UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION	2012/13
TITLE OF PAPER:	SOLID STATE ELECTRONICS
COURSE NUMBER:	EE429
TIME ALLOWED:	3 HOURS

INSTRUCTIONS:

ANSWER ANY FOUR OUT OF FIVE QUESTIONS.

EACH QUESTION CARRIES 25 MARKS.

MARKS FOR DIFFERENT SECTIONS ARE SHOWN ENCLOSED IN SQUARE BRAKETS.

THIS PAPER HAS 6 PAGES INCLUDING THIS PAGE.

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Q1. (a) What is a crystal? [4]

(b) The face-centered cubic (fcc) structure is the most important cubic structure in the study of solid state electronics. Construct the axes of a primitive unit cell for the fcc structure, relative to the conventional unit cell of edge length, a. [6]

(c) If the cube edge is $a = 4.00$ Å for an fcc crystal, determine:

(i) The volume of the conventional unit cell; [3]

(ii) The volume of its primitive cell; [4]

(iii) The nearest neighbor distance; [4]

(iv) The angle between any pair of primitive axes. [4]

Q2. (a) Define a Brillouin zone. [3]

(b) Show that the volume of the first Brillouin zone is:

$$V_G = (2\pi)^3/V_c,$$

where V_c is the volume of a crystal primitive cell in real space. Hint: Recall the vector identity,

$$(\boldsymbol{c} \times \boldsymbol{a}) \times (\boldsymbol{a} \times \boldsymbol{b}) = [\boldsymbol{a} \bullet (\boldsymbol{b} \times \boldsymbol{c})]\boldsymbol{a}.$$ [12]

(c) In zone refining, assume that the concentration distribution $C_s(x)$ of a particular impurity in a solid after a pass of a molten zone of length l is given by:

$$C_s(x) = C_o - C_o(1 - k_d)e^{-k_d x/l},$$

where C_o is the starting concentration. We wish to zone refine an ingot of Si which contains a uniform Al ($k_d = 2\times10^{-3}$) concentration of 10^{17} cm^{-3}. One pass is made of a molten zone 1 cm long. Over what distance is the resulting Al concentration below 5×10^{15} cm^{-3}? [10]

Q3. (a) A particle in an infinite potential well from $x = 0$ to $x = L$ in the n_x state has the wave function:

$$\psi_{n_x}(x) = A sin\left(\frac{n_x \pi x}{L}\right).$$

Normalize this wave function and write down the normalized wave function, $\psi_{n_x n_y n_z}(x, y, z)$ in three dimensions. [10]

(b) GaAs crystallizes in the zinc blend structure which ~~in~~ is made up of two interpenetrating fcc structures of Ga and As. The band structure of GaAs is shown in Fig. 2 of Appendix A. Fig. 1 in Appendix A gives the first Brillouin zone of the fcc crystal structure in three dimensions. Use Fig. 1 and Fig. 2 to answer the following:

(i) What path in **k**-space is used to produce the band structure in Fig. 2? [3]

(ii) Write the coordinates of each of the high-symmetry **k**-vector points used in the path, in units of $2\pi/a$; [6]

(iii) Estimate the band gap of GaAs; [3]

(iv) What type of semiconductor is GaAs, in relation to its band structure? [3]

Q4. (a) By referring to the general expression for resistivity:

$$\rho = \frac{1}{ne\mu},$$

explain the difference in the variation of resistivity in metals and semiconductors. [4]

(b) Define the emitter injection efficiency, γ of a p-n-p transistor in an integrated circuit. [3]

(c) Consider separate regions of p and n-type semiconductor material brought in contact to form a p-n junction. The contact potential, V_o separates the energy bands such that the bands are higher on the p side of the junction by the amount qV_o. This separation is required to keep the Fermi level constant throughout the device at equilibrium.

(i) Draw three energy band diagrams in the transition region of a p-n junction for the cases of: equilibrium; forward bias, V_f; reverse bias, V_r. [3]

(ii) The potential gradient across a p-n junction is given by:

$$-\frac{q}{kT}\frac{dV(x)}{dx} = \frac{1}{P(x)}\frac{dP(x)}{dx},$$

where $P(x)$ is the carrier concentration. Show that the contact potential is given by:

$$V_0 = \frac{k_B T}{q} ln \frac{N_a N_d}{n_i^2},$$

where N_a and N_d are concentrations of acceptors on the p-side and that of donors on the n-side respectively; n_i is the intrinsic carrier concentration. [9]

(d) Several opto-electronic devices like photo diodes and solar cells make use of the response of p-n junctions to optical generation of electron-hole pairs (EHPs). The resulting current due to collection of optically generated carriers in an illuminated and biased p-n junction is given by:

$$I = qA\left(\frac{D_p}{L_p}P_n + \frac{D_n}{L_n}n_p\right)(e^{\frac{qV}{kT}} - 1) - qAg_{op}(L_p + L_n + W).$$

where the symbols have their usual meaning. Show how this expression reduces to the diode equation and state the conditions under which this happens. [6]

