$$\exp\left(\frac{-E_c + E_F + E_F - E_v}{K_B T}\right) = \frac{\mathrm{Nv}}{\mathrm{N_C}}$$

$$\frac{2E_F}{K_B T} - \frac{(E_C + E_V)}{K_B T} = \ln\frac{\mathrm{Nv}}{\mathrm{N_C}}$$

$$E_F = \frac{(\mathrm{Ec} + \mathrm{Ev})}{2} + \frac{K_B T}{2}\ln\frac{\mathrm{Nv}}{\mathrm{N_C}} \text{ ----------- (1)}$$

At T = 0 k,

$$E_F = \frac{(\mathrm{Ec} + \mathrm{Ev})}{2} \text{ -------- (2)}$$

Fermi energy level lies exactly in the middle of the forbidden gap at absolute zero K.

INTRINSIC CARRIER CONCENTRATION (n_i) [law of mass action]

In the intrinsic semiconductor, n = p = n_i. Where n_i is known as intrinsic carrier concentration.

$\therefore$ np = n_i^2

$$n_i^2 = 2\left[\frac{2\,\mathrm{m_e^*}\pi \mathrm{k_B T}}{\mathrm{h}^2}\right]^{3/2} \exp\left(-\frac{(E_c - E_F)}{K_B T}\right) 2\left(\frac{2m_h^*\pi k_B T}{h^2}\right) \exp-\left(\frac{E_F - E_V}{K_B T}\right)$$

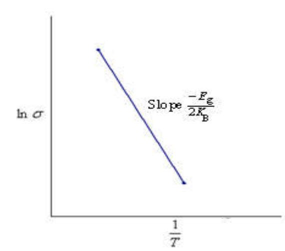
$$n_i^2 = 4\left[\frac{2\,\Pi \mathrm{k_B T}}{\mathrm{h}^2}\right]^3 \left(m_e^* m_h^*\right)^{3/2} \exp\left(\frac{-E_c + E_F - E_F + E_V)}{K_B T}\right)$$

$$n_i^2 = 4\left[\frac{2\,\Pi \mathrm{k_B T}}{\mathrm{h}^2}\right]^3 \left(m_e^* m_h^*\right)^{3/2} \exp\left(\frac{-(E_c - E_V)}{K_B T}\right)$$

$$n_i = 2\left[\frac{2\,\Pi \mathrm{k_B T}}{\mathrm{h}^2}\right]^{3/2} \left(m_e^* m_h^*\right)^{3/4} \exp\left(\frac{-E_g)}{2K_B T}\right) \quad (\text{since } E_c\text{-}E_v = E_g)$$

This equ Shows that for a given semiconductor the product of holes and electron concentration at a given temp. is equal to square of the intrinsic semiconductor carrier concentration. This is called law of mass action and holds both for intrinsic and extrinsic semiconductors.

CONDUCTIVITY OF INTRINSIC SEMICONDUCTORS



When the electric field is applied to the semiconductor, charge carriers acquire velocity.

$v_d \propto E$

$v_d = \mu E$ --------- (1)

where μ is called mobility of charge carriers.

Current density $J = ne\, v_d$

$J = ne\mu E$ ---------- (2)
This is in the form of $J = \sigma E$
Where $\sigma = ne\mu$ --------- (3) is conductivity
For electrons $\sigma_n = ne\mu_e$
For holes $\sigma_p = pe\mu_h$

Where μ_e ,μ_h are mobilities of electrons and holes respectively.

$\therefore\ \sigma = ne\mu_e + pe\mu_h$

$= (n\mu_e + p\mu_h)e$

$= n_i(\mu_e + \mu_h)e$ --------- (4) where n_i is called intrinsic carrier concentration.

$$\sigma = 2\left[\frac{2\Pi k_B T}{h^2}\right]^{3/2} \left(m_e^* m_h^*\right)^{3/4} \exp\left(\frac{-E_g}{2K_B T}\right) (\mu_e + \mu_h)e$$

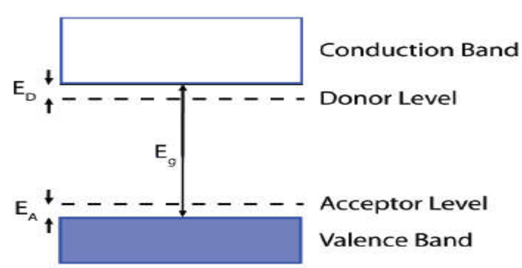
$$\sigma = \sigma_o \exp\left(\frac{-E_g}{2K_B T}\right) \quad \text{where } \sigma_o = 2\left[\frac{2\Pi k_B T}{h^2}\right]^{3/2} \left(m_e^* m_h^*\right)^{3/4} (\mu_e + \mu_h)e$$

$$\ln\sigma = \ln \sigma_o - \frac{E_g}{2K_B T} \text{ -----------(4)}$$

The above equ. gives the expression for conductivity of intrinsic semiconductor.

