UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS & ELECTRONIC ENGINEERING

SUPPLEMENTARY EXAMINATION 2006

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES I

COURSE NUMBER: E321

TIME ALLOWED : THREE HOURS

INSTRUCTIONS: ANSWER ANY FOUR QUESTIONS .

EACH QUESTION CARRIES 25 MARKS

MARKS FOR DIFFERENT SECTIONS ARE SHOWN IN THE RIGHT HAND MARGIN

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Question One.

(a) The energy of an electron in hydrogen atom is given as: $E_n = \frac{-q^4 m_0}{8\varepsilon_o^2 n^2 h^2}$, where the symbols have their usual meanings.

(i) Using the numerical values from Appendix, calculate the value of the energy of the electron when it is in the ground state. (5 marks)

(ii) What is the significance of the negative sign in the equation? (1 mark)

(iii) What is meant by ionization energy of an atom? (2 marks)

(b) A particle of mass 2g with a speed of 5 m/s is located within 10^{-6} m. Use the Heisenberg uncertainty principle to calculate the uncertainly in its momentum. (3 marks)

(c) (i) Draw a unit cell of a face centred cubic lattice showing the atomic positions of lattice constant 'a'. (3 marks)

(ii) Calculate the number of lattice points in the cell. (2 marks)

(iii) Find the nearest neighbour distance of the lattice. (4 marks)

(iv) Calculate the packing efficiency of the lattice. (5 marks)

Question Two.

(a) (i) State the difference between single crystalline, polycrystalline and amorphous materials in terms of their structure and electrical properties. (6 marks)

(ii) Distinguish between an elemental and a compound semiconductor giving two examples each. (4 marks)

(iii) In an intrinsic semiconductor $np = n_i^2$ where n and p are the electron and hole concentrations. When doped with donors the electron concentration n_0 increases above its intrinsic value. However, the product $n_0 p_0$ still remains n_i^2. Explain. (2 marks)

(b) (i) Distinguish between degenerate and non-degenerate semiconductors.

Verify whether or not a silicon sample doped with $2x10^{20} m^{-3}$ donors is degenerate.

[Hint: find the effective density of states N_c in the conduction band and compare] (2+7 marks)

(ii) Find by how much and in which direction the Fermi level will shift due the doping. (4 marks)

Question Three.

(a) (i) Show that for a homogenous extrinsic semiconductor the conductivity:

$\sigma = q(\mu_n n + \mu_p p)$, where symbols have their usual meanings.

(8 marks)

(ii) Simplify the above expression for an intrinsic semiconductor.

(2 marks)

(b) (i) Use the above equation to show that the maximum resistivity of an extrinsic semiconductor sample can be expressed as:

$$\rho_{\max} = \frac{1}{2qn_i\sqrt{\mu_n\mu_p}}$$

(7 marks)

(ii) Calculate the maximum resistivity of silicon at 300K and compare it with its intrinsic value (8marks)

Question Four.

(a) Excess electrons are generated in a semiconductor sample by illumination. Write down the expression showing how the electron concentration varies with time after the light source has been cut off. State what each term represent in the expression.

(4 marks)

(b) A p-type germanium sample has a resistivity of 40 Ω- cm at 300 K. It is illuminated with light that generates 10^{13} excess electron - hole pairs per second.

(i) Calculate the change in conductivity of the sample caused by the light.

(6 marks)

(ii) If the light is switched off at t = 0, calculate the time required for the excess conductivity to drop to 10% of its value at t = 0.

[Given: $\tau_n = 10^{-6}$ s, μ_n = 3900 $cm^{-2} V^{-1}s^{-1}$. μ_p = 1900 $cm^{-2} V^{-1}s^{-1}$.
n_i for Ge = 2.4×10^{13} cm^{-3}]

(5 marks)

(c) A silicon sample doped with 10^{15} donors cm^{-3} is illuminated producing 2×10^{13} cm^{-3} excess pairs.

(i) Calculate the non-equilibrium electron and hole concentrations, n and p.

(4 marks)

(ii) Find the position of the electron and hole quasi- Fermi levels.

