UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

SUPPLEMENTARY EXAMINATION 2011/12

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 4 PAGES INCLUDING THIS PAGE.

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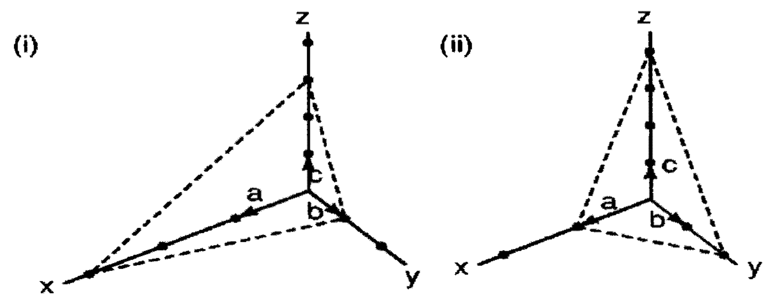
Q1. (a) Most metals crystallize in the FCC structure. Find the packing fractions of identical spheres in the FCC crystal structure. **[6]**

(b) The translation vectors of some space lattice are given by:
$\boldsymbol{a} = (1/2)a(\boldsymbol{i} + \boldsymbol{j} - \boldsymbol{k})$; $\boldsymbol{b} = (1/2)a(-\boldsymbol{i} + \boldsymbol{j} + \boldsymbol{k})$; $\boldsymbol{c} = (1/2)a(\boldsymbol{i} - \boldsymbol{j} + \boldsymbol{k})$.
Calculate the volume of the unit cell of this lattice. **[6]**

(c) Beginning with sketches of cubic unit cells, show the following planes:
(i) (111); (ii) (100); (iii) (110). **[6]**

(d) Show for a simple cubic lattice that, $d^2 = a^2/(h^2+k^2+l^2)$ where a is the lattice constant and $(h\ k\ l)$ are miller indices. **[7]**

Q2. (a) Label the planes illustrated in (i) and (ii) below, using miller indices. **[6]**



(b) Silicon crystallizes in the diamond structure. Find the atomic density (atoms/cm^2) of crystalline Si on the surface of a (100) oriented Si wafer. The lattice constant for Si is a = 5.43×10^{-8} cm. **[6]**

(c) Calculate the density of InP given that its zinc blend lattice constant is a = 5.87 Å and the atomic weights of In and P are 114.8 and 31 respectively. Avogadro's number is 6.02×10^{23} atoms/mole. **[6]**

(d) Aluminium is alloyed into an n-type Si sample ($N_d = 10^{16}$ cm^{-3}), forming a junction. Assume that the acceptor concentration in the alloyed region is $N_a = 4\times10^{18}$ cm^{-3} and that this junction is at equilibrium with T = 300K. Calculate the intrinsic carrier density if the contact potential is 0.85 V. **[7]**

Q3. (a) Give the three postulates of quantum mechanics. **[6]**

(b) Starting with the time independent Schrödinger equation:

$$\frac{d^2\psi(x)}{dx^2} + \frac{2m}{\hbar^2}[E - V(x)]\psi(x) = 0,$$

find the quantized energy levels of an infinite potential well of width, L. **[7]**

(c) With the help of a diagram, explain what quantum mechanical tunneling is. **[3]**

(d) The total energy of an electron in the n^{th} orbit of a hydrogen atom is given by the Bohr model as,

$$E_n = -\frac{mq^4}{2k^2n^2\hbar^2},$$

where the symbols have their usual meaning and $k = 4\pi\varepsilon_o$; not the usual $1/4\pi\varepsilon_o$. Derive this result. **[9]**

Q4. (a) 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]**

(b) Use a diagram to explain what minority carrier injection is in a p-n junction with a bias voltage. **[5]**

(c) 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:

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

Use a diagram to explain all the symbols in the expression above, except for, q, k and T. **[10]**

Q5. (a) Describe the Hall effect and explain what it is used for in relation to solid state electronics. **[6]**

(b) Consider a piece of semiconducting material of thickness, b carrying a current, I_x and placed in a transverse magnetic field, B_z. Show that the Hall coefficient of this system is given by,

$$R_H = \frac{V_H b}{I_x B_z},$$

where V_H is the Hall voltage. **[9]**

(c) We introduce,

$$k = \cosh\frac{W_b}{L_p^n} + \frac{L_p^n n_n \mu_n^p}{L_n^p p_p \mu_p^p}\sinh\frac{W_b}{L_p^n}$$

where the symbols have their usual meaning in terms of the emitter and base properties of a p-n-p transistor. The transfer ratio, β can be written as,

$$\beta = \frac{1}{k-1}.$$

Find an expression for the current transfer ratio, α in terms of the emitter and base properties. **[6]**

(d) Define the emitter injection efficiency of a p-n-p transistor, γ. **[4]**

APPENDIX A – PHYSICAL CONSTANTS AND USEFUL EQUATIONS

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

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

$$\tanh(x) = \frac{\sinh(x)}{\cosh(x)}$$

$$\text{sech}(x) = \frac{1}{\cosh(x)}$$

END OF EE429 EXAMINATION