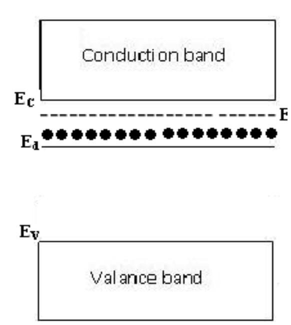
EXTRINSIC SEMICONDUCTORS

To increase the conductivity of pure semiconductors some impurities are added. This process is called doping**.** When impurities are added to semiconductor the available energy levels are altered. One or more energy levels are appeared in the band structure. Doping may create energy levels within the forbidden band.



N-TYPE SEMICONDUCTOR

When pentavalent impurities such as phosphorous, Arsenic or Antimony is introduced into Si, or Ge, four of its valence electrons form 4 covalent bonds with other 4 neighboring Si or Ge atoms while the fifth valence electron loosely bound to its nucleus. A small amount of energy is required to detach fifth electron from its nucleus and make it free to conduct. So pentavalent impurities are known as donor impurities. The energy level corresponding to the fifth valence electron lies in the band gap just below the C.B. edge as shown in figure.



NUMERICALS

1. The R_H of a specimen is 3.66×10^{-4} $m^{-3}c^{-1}$.Its resistivity is 8.93×10^{-3} Ωm. Find μ and n.
2. The following data are given for intrinsic germanium at 300k $n_i = 2.4\times10^{19}/m^3$, μ_e=0.39 m^2 V^{-1} s^{-1}, μ_p=0.19 m^2 V^{-1} s^{-1}.Calculate the resistivity of sample.
3. The hall coefficient of a specimen is 3.66×10^{-4} m^3C^{-1}. Its resistivity is 8.93×10^{-3} Ω^{-m}. Find carrier density and mobility of charge carriers.
4. Find the Diffusion coefficient of an electron in silicon at 300 K, if μ_e is 0.19 m^2/V-s
5. The resistivity of an intrinsic semiconductor is 4.5 ohm-m at 20^{o}C and 2 ohm-m at 32ºC What is the energy gap.

MULTIPLE CHOICE QUESTIONS

1. Solids with high value of conductivity are called:
   a. **Conductors** b. Non – metal c. Insulator d. Semi conductor

2. Flow of electrons is affected by the following
   a. Thermal vibrations b. Impurity atoms c. Crystal defects **d. All**

3. The unit of electrical conductivity is
   a**. ohm / metre** b. ohm / sq. M c. ohm / metre d. ohm / sq. m

4. All good conductors have high
   a. resistance b. electrical conductivity
   c. electrical and thermal conductivity d. **conductance**

5. The probability that an electron in a metal occupies the Fermi-level, at any temperature (>0 K) is:
   a. 0 b. 1 **c. 0.5** d. None of these

6. For metals conduction band and valenceband are
   a. Fully occupied b. Empty c. Partially occupied d. **Overlapping**

7. What is the correct statement for an insulator?
   a. The band gap energy is very high b. **The conduction band and valence cannot overlap**
   c. The conduction band and valence band may overlap
   d. The conduction band and valence cannot have very little difference of energy

8. P-type and N-type extrinsic semiconductors are formed by adding impurities of valency?
   a. 5 and 3 respectively. b. 5 and 4 respectively.
   c. **3 and 5 respectively.** d. 3 and 4 respectively

9. The bond that exists in a semiconductor is
   a. Ionic bond b. **Covalent bond** c. Metallic bond d. Hydrogen bond

10. A semiconductor is formed by ……… bonds.
    a. **Covalent** b. Electrovalent c. Co-ordinate d. None of the above

11. A semiconductor has ………… temperature coefficient of resistance.
    a. Positive b. Zero c. **Negative** d. None of the above