Q5. (a) Give a brief distinction between: diamagnetism; paramagnetism; ferromagnetism; antiferromagnetism; ferrimagnetism. [5]

(b) The magnetic field strength in silicon is 1000 amperes/metre. If the magnetic field susceptibility is -0.3×10^{-5}, calculate the magnetization and flux density in silicon. [5]

(c) Derive the simplest relationship between the magnetic susceptibility, χ and the relative permeability, μ_r of a substance. [5]

(d) A magnetic material has a magnetization of 3300 amperes/metre and flux density of 0.0044 Wb/m^2. Calculate the magnetic field in the material. [5]

(e) Calculate the relative permeability of the material described in (d). [5]

APPENDIX A – FIGURES

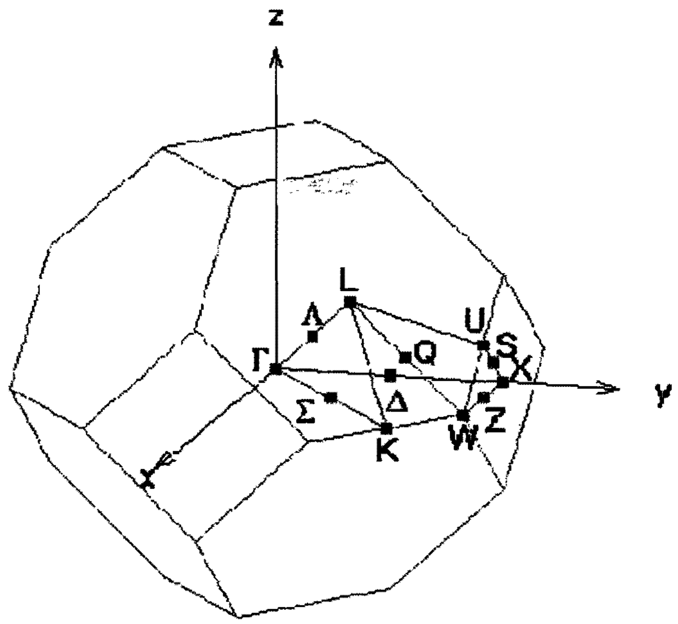

Figure 1

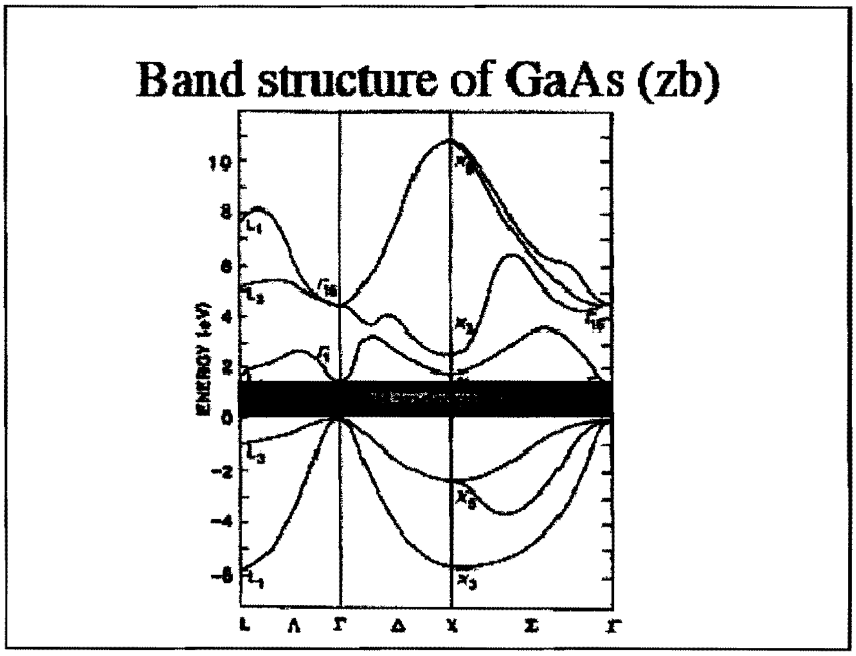

Figure 2

APPENDIX B – PHYSICAL CONSTANTS

Electron rest mass $m_e = 9.109 \times 10^{-31}$ kg

Proton rest mass $m_p = 1.673 \times 10^{-27}$ kg

Neutron rest mass $m_n = 1.675 \times 10^{-27}$ kg

Planck's constant $h = 6.626 \times 10^{-34}$ Js^{-1}

Planck's constant (reduced) $\hbar = 1.0546 \times 10^{-34}$ Js^{-1}

Boltzmann constant $k_B = 1.381 \times 10^{-23}$ JK^{-1}

Avogadro's number $N_A = 6.022 \times 10^{23}$ per g mole

Bohr magneton $\mu_B = 9.274 \times 10^{-24}$ Am^2

Permeability of free space $\mu_0 = 4\pi \times 10^{-7} Hm^{-1}$

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12} Fm^{-1}$

Electronic charge $e = 1.6 \times 10^{-19} C$

Velocity of light $c = 3.00 \times 10^8 ms^{-1}$

END OF EE429 EXAMINATION