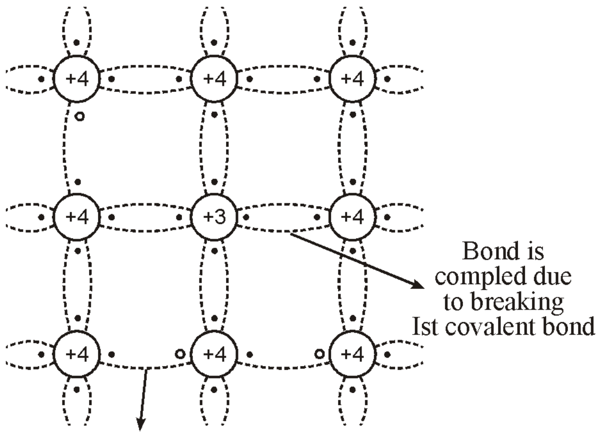


Crystalline structure at 0 K

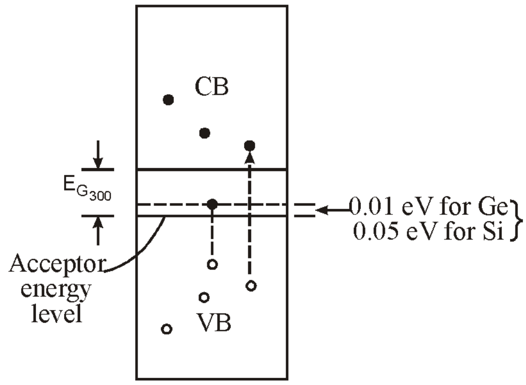


Energy level diagram at 0 K

- P-type semiconductor at 0 K behave like insulator (as 7 valence e^-)
- N-type semiconductor at 0 K behave perfect insulator (as 8 valence e^-)
- Acceptor energy level is a discrete energy level created just above the valence band.
- Acceptor energy level denotes energy level of trivalent atoms added to the pure semiconductor.
- P-type semiconductor at 0 K is an insulator.



Breaking of covalent bond at T = 300 K



at T = 300 K

- In P-type semiconductor every impurity atom will be receiving one e^- to complete its covalent bonding.
- As temperature increases a large number of covalent bond will be broken creating equal no. of e^-s and equal no. of holes and majority of these electrons will be going into acceptor energy level for bonding and very few electrons will be reaching the conduction band. Hence electron concentration in the conduction band is very less when compared to hole concentration in VB.
- Hence, holes are majority carrier and e^-s are minority carrier.

  Condition for P-type semiconductor is $p > n_i$, $n < n_i$.
- In P-type semiconductor as hole concentration increases above n_i, the electron concentration falls below n_i and this is due to large number of bondings.

According to law of electrical neutrality.

$$N_D + p = N_A + n$$

In P-type semiconductor $N_D = 0$

$$p = N_A + n$$

Since $p >> N_A$

$$p \simeq N_A$$

N_A is called acceptor concentration and it denotes the number of trivalent atoms added to the pure semiconductor.

$$N_A = \frac{\text{Total no. of atoms}}{\text{volume}} \times \text{Impurity ratio}$$

In P-type semiconductor current is dominated by holes. The conductivity of P-type semiconductor is

$$\sigma_P = nq\mu_n + Pq\mu_p \ \mho/\text{cm}$$

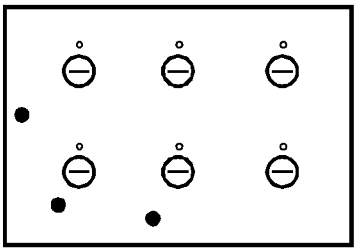
$$\sigma_P \simeq pq\mu_p \ \mho/\text{cm}$$

$$\sigma_P \simeq N_A q\mu_0 \ \mho/\text{cm}$$

$$\sigma_p \propto N_A$$

$\Rightarrow$ $\sigma_p \uparrow$ with doping

- **Representation for P-type semiconductor :** The impurity atom after receiving the e^- will become an negative ion.



