RAJARATA UNIVERSITY OF SRI LANKA
FACULTY OF APPLIED SCIENCES

Bachelor of Science Honours in Applied Sciences /
B. Sc. (Joint Major) in Chemistry and Physics
Fourth Year - Semester I Examination – July / August 2023

PHY 4209 – PHYSICS OF SEMICONDUCTOR DEVICES

Time: Two (02) hours

Answer all four questions

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

Some fundamental constants;

Electron volt $eV = 1.6 \times 10^{-19} J$
Boltzmann Constant $k = 1.38 \times 10^{-23} J K^{-1}$

Useful formulae;

$$f(E) = \frac{1}{1+exp^{\frac{(E-E_F)}{kT}}} \qquad N_c \propto T^{\frac{3}{2}}$$

$$n_o = N_c \exp[\frac{-(E_c-E_F)}{kT}] \qquad N_v \propto T^{\frac{3}{2}}$$

$$P_o = N_v \exp[\frac{-(E_F-E_v)}{kT}] \qquad n_i^2 = N_c N_v \exp[\frac{-E_g}{kT}]$$

$$n_o = \frac{(N_d-N_a)}{2} + \sqrt{\left(\frac{(N_d-N_a)}{2}\right)^2 + n_i^2} \qquad n_o p_o = n_i^2$$

$$p_o = \frac{(N_a-N_d)}{2} + \sqrt{\left(\frac{(N_a-N_d)}{2}\right)^2 + n_i^2}$$

1. a) In an intrinsic semiconductor, the density of states for the electrons in the conduction band, $g_c(E)$ and the density of states for the holes in the valence band, $g_v(E)$ are symmetrical about the energy midway between E_c and E_v, if the effective masses of electrons and holes of the density of states are equal.

Suppose that effective mass of an electron is larger than that of a hole in the density of states

i. Draw a graph of E vs Fermi-Dirac probability function ($f_{F(E)}$) for T > 0 K, to show the variation of $g_v(E), g_c(E)$ and Fermi energy level (E_F) with respect to the Fermi-Dirac probability function in the same plot.

(10 marks)

ii. Indicate the intrinsic Fermi energy level (E_{Fi}) in the above graph.

(02 marks)

b) What is the probability of occupying an electron in the conduction band at room temperature (300 K) for an intrinsic semiconductor Si with Energy gap $E_g = 1.1\ eV$. Consider that, $kT =$ 0.026 eV at 300 K.

(08 marks)

2. a) For an intrinsic semiconductor, the concentration of electrons in the conduction band is equal to the concentration of holes in the valence band.

Starting with the equations of thermal equilibrium electron concentration (n_o) and thermal equilibrium hole concentration (P_o), derive an expression for the intrinsic carrier concentration (n_i) as a function of temperature in an intrinsic semiconductor.

(08 marks)

b) Calculate the intrinsic carrier concentration in gallium arsenide (GaAs) at temperature T = 300 K and T = 450 K.

The values of N_c and N_v at 300 K for GaAs are $4.7 \times 10^{17}\ cm^{-3}$ and $7.0 \times 10^{18}\ cm^{-3}$ respectively. Both N_c and N_v vary as $T^{\frac{3}{2}}$. Assume that the band gap energy of $GaAs$ is 1.42 eV and does not vary with temperature over this range.

Consider that, $kT = 0.026\ eV$ at 300 K and $kT = 0.039\ eV$ at 450 K.

(12 marks)

3. a) i. Explain what is meant by an extrinsic semiconductor.

(03 marks)

ii. Briefly explain the formation of n-type and p-type semiconductors. Sketch the energy band diagram of each.

(08 marks)

b) Calculate the thermal equilibrium electron and hole concentrations in a germanium sample for the doping density given below.
Consider germanium sample at T = 300 K in which the concentration of donor atoms, $N_d = 5 \times 10^{13}\ cm^{-3}$ and concentration of acceptor atoms, $N_a = 0$.
Assume that the intrinsic carrier concentration, $n_i = 2.4 \times 10^{13}\ cm^{-3}$.

(09 marks)

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

a) Compensated semiconductors (07 marks)

b) Carrier transport mechanisms of a semiconductor (06 marks)

c) Bipolar Junction Transistor (BJT) (07 marks)

END.