Phys 570

Lecture #10

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- We should notice that (np) as a whole is constant at any given temperature:
- To prove this:
- Suppose that the equilibrium population of electrons and holes is maintained by black-body photon radiation at temperature *T.*
- Let A(T) be the electron-hole pairs generation.
- Let B(T)np is the rate of the recombination reaction e + h = photon.
- Then:

$$\frac{dn}{dt} = A(T) - B(T)np = \frac{dp}{dt} \qquad (44)$$

$$\text{In equilibrium}: \frac{dn}{dt} = \frac{dp}{dt} = 0 \quad and \quad np = \frac{A(T)}{B(T)}$$

INTRINSIC CARRIER CONCENTRATION

- Because the product of the electron and hole concentrations is a constant independent of impurity concentration at a given temperature, the introduction of a small proportion of a suitable impurity to increase ***n***, say, must decrease ***p***.
- This result is important in practice-we can reduce the total carrier concentration ***n + p*** in an impure crystal, sometimes enormously, by the controlled introduction of suitable impurities. Such a reduction is called **compensation**.

- In an intrinsic semiconductor the number of electrons is equal to the number of holes, because the thermal excitation of an electron leaves behind a hole in the valence band. (43)➔

$$n_i = n = p = 2\left(\frac{k_B T}{2\pi\hbar^2}\right)^{3/2} \left(m^*_e m^*_h\right)^{3/4} e^{-E_g/2k_B T} \qquad (45)$$

- Intrinsic carrier concentration depends exponentially on $E_g/2k_BT$,. We let (39) = (42) to obtain, for the Fermi level as measured from the top of the valence band: (*please derive at home*):

$$e^{\frac{2\mu}{K_BT}} = \left(\frac{m_h}{m_e}\right)^{3/2} e^{-\frac{E_g}{2K_BT}} \qquad (46)$$

$$\mu = \frac{1}{2}E_g + \frac{3}{4}K_BT\,\ln\frac{m_h}{m_e} \qquad (47)$$

If $m_h = m_e$ then $\mu = \frac{1}{2}E_g$ and the Fermi level is in the middle of the forbidden gap.

Chapter 8: SEMICONDUCTOR CRYSTALS

INTRINSIC Mobility

- The mobility is the magnitude of the drift velocity of a charge carrier per unit electric field:

$$\mu = |v| / E \qquad (48)$$

- The mobility is defined to be positive for both electrons and holes, although their drift velocities are opposite in a given field.
- For distinction : use μ_e for electrons and μ_h for holes.
- Electrical conductivity is the sum of both:

$$\sigma = (ne\mu_e + pe\mu_h) \qquad (49)$$

$$\because v = \frac{q\tau E}{m} \quad \text{(from Chapter 6)}$$

$$\therefore \mu_e = \frac{e\tau_e}{m_e} \quad and \quad \mu_h = \frac{e\tau_h}{m_h} \qquad (50)$$

where τ is the collision time

Germanium Example

- In Ge; let E_g = 0.670 *eV* , m^* = 0.55 m_o , chemical potential μ, is given by $\mu = -7.69 \times 10^{-3}$ eV . Find:

a) ε_F relative to the TOP of valence band.

b) Probability of occupancy at the bottom of conduction band $f(E_c)$ for T = 300 K

c) Density of electrons at same temperature

(a)

From Fig. 18:

$$\varepsilon_F = \frac{1}{2}(E_v - E_c)$$

$$Let\ E_v\ be\ at\ 0eV$$

$$\Rightarrow \varepsilon_F = \frac{1}{2}(0 + 0.67) = 0.335eV$$

(b) for the case when $(\varepsilon-\mu) >> k_B T$ (at $300\,K$)

$$f(\varepsilon) \approx e^{(\mu-\varepsilon)/k_B}$$

$$\therefore f(E_C) = e^{(\mu-E_C)/k_B} = e^{\frac{-7.69\times10^{-3}-0.67+0.335}{8.62\times10^{-5}\times300}}$$

$$= 1.7\times10^{-6}\ eV$$

(c)

$$\because n(e) = 2\left[\frac{m^{*}k_B T}{2\pi\hbar^2}\right]^{3/2} e^{\frac{\mu-E_C}{k_B T}}$$

$$= 2\left[\frac{0.55\times9.11\times10^{-31}\times1.38\times10^{-23}\times300}{2\pi\times(1.05\times10^{-24})^2}\right]^{3/2}\times1.74\times10^{-6}$$

$$= 6.55\times10^{18}\ e/m^3$$

Silicon Example

❑ In Si; if we have: $m_e^* = 0.259\, m_o$, $\mu_e = 0.135\ m^2/v.s$, $\mu_h = 0.048$, and $m^*_h = 0.537\, m_e$. Calculate relaxation time for (e) and (holes).

Solution:

From Eq. (5):

$$\tau_e = \frac{m^*_e \mu_e}{e} = \frac{0.259 \times 9.11 \times 10^{-31} \times 0.135}{1.6 \times 10^{-19}} = 1.99 \times 10^{-13}\ Sec$$

$$\tau_h = \frac{m^*_h \mu_h}{e} = \frac{0.537 \times 9.11 \times 10^{-31} \times 0.048}{1.6 \times 10^{-19}} = 1.47 \times 10^{-13}\ Sec$$