1.3 MASS-ACTION LAW

In a semiconductor (intrinsic and extrinsic) under thermal equilibrium the product of e^- holes is always a constant and is equal to the square of intrinsic concentration.

$$n \cdot p = n_i^2$$

where n = concentration of e^-

p = concentration of holes

n_i = intrinsic concentration

1.3.1 For N-type semiconductor

Mass-action law is given by

$$n_n\, p_n = n_i^2$$

where n_n = concentration of e^-

p_n = concentration of holes

For n-type materials concentration of e^- is almost equal to the donor concentration.

$$\therefore \quad n_n \simeq N_D$$

$$N_D p_n = n_i^2$$

$$p_n = \frac{n_{i^2}}{N_D}$$

1.3.2 For p-type semiconductor

Mass action law is given by

$$n_p\, n_p = n_i^2$$

where n_n = concentration of e^-

p_n = concentration of holes

For n-type materials concentration of e^- is almost equal to the acceptor concentration

$$p_p \simeq n_A$$

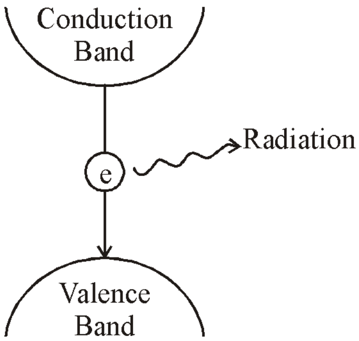
$$N_p \cdot N_A = n_i^2$$

$$N_p = \frac{n_i^2}{N_A}$$

1.4 DIRECT AND INDIRECT BAND GAP SEMICONDUCTORS

1.4.1 Direct Band-Gap semiconductor

In this type of semiconductor electrons from excited state in conduction band jump directly to valence band.



While jumping from conduction band to valence band the electron loose an energy, equal to the band gap in the form of radiation.

$$h\nu = E_G$$

where h = plank constant = 6.626×10^{-34} JS

ν = frequency of radiation

$$\nu = \frac{c}{\lambda}$$

where c = velocity of light = 3×10^8 m/s

λ = wave length

$$\frac{hc}{\lambda} = E_G$$

$$\lambda = \frac{hc}{E_G} \Rightarrow \lambda = \frac{1.24}{E_G} \ \mu m$$

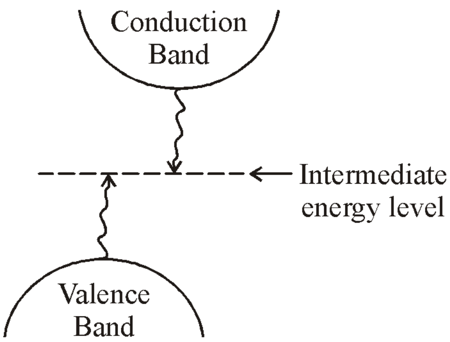
where λ in μm and E_G in eV.

Example : GaAs

Note : In this most of the falling e^- from conduction band to valence band will be directly releasing energy in form of light (99%) and very few e^- while falling from conduction band to valence band will collide with the crystal of atoms and these crystal will be absorbing the energy from the falling electrons and gets heated up and they will release energy in form of heat (1%).

1.4.2 Indirect Band-Gap

The semiconductor in which electrons from conduction band do not jump directly to valence band rather first jump from conduction band to some intermediate energy level called defect level and then from intermediate energy level to valence band are called indirect band gap.



Example : Ge and Si

Note : In Indirect Band Gap semiconductor most of the falling electrons from conduction band to valence band will collide with the crystal of the atom and these crystal will be absorbing the energy from the falling electron and gets heated up and they will release energy in the form of heat (99%) and very few electrons falling on conduction band to valence band will directly falling and they will release energy in form of light (1%).