(6 marks)

[μ_n = 1325 $cm^{-2} V^{-1}s^{-1}$. μ_p = 450 $cm^{-2} V^{-1}s^{-1}$; Eg of Si = 1.2 eV. T = 300K

Question Five

(a) Explain how an electric field is created when a p - type and an n - type semiconductors are joined together to form a junction. (6 marks)

(b) Derive an expression for the built-in potential of an abrupt p-n junction in terms of the dopant concentrations on each side. (11 marks)

(c) A p-n junction is formed between an n- type p-type silicon having donor and acceptor concentration of $10^{16}/cm^3$ and $4x10^{18}/cm^3$ respectively.

(i) Calculate the built-in potential. (4 marks)

(ii) If the depletion width is 0.4 micrometer how far does the depletion region extend into the n and p type sides?
(silicon has an intrinsic concentration of $1.5x10^{10}/cm^3$) (4 marks)

APPENDIX A

SOME USEFUL EQUATIONS.

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_F}{kT}\right)}$$

$$\sigma = q(\mu_n n + \mu_p p)$$

$$n = n_i \exp\left(\frac{E_{Fn} - E_i}{kT}\right);$$

$$p = n_i \exp\left(\frac{E_i - E_{Fp}}{kT}\right);$$

$$V_i = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}$$

$$W = \left[\frac{2\varepsilon V_i (N_a + N_d)}{q N_a N_d}\right]^{1/2}$$

$$C_j = A\left[\frac{\varepsilon q N_a N_d}{2V_i (N_a + N_d)}\right]^{1/2}$$

$$Jp(x) = q\left[\mu_p p(x) E(x) - D_p \frac{dp(x)}{dx}\right]$$

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = \frac{kT}{q}$$

$$E_I = 13.6\left(\frac{m_e^*}{m_0}\right)\left(\frac{\varepsilon_0}{\varepsilon_s}\right)^2 eV$$

$$N_{c,v} = 2\left(\frac{2\pi m kT}{h^2}\right)^{3/2}$$

APPENDIX **B**

PHYSICAL CONSTANTS

Quantity	Symbol	Value
Angstrom unit	Å	1 Å = 10^{-8} cm = 10^{-10} m
Avogadro number	N	6.023×10^{23}/mol
Boltzmann constant	k	8.620×10^{-5} eV/K = 1.381×10^{-23} J/K
Electronic charge	q	1.602×10^{-19} C
Electron rest mass	m_o	9.109×10^{-31} kg
Electron volt	eV	1 eV = 1.602×10^{-19} J
Gas constant	R	1.987 cal/mole-K
Permeability of free space	μ_o	1.257×10^{-6} H/m
Permittivity of free space	ϵ_o	8.850×10^{-12} F/m
Planck constant	h	6.626×10^{-34} J-s
Proton rest mass	m_p	1.673×10^{-27} kg
$h/2\pi$	$\hbar$	1.054×10^{-34} J-s
Thermal voltage at 300 K	V_T	0.02586 V
Velocity of light in vacuum	c	2.998×10^{10} cm/s
Wavelength of 1-eV quantum	λ	1.24 μm

APPENDIX C

Properties of Ge, Si and GaAs at 300 K

Property	Ge	Si	GaAs
Atomic/molecular weight	72.6	28.09	144.63
Density (g cm^{-3})	5.33	2.33	5.32
Dielectric constant	16.0	11.9	13.1
Effective density of states			
Conduction band, N_C (cm^{-3})	1.04×10^{19}	2.8×10^{19}	4.7×10^{17}
Valence band N_V (cm^{-3})	6.0×10^{18}	1.02×10^{19}	7.0×10^{18}
Electron affinity (eV)	4.01	4.05	4.07
Energy gap, E_g (eV)	0.67	1.12	1.43
Intrinsic carrier			
concentration, n_i (cm^{-3})	2.4×10^{13}	1.5×10^{10}	1.79×10^{6}
Lattice constant (Å)	5.65	5.43	5.65
Effective mass			
Density of states m_e^*/m_o	0.55	1.18	0.068
m_h^*/m_o	0.3	0.81	0.56
Conductivity m_e/m_o	0.12	0.26	0.09
m_h/m_o	0.23	0.38	
Melting point (°C)	937	1415	1238
Intrinsic mobility			
Electron (cm^2 V^{-1} sec^{-1})	3900	1350	8500
Hole (cm^2 V^{-1} sec^{-1})	1900	480	400