$$n_c = N_c\, exp\left(\frac{E_f - E_c)}{K_\beta T}\right) - --\rightarrow (10$$

$$n_v = N_v exp\left(\frac{E_v - E_f)}{K_\beta T}\right) - --\rightarrow (11)$$

In intrinsic semiconductor the number of electrons per unit volume in the conduction band is equal to the number of holes in the valence band.so that n = p = $n_i$.

$N_i$ : The concentration of electrons at the conduction band edge in pure semiconductor also concentration of hole in valance band

The factors, $N_C$ and $N_V$, respectively define effective electron and hole concentrations at the bottom of the conduction band and top of the valence band under conditions of full occupancy. These values are independent of Fermi energy and depend only on the density of states for a specific semiconductor material. If one multiplies these expressions together, it evidently follows that $n = p$

$$n_i^2 = N_c N_v \exp\left(\frac{E_v - E_c}{K_\beta T}\right) - - - -\rightarrow (12)$$

$$n_i^2 = N_c N_v \exp\left(\frac{-E_g}{K_\beta T}\right) - - - -\rightarrow (13)$$

$$n_i = \sqrt{N_c N_v} \exp\left(\frac{-E_g}{2K_\beta T}\right) - - - -\rightarrow (14)$$

For doped extrinsic semiconductor the increases in one type of carriers the reduce the number of other type. Thus, the product of the two type of carriers constant at a given temperature. For si , $n_i$ = 1.45* $10^{10}$cm$^{-3}$ and for GaAs, $n_i$ =1.79 8 $10^{6}$ $^{-3}$cm, GaAs has lower intrinsic carriers density and large band gap.

Note:

1-The equation 13is independent of the fermi energy .

2- The equation 13is independent of the charge in carrier concentration .

3-$n_i$ depend only on absolute temperature T.

$E_c$ : The energy at the bottom of the conduction band and $E_v$ the energy at the top of valance band and the difference between $E_c$ and $E_v$ ( $E_c$ - $E_v$ ) corresponds to the band gap energy $E_g$

$$E = E_c + \frac{\hbar^2 k^2}{2m_n^*} - --\rightarrow E - E_c = \frac{\hbar^2 k^2}{2m_n^*} - --\rightarrow$$

$$E = E_v - \frac{\hbar^2 k^2}{2m_n^*} - - - - -\rightarrow \quad E_v - E = \frac{\hbar^2 k^2}{2m_h^*}$$

**Exp** : Calculate the probability that a state in the conduction band is occupied by an electron and calculate the thermal equilibrium electron concentration in silicon at ***T*= 100 K.
Assume the Fermi energy is 0.25 eV below the conduction band. The value **of $N_c$** for silicon at T = 100 K is $N_c$ = 2.8 x $I0^{19}$ cm$^{-3}$

**Solution :**

The probability that an energy state at E - $E_c$ is occupied by an electron is given by

$$f(E) = \frac{1}{1 + \exp\left(\frac{E_c - E_f}{k_\beta T}\right)} \cong \exp - \left(\frac{E_c - E_f}{k_\beta T}\right)$$

$$f(E) = \exp - \left(\frac{0.25}{0.0259}\right) = 6.43 \times 10^{-5}$$

The electron concentration is given by

$$n_c = N_c \, exp\left(\frac{E_f - E_c)}{K_\beta T}\right)$$

$$n_c = 2.8 \text{ x } \mathrm{I}0^{19} \times 6.43 \times 10^{-5} = 1.8 \times 10^{15} cm^{-3}$$

.

**Exp** :Calculate the thermal equilibrium hole concentration in silicon at T = 400 K. Assume that the Fermi energy is 0.27 **eV** above **the** valence hand energy. The value of $\boldsymbol{N_h}$ For silicon at T = 300 ***K is*** $\boldsymbol{N_h}$= 1.04 *x* $10^{19}$ $cm^{-3}$.

**Solution :** The parameter values at T = 400 K are found as

$$N_v = 1.04 \; x \; 10^{19} (\frac{400}{300})^{\frac{3}{2}} = 1.60 \times 10^{19} \; cm^{-3}$$

$$K_\beta T = 0.0259 \; (\frac{400}{300}) = 0.03453 \; e \; V \;\; delete \; the \; power \frac{3}{2}$$

The hole concentration is then

$$n_v = N_v exp\left(\frac{E_v - E_f)}{K_\beta T}\right)$$

$$n_v = \; p_o = 1.60 \times 10^{19} exp\left(\frac{0.27}{0.03453}\right) = 6.43 \times 10^{15} cm^{-3}$$

The parameter values at any temperature can easily he found by using the 300 K values and' the temperature dependence.

For an intrinsic semiconductor, the concentration of electrons in the conduction band is equal to the concentration of holes in the valence band. We may denote $n_c = n_v = n_{i\,,}$ The Fermi energy level for the intrinsic semiconductor is called the intrinsic Fermi energy, or $\mathbf{E_F = E_{Fi}}$

$$n = p = n_v = n_c = N_c \, exp\left(\frac{E_f - E_c)}{K_\beta T}\right) = N_v exp\left(\frac{E_v - E_f)}{K_\beta T}\right)$$

**Exp:** Calculate the intrinsic carrier concentration in ~allium arsenide at T = 300 K and at T = 450 K.

The values of $N_c$ and $N_v$ at 300 K for gallium arsenide are 4.7 x $10^{17}$ $cm^{-3}$ and 7.0 x $10^{18}$ $cm^{-3}$ respectively. Both $\mathbf{N_c}$ and $N_v$ vary as $\boldsymbol{T^{\frac{3}{2}}}$**.** Assume the bandgap energy of gallium arsenide is 1.42 eV and does not vary with temperature **(over** this range. The value. of kT at 450 K is

Solution :

$$K_\beta T = 0.0259\ (\frac{450}{300}) = 0.03885\ eV$$

$$n_i^2 = N_c N_v \exp\left(\frac{E_v - E_c}{K_\beta T}\right)$$

$$n_i^2 = (4.7 \text{ x } 10^{17})(7.0 \text{ x } 10^{18}) \exp\left(\frac{-1.42}{0.0259}\right) = 5.09 \times 10^{12} cm^{-6}$$

$$n_i = 2.26 \times 10^6 cm^{-3}$$

At 450 K we get

$$n_i^2 = N_c N_v \exp\left(\frac{E_v - E_c}{K_\beta T}\right)$$

$$n_i^2 = (4.7 \text{ x } 10^{17})(7.0 \text{ x } 10^{18})(\frac{400}{300})^3 \exp\left(\frac{-1.42}{0.03885}\right) = 1.48 \times 10^{21}$$

$$n_i = 3.85 \times 10^{10} cm^{-3}$$

Comment : ( تعليق)We may note from this example that the intrinsic carrier concentration increased by over 4 orders of magnitude as the temperature increased by 150°C.