1.5 BAND GAP OF Si AND Ge

E_G depends on Temperature,

(i) For Si : $E_G(T) = 1.21 - 3.60 \times 10^{-4}\ T$

at T = 0 K, $E_G(T) = 1.21$ eV

at room temperature of 300 K

$E_G(T) = 1.12$ eV

(ii) For Ge : $E_G(T) = 0.785 - 2.23 \times 10^{-4}\ T$

at T = 0 °C, $E_G(T) = 0.785$ eV

at room temperature of 300 K

$E_G(T) = 0.72$ eV

1.6 ELECTRICAL PROPERTIES OF SEMICONDUCTORS

(1) Resistivity (ρ)

- Unit (ohm-m)
- Semiconductors are having negative temperature co-efficient (NTC) of resistance.
  Means $\rho \downarrow$ with Temperature
  Note : In metal : $\rho \uparrow$ with Temperature having positive temperature coefficient (PTC).

(2) Conductivity (σ)

- It is the reciprocal of resistivity.
- Unit ℧-m
- Conductivity for semiconductor is given by

$$\sigma = nq\mu_n + pq\mu_p$$

(i) For intrinsic semiconductor

$$n = p = n_i$$

$$\sigma = n_i q(\mu_n + \mu_p)$$

(ii) For n-type semiconductor

$$n >> p \text{ and } n_n \approx N_D$$

$$\sigma \approx N_D q\mu_n$$

(iii) For p-type semiconductor

$$p >> n,\ p_p \approx N_A$$

$$\sigma \approx N_A q\mu_p$$

In semiconductor $\rho \uparrow$ with temperature

Temperature $\uparrow\ \rho \downarrow\ \sigma \uparrow$

$\because$ $\sigma = nq\mu_n + pq\mu_p$

when Temperature $\uparrow = n \uparrow,\ p \uparrow$ [covalent bond will be broken]

but $= \mu_n \downarrow,\ \mu_p \downarrow$ [slightly]

Means conductivity (σ) increases with temperature.

(3) Current Density (J) : Current passing per unit area.

$$J = I/A \text{ Amp/m}^2$$

$$J = \sigma E \text{ Amp/m}^2$$

In semiconductor $J = (nq\mu_n + pq\mu_p)E \text{ A/m}^2$

(4) Drift velocity : The motion of charge carriers under the influence of electric field is called "Drifting". The drift velocity of charge curriers is given by

$$V_d = \mu E$$

(5) Mobility : Mobility means how fast the charge carrier moves from one place to another place.

$$\mu = \frac{\text{Drift velocity}}{\text{Field intensity}} = \frac{V_d}{E}, \frac{m^2}{V.sec} \text{ or } \frac{cm^2}{V.sec}$$

Mobility of e^- and holes is given by :

$$\mu_n = \frac{e\tau_n}{2m_n}$$

$$\mu_p = \frac{e\tau_p}{2m_p}$$

where, τ_n = average collision time of electrons

τ_p = average collision time of holes

m_n = effective mass of e^-

m_p = effective mass of holes

Mobility of semiconductor as a function of temperature

$$\mu \propto T^{-m}$$

where m is a constant and is given by :

For Ge	For Si
m = 1.66 for e^-	m = 2.5 for e^-
= 2.33 for hole	= 2.7 for hole

Mobility of semiconductors as a function of electric field

m = constant for $E < 10^3$ V/cm

$\mu \propto E^{-1/2}$ for $10^3 \text{ V/cm} < E < 10^4$ V/cm

$\mu \propto E^{-1}$ for $E > 10^4$ V/cm

Electron mobility is always greater than hole mobility

$$\mu_n > \mu_p$$

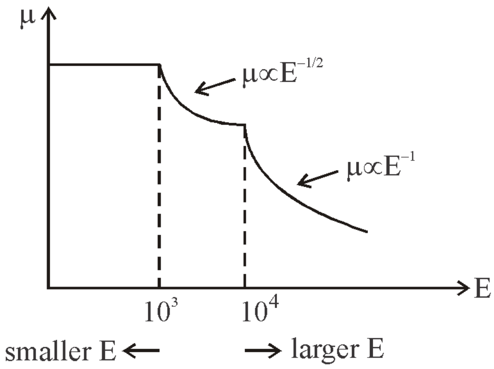
For Si $\mu_n = 1300 \text{ cm}^2\text{/V-s}$

