Ollscoil na hÉireann, Gaillimh
National University of Ireland, Galway

Semester II Examinations, 2002/2003

Exam Code(s)	3BS1, 3BS9, 3EL1, 3EL2, 3PT1, 3PT2
Exam(s)	3rd Science
Module Code(s)	EP326
Module(s)	EP326: Solid State Electronics
Paper No.	
Repeat Paper	Special Paper
External Examiner(s)	Professor E. Kennedy
Internal Examiner(s)	Professor S. G. Jennings
	Dr. G.P. Morgan
	Dr. J. Martin

Instructions: Answer THREE questions.

Duration	2 hrs
No. of Answer Books	
Requirements:	
Handout	
MCQ	
Statistical Tables	
Graph Paper	
Log Graph Paper	
Other Material	
No. of Pages	
Department(s)	Experimental Physics

EP326: Solid State Electronics

Answer THREE questions. Time allowed: TWO hours.

Physical data for silicon at 300 K, and other constants

(a) Silicon at 300 K:

N_C =	2.8×10^{25} m^{-3}	N_V =	1.04×10^{25} m^{-3}
μ_n =	0.14 m^2 V^{-1} s^{-1}	μ_p =	0.05 m^2 V^{-1} s^{-1}
D_n =	36×10^{-4} m^2 s^{-1}	D_p =	13×10^{-4} m^2 s^{-1}
n_i =	1.45×10^{16} m^{-3}	E_G =	1.12 eV

Relative dielectric constant, ε_S = 11.9

Density of Si atoms (crystalline) = 5.0×10^{28} atoms m^{-3}

Resistivity of intrinsic Si = 2300 Ω m

(b) Other constants:

kT = 0.0259 eV at T = 300K

e =	1.602×10^{-19} C	m_e =	9.11×10^{-31} kg
h =	6.626×10^{-34} J s	ε_0 =	8.85×10^{-12} F m^{-1}

Relative dielectric constant of SiO_2, ε_{OX} = 3.9

Q.1 Write full notes on *TWO* of the following:

[5 marks for each part]

(a) The characteristics and behaviour of metal to semiconductor contacts.

(b) Minority carrier storage in pn junctions, and its effect on the switching speeds of diodes and bipolar junction transistors.

(c) The Haynes-Shockley experiment.

Q.2 Sketch the E vs. k relationships found in typical semiconductors, paying particular attention to the differences found between direct and indirect bandgap semiconductors.

[2 marks]

State the assumptions of the Feynman close-coupling model for electron energy states in a 1-d crystal. Give a brief quantum mechanical derivation of how this model predicts the electron energy band formula of the form

$$E = E_o - 2A\text{Cos}(ka)$$

[4 marks]

An unperturbed atomic energy level at 5 eV is broadened into a band in a 1-d crystal which has an inter-atomic spacing a = 0.4 nm. If the Feynman coupling coefficient for nearest-neighbour interaction is 0.5 eV, find the width of the band. Calculate the ratio of the effective mass to electron rest mass for an electron with an energy of 4.5 eV.

[4 marks]

Q.3 By analogy with Bragg scattering of X-rays in a 1-d crystal, show that travelling wave functions for electrons in a 1-d crystal cannot exist with wavenumbers $k = n\pi/a$, where n is an integer, and a is the interatomic spacing. By considering the only two possible electron standing wave functions in such a 1-d crystal show that the electron energy E versus k relationship exhibits discontinuities at these k values.

[5 marks]

Sketch the general form of the E-k curves in this crystal, and indicate how they confirm the band theory of electron energy. Explain briefly how this energy band theory accounts for the main qualitative features of conduction in insulators, metals and semiconductors.

[5 marks]

Q.4 Give a brief description of a modern high-speed, drift Bipolar Junction Transistor (BJT).

[2 marks]

Sketch the excess carrier concentration under steady-state injection across the narrow base region in a npn BJT. This predicts an electron diffusion time across a uniformly-doped narrow base, with width W, given by

$$\tau_n = \frac{W^2}{2D_n}$$

In addition, sketch the majority hole concentration, charge density and built-in electric field in the base region of a typical npn drift BJT.

[2 marks]

A certain silicon npn drift BJT has a base width W = 1.5 μm and a minority carrier diffusion length in the base of 53 μm. A built-in electric field exists in the base which results in a drift velocity v_F = 3700 m s^{-1}. Find the minority carrier recombination lifetime in the base and the total base transit time. Define and estimate the transition frequency f_T for this transistor.

[5 marks]

Why are most modern high speed BJTs constructed as npn devices, rather than pnp?

[1 mark]

Q.5 State the assumptions made in the definition of an abrupt semiconductor p-n junction. Sketch the charge density, electric field and potential variation across such a junction. Show that the depletion width, d_o, for such a junction is given by the following equation, defining all the terms used.

$$d_o = \left(\frac{2\varepsilon\varepsilon_o}{qN}V_o\right)^{1/2}$$

where

$$\frac{1}{N} = \frac{1}{N_A} + \frac{1}{N_D}$$

and V_o is the built-in junction barrier potential. All other terms have their usual meaning.

[6 marks]

The built in potential for such an abrupt junction, with $N_A = 10^{22}$ m^{-3} and $N_D = 5 \times 10^{21}$ m^{-3}, is found to be V_o = 0.678 V. Find the depletion width, d_o, and the p- and n-region depletion widths, l_p and l_n, respectively at zero bias for this junction. What will the junction depletion width be if a reverse bias of – 2V is applied to the diode? ***[4 marks]***