RAJARATAUNIVERSITY OF SRI LANKA
FACULTY OF APPLIED SCIENCES

B.Sc. (Four Year) Degree in Applied Sciences /
B. Sc. (Joint Major) Degree in Chemistry and Physics

Fourth Year - Semester I Examination - January/February 2021

PHY 4209 - PHYSICS OF SEMICONDUCTOR DEVICES

Time: Two (02) hours

Answer all four questions

Use of a non - programmable calculator is permitted.
Unless otherwise specified, all the symbols have their usual meaning.

Some fundamental constants;

Electron rest mass m_e= 9.1 x $10^{-31}kg$Elementary charge e = 1.6x$10^{-19}C$Electron volt eV= 1.6 x $10^{-19}J$Boltzmann Constant k = 1.38 x $10^{-23} J\,K^{-1}$

Useful formulae;

$$E_F = \frac{E_C + E_V}{2} + kT\ln\left(\frac{N_V}{N_C}\right)^{1/2} \quad n(T) = N_C(T)e^{-(E_C - E_F)/kT}$$

$$p(T) = N_V(T)e^{-(E_F - E_V)/kT}$$

$$E_F = \frac{E_C + E_D}{2} + kT\ln\left(\frac{N_D}{2N_C}\right)^{1/2} \quad \sigma = ne(\mu_n + \mu_h)$$

$$D_n = \frac{kT}{e}\mu_n,\ D_h = \frac{kT}{e}\mu_h$$

$$N_C = 2.5\times10^{19}\left(\frac{m_e^*}{m_e}\right)^{3/2}\left(\frac{T}{300}\right)^{3/2} \quad R = \rho\frac{l}{A}\ ,\ \rho = \frac{1}{\sigma}$$

$$f(E) = \frac{1}{e^{\frac{E-E_F}{KT}} + 1} \quad n_i = \sqrt{n_0 p_0}\, e^{\frac{-E_g}{2kT}}$$

1. a) i. Derive an expression for the position of the Fermi level(E_F) relative to the center of the band gap as a function of temperature in an intrinsic semiconductor.

(10 marks)

ii. Calculate the displacement of E_F from the center of the gap in Si at 300 K assuming $m_e^* = 1.1\, m_e$ and $m_h^* = 0.56\, m_e$. ($kT \sim 0.026$ eV at 300 K)

(05 marks)

b) If there are no acceptors and N_d donors per unit volume present in a doped semiconductor at very low temperature, then the density of electrons in the conduction band is $n(T) = N_d e^{-\Delta E/2kT}$ where ΔE is the binding energy of the donor level relative to the edge of the conduction band with the assumption of $\Delta E >> kT$. Explain why the low temperature behavior of $n(T)$ changes to $n(T) = (N_d - N_a)e^{-\Delta E/kT}$, when there are N_d donors and N_a acceptors per unit volume with $N_a < N_d$.

(10 marks)

2. a) i. According to the band theory, show that a solid formed from an element with an odd number of electron per atom cannot have an energy gap, and therefore must be a metal.

(08 marks)

ii. State any mechanism by which a gap could appear in such a solid. (04 marks)

b) Intrinsic semiconductor material A has an energy gap of 0.36 eV, while material B has an energy gap of 0.72 eV. Compare the intrinsic densities of carriers in these two semiconductors at 300 K. Assume that the effective masses of all the electrons and holes are equal to the free electron mass.

(13 marks)

3. a) Considering the pattern of variation in the the positions of Fermi level with temperature in an extrinsic semiconductor, we can conditionally single out three regions: the region of typical of low temperatures, the region of impurity depletion, and the region of transition to the intrinsic condition

i. Draw a schematic graph showing the change in the position of the Fermi level with temperature in extrinsic n-type semiconductors. Clearly indicate the saturation temperature, intrinsic temperature, energy of the donor level (E_D) and the variation of Fermi level on your graph

(09 marks)

Contd.

ii. Use the formula for the position of the Fermi level of an extrinsic semiconductor and the above graph to describe what is meant by low temperature region and high temperature region of an extrinsic semiconductor. (07 marks)

b) Explain why Si doped with $10^{14} cm^{-3}$ Sb is n-type at 400K, but similarly doped Ge is not. (09 marks)

4. Write <u>short notes</u> on the following.

a) Mobility of carriers in metals (08 marks)

b) Optical properties of quantum wells (10 marks)

c) Law of mass action (07 marks)

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