$\mu_p = 500 \text{ cm}^2\text{/V-s}$

For Ge $\mu_n = 3800 \text{ cm}^2\text{/V-s}$

$\mu_p = 1800 \text{ cm}^2\text{/V-s}$

Mobility V/s electric field intensity curve :



1.7 EINSTEIN'S EQUATION

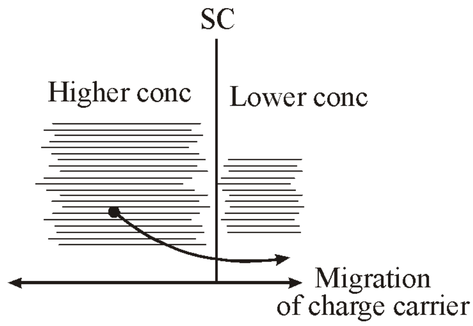
It gives the relation between diffusion constant, mobility and thermal voltage.

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{KT}{q} = V_T = \frac{T}{11600}$$

Thermal voltage $$V_T = \frac{KT}{q}$$

1.8 DIFFUSION AND DIFFUSION CURRENT

- The migration of charge carrier from higher concentration to lower concentration (or) from higher density to lower density is called as diffusion.
- Diffusion is mainly due to concentration gradient.
- Diffusion current flows only in semiconductor.
- In semiconductor diffusion is due to unequal distribution of charge carrier. (in metal charge carriers are density packed. So no unequal distribution no diffusion. In insulators charge carrier are negligible so no question of diffusion).



$$\frac{dn}{dx} = \text{electron concentration gradient}$$

$$\frac{dp}{dx} = \text{hole concentration gradient}$$

L is the length of diffusion $L = \sqrt{D\tau}$ cm

But $D = \mu \times V_T$

$$L = \sqrt{\mu V_T \tau} \text{ cm}$$

Length of diffusion depends on : (i) diffusion constant (ii) mobility, (iii) temperature, (iv) carrier life time.

Electron diffusion length $L_n = \sqrt{D_n \cdot \tau_n}$ cm

τ_n = carrier life time of e^-

Hole diffusion length $L_p = \sqrt{D_p \cdot \tau_p}$ cm

e^- diffusion current density

$$J_n(\text{diff.}) = +qD_n \cdot \frac{dn}{dx} \text{A/cm}^2$$

hole diffusion current density

$$J_p(\text{diff.}) = -qD_p \cdot \frac{dp}{dx} \text{A/cm}^2$$

Total Current Density in a Semiconductor

The total current density $J = J_n + J_p$

But $J_n = J_n(\text{drift}) + J_n(\text{diffusion})$

$$= nq\mu_n E + qD_n \frac{dn}{dx} \text{ A / cm}^2$$

$$J_p = J_p + J_p(\text{diffusion})$$

$$= pq\mu_p E - qD_p \frac{dp}{dx} \text{A/cm}^2$$

1.9 CONTINUITY EQUATION

The continuity equation gives the rate of change of carrier concentration inside a differential section of semiconductor bar. Let J_p is holes current density inside bar. The change of concentration of minority carriers as a function of time is given by :

$$\frac{\partial P}{\partial t} = \frac{P_0 - P}{\tau_p} - \frac{1}{q}\frac{\partial J_p}{\partial x}$$

where

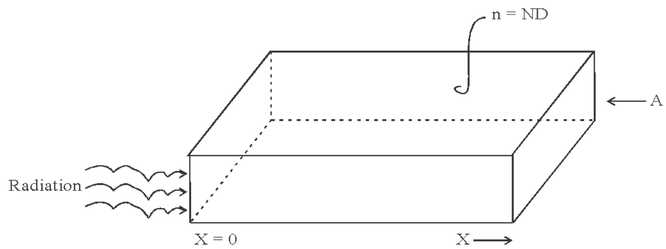
$\dfrac{P_0 - P}{\tau_p}$ = change in concentration due to generation and recombination.

$-\dfrac{1}{q}\dfrac{\partial J_p}{\partial x}$ = decrease in concentration due to J_p.

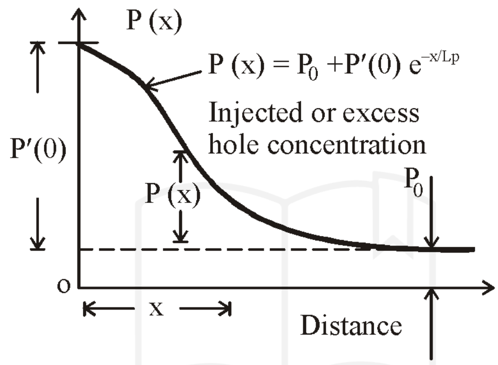
Note : Continuity equation based upon the principle of conservation of charges.

1.10 INJECTED MINORITY-CARRIER CHARGES

When radiation falls upon the end of the semiconductor by at x = 0, some of the photons are captured by the bound electrons in the covalent bonds near the illuminated surface. As a result of this energy transfer, these bonds are broken and holes electron pairs are generates.



Light falls upon the end of a - long semiconductor bar



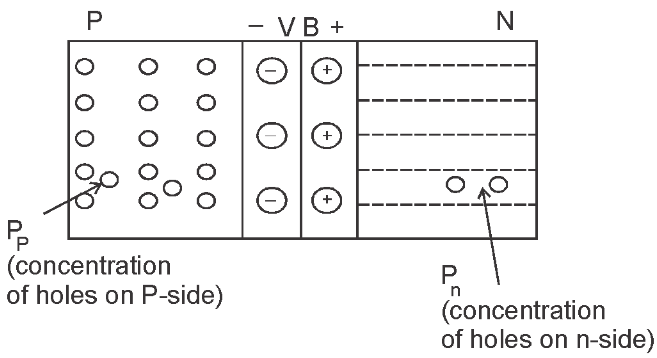
Injected concentration is

$$P'(x) = P'(0)\ e^{-x/Lp}$$
$$= P(x) - P_0$$

where L_p = diffusion length for holes

$L_p = (D_p \tau_p)^{1/2}$ m

1.11 POTENTIAL VARIATION IN GRADED SEMICONDUCTOR



Diffusion current density due to holes from P to N

$$= -q\ D_p \frac{dp}{dx}$$

Drift current density of holes from N to P

$$= \sigma_p E = pq\mu_p E$$

So net current inside the bar is zero

$$J_{drift} + J_{diffusion} = 0$$

$$+pq\mu_p E - qD_p \frac{dp}{dx} = 0$$

$$pq\mu_p E = qD_p \frac{dp}{dx}$$

$$pE = \frac{D_p}{\mu_p}\frac{dp}{dx}$$

$\because$ $$E = -\frac{dv}{dx}$$

$$\frac{Dp}{\mu_p} = V_T \quad \text{[From Einstein relation]}$$

$$p\left(-\frac{dv}{dx}\right) = V_T \frac{dp}{dx}$$

$$\int_0^{V_B} dv = -\int_{p_p}^{p_n} V_T \frac{dp}{p}$$

$$V_B = -V_T \ln \frac{p_n}{p_p}$$

$$V_B = V_T \ln \frac{p_p}{p_n}$$

On p-side $p_p \approx N_A$

on N-side $n_n \approx N_D$

$\because$ $n_n\, p_n = n_i^2$ (mass-action law)

$$p_n = \frac{n_i^2}{n_n} = \frac{n_i^2}{N_D}$$

$$V_B = V_T\, l n \frac{N_A N_D}{n_i^2}$$

1.12 FERMI LEVEL IN SEMICONDUCTOR

1.12.1 Fermi level

- Fermi energy is expressed in eV.
- Fermi energy is defined as the maximum energy possessed by an electron at 0 K.
- Fermi energy is defined as the maximum kinetic energy possessed by an electron at 0 K.

$$\text{Max. KE} = \frac{1}{2}mV_{max}^2$$

$$E_F = \frac{1}{2}mV_{max}^2$$

$$\text{Max. velocity of } e^- = V_{max} = \sqrt{\frac{2E_F}{m}} \text{ m/sec}$$

- Fermi energy is also defined as the energy possessed by fastest moving e^- electron at 0 K.

1.12.2 Fermi-Diarc Function f(E)

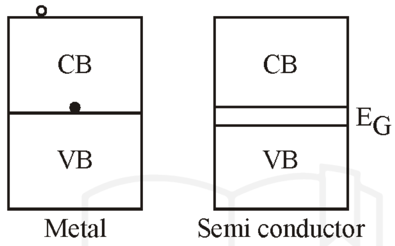
Also called fermi-Diarc probability function. In a metal or in a semiconductor $f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$ fermi-diarc probability function.

Fermi diarc function is used to find the probability of e^- (s) existing as a function of energy level. E is called energy possessed by electron in eV.

At T = 0 K : We get 2 conditions :

(i) $E > E_F$ $\quad f(E) = \frac{1}{1+e^{\infty}} = \frac{1}{1+\infty} = 0$

(ii) $E < E_F$ $\quad f(E) = \frac{1}{1+e^{-\infty}} = \frac{1}{1+0} = 1$



At $T \neq 0$ K :

Let $\quad E = E_F$

$$f(E) = \frac{1}{1+e^0} = \frac{1}{1+1} = \frac{1}{2} = 0.5 = 50\%$$

- Fermi level energy is the energy level with 50% probability of being filled if no forbidden band exist.
- For metals f(E) = 1 (or) 100%.
- In a semiconductor if the probability of electron existing is f(E) then probability of hole existing is 1 − f(E).

1.12.3 Fermi Level in Intrinsic Semiconductor

The condition in intrinsic semiconductor is n = p

$$\Rightarrow \quad N_C e^{-(E_C-E_F)/kT} = N_V e^{-(E_F-E_V)/kT}$$

$$\Rightarrow \quad \frac{N_C}{N_V} = e^{(-E_F+E_V+E_C-E_F)/kT}$$

$$\frac{N_C}{N_V} = e^{(E_C+E_V-2E_F)/kT}$$

$$\log_e \frac{N_C}{N_V} = \frac{E_C+E_V-2E_F}{kT}$$

$$\frac{E_C+E_V-2E_F}{kT} = \ln\frac{N_C}{N_V}$$

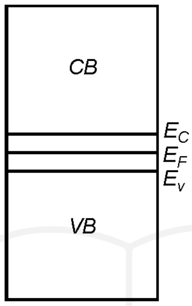
$$E_C + E_V - 2E_F = kT\ln\frac{N_C}{N_V}$$

$$E_F = \frac{E_C + E_V}{2} - \frac{kT}{2}\ln\left(\frac{N_C}{N_V}\right)$$

Case I : Let $\qquad M_n = M_p$

then $\qquad N_C = N_V;\ \ln\frac{N_C}{N_V} = 0$

$$E_F = \frac{E_C + E_V}{2}$$



at T ≠ 0K

Case II : T = 0K $\qquad E_F = \dfrac{E_C + E_V}{2}$

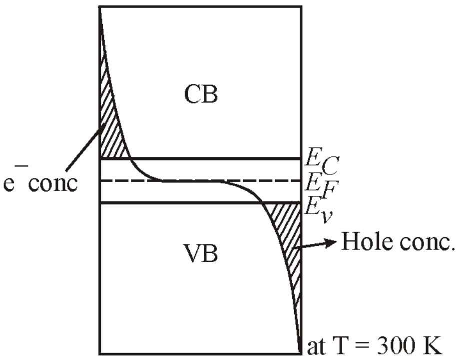
In intrinsic semiconductor at 0K, fermi level will be existing exactly at the center of energy gap.

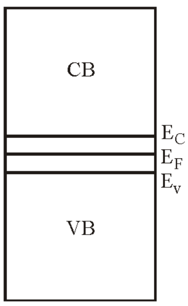
Note : In intrinsic semiconductor fermi level will be existing at the center of energy gap when :

- $M_n = M_p$
- $N_c = N_v$
- T = 0K

Case III : T = 300 K $\qquad E_F = \dfrac{E_C + E_V}{2} - \dfrac{kT}{2}\ln\dfrac{N_C}{N_V}$

e^- concentration = hole concentration





Fermi level energy diagram at T = 0 K.

At 0 K electron concentration and hole concentration are zero and therefore conductivity is 0 and intrinsic semiconductor at 0 K is an insulator.

Notes on Case III : In intrinsic semiconductor, at room temperature. Fermi level will be passing through the center of energy gap. At 300 K, e^- concentration and hole concentration are created and there will be a conductivity in the semiconductor.

Case IV :

- Position of Fermi Level at Different Temperature.
- As temperature increases carrier concentration increases and conductivity increases.

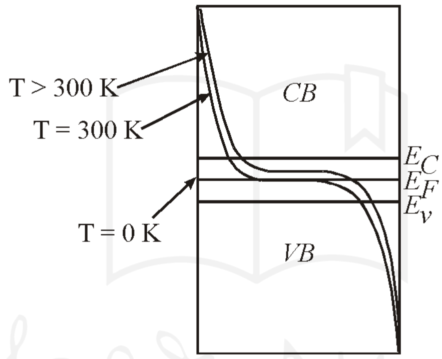
1.12.4 Fermi Level in N-Type Semiconductor

$$n \simeq N_D$$

$$N_C e^{-(E_C - E_F)/kT} = N_D$$

$$\frac{N_C}{N_D} = e^{(E_C - E_F)/kT}$$

$$\ln\frac{N_C}{N_D} = \frac{E_C - E_F}{kT}$$



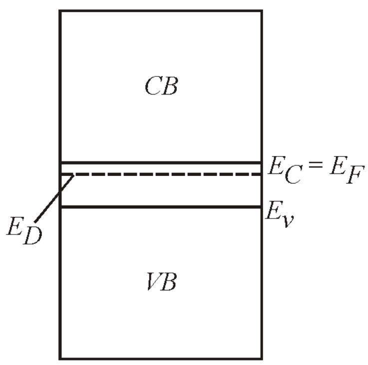
$$E_C - E_F = kT\ln\frac{N_C}{N_D}$$

$$E_F = E_C - kT\ln\frac{N_C}{N_D}$$

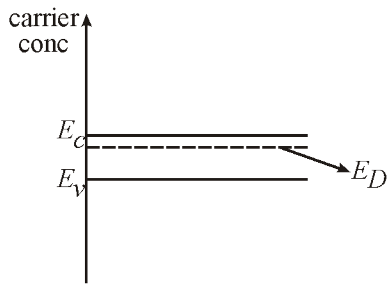
In entire semiconductor fermi level depends on temperature and doping concentration (N_D).

Case I : T = 0K $E_F = E_C$

E_F coincides with E_c.



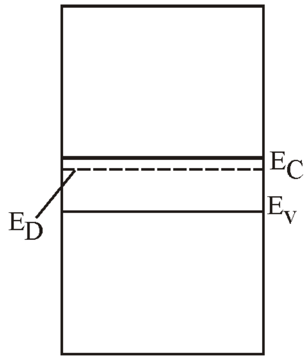
Ferrmi level at T = 0K



At 0 K, e^- concentration and hole concentration are zero. Hence conductivity is zero. Hence entire semiconductor at 0 K is an insulator.

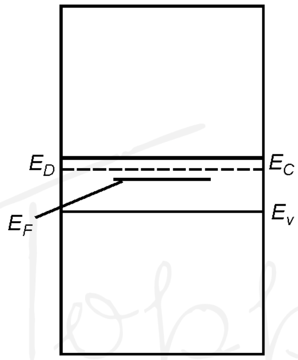
Case II : T = 300 K $E_F = E_C - kT \ln \frac{N_C}{N_D}$

In N-type semiconductor at room temperature

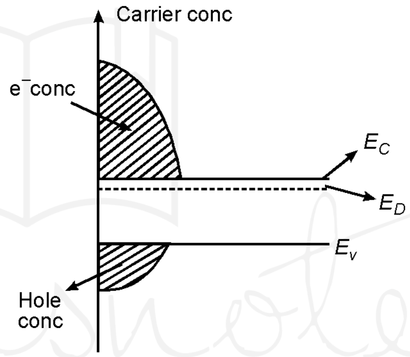


at T = 0K

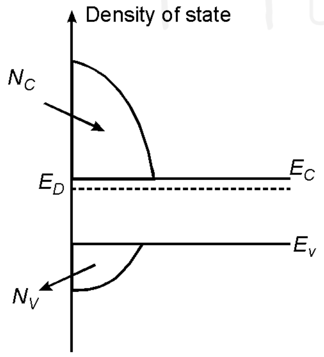
Fermi level will be existing just below the donor energy level.

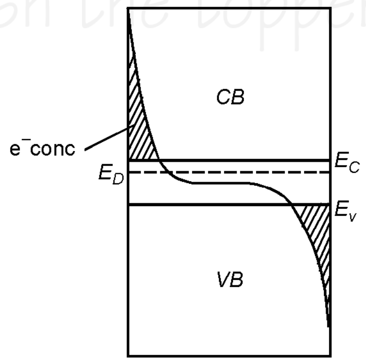


T = 300 K



e^-conc > hole conc





Case III : $E_F - E_C = kT \ln \frac{N_C}{N_D}$

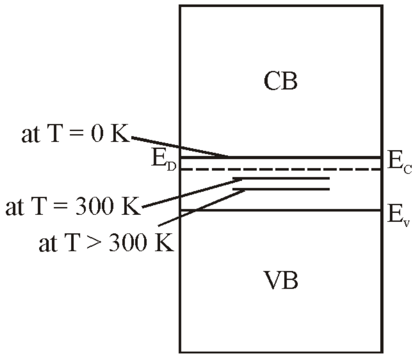
(i) When T ↑, N_C ↑ and let $N_C > N_D$

$$E_C - E_F > 0$$

or $$E_C > E_F$$

As T ↑ in N-type semiconductor, E_F moves away from CB.

or E_F moves towards the center of energy gap.



Hence σ↓ with temperature

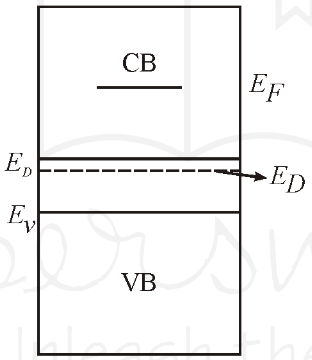
In N-type semiconductor, at curie temperature fermi level exist at the center of **energy gap**.

(ii) When dopping ↑, N_D ↑ and let $N_D > N_C$

$$E_C - E_F < 0$$

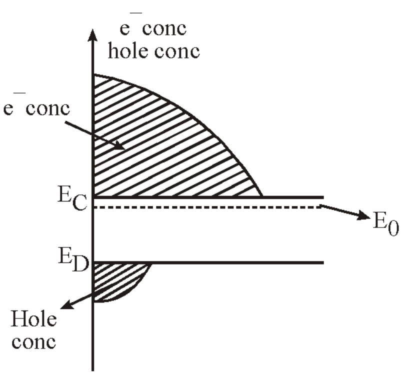
$$E_C < E_F$$

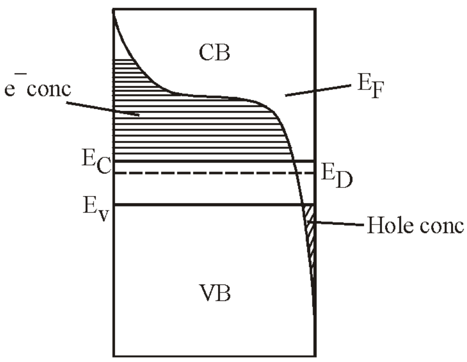
As doping ↑ in N-type semiconductor, E_F moves into the CB or E_F moves away from the centra of energy gap.



Hence σ ↑ with doping

In N-type semiconductor, as dopping increases, fermi level takes upward shift. In a highly degenerative, N-type (means N^+) the fermi level lies in the CB.





Case IV : Shift in the position of E_F due to doping (or)

Shift in the position of E_F from the center of energy gap.