UNIVERSITY OF SWAZILAND

FIRST SEMESTER EXAMINATION DECEMBER, 2008

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

TITLE OF PAPER: ELECTRONIC MATERIALS
AND DEVICES I

COURSE CODE: E321

TIME ALLOWED: THREE HOURS

INSTRUCTIONS:

1. **Answer any <u>FOUR</u> (4) of the FIVE questions.**
2. **Each question carries 25 marks.**
3. **The following documents are attached at the end of the question paper:**
   - **Some Useful Equations**
   - **Selected Physical Constants**
   - **Properties of Ge, Si and GaAs at 300 K**

THIS PAPER SHOULD NOT BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR

THIS PAPER CONTAINS NINE (9) PAGES INCLUDING THIS PAGE

Question One

(a) (i) State Heisenberg's uncertainty principle in quantum mechanics. (2 marks)

(ii) Consider a particle of mass 50 mg moving with a velocity of 3 ms^{-1}. The momentum **p** of the particle is not known more accurately than $\Delta \mathbf{p} = 10^{-6}\,\mathbf{p}$. What limitations does quantum mechanics impose on the simultaneous measurement of its position?

(5 marks)

(b) (i) Define "ionisation energy" of an atom. (2 marks)

(ii) Calculate ionisation energy of silicon. (3 marks)

(iii) Calculate the thermal energy of an electron at 300K and hence comment on the conductivity of silicon at room temperatures. (4 marks)

(c) (i) Draw a unit cell of an fcc lattice. (2 marks)

(ii) State with reason whether or not the unit cell you have drawn is primitive or non-primitive. (2 marks)

(iii) One of the planes in a cubic crystal has intercepts 2, 3 and 4 units along its axes. Find the miller indices of this plane. (2 marks)

(iv) Calculate the spacing between two such planes in terms of the lattice constant

(3 marks)

Question Two

(a) Explain briefly how energy bands are formed in solids. (4 marks)

(b) Calculate the density of states N_C and N_V for silicon at 300 K. Hence obtain the value of its intrinsic carrier concentration. (effective masses of electrons and holes are $1.1\ m_0$ and $0.56\ m_0$ respectively) (11 marks)

(c) A uniformly doped silicon sample has a donor concentration of $5\text{x}10^{15}\ \text{cm}^{-3}$ and an acceptor concentration of $1.1\text{x}10^{16}\ \text{cm}^{-3}$. Assume that all dopant atoms are ionized.

(i) Calculate the electron and hole equilibrium concentrations n_o and p_o. (5 marks)

(ii) Determine the position of the Fermi level in the sample. (3marks)

(iii) Draw the resulting band diagram of the sample. (2 marks)

[given: $n_i = 1.5\ \text{x}10^{10}\ \text{cm}^{-3}$]

Question Three

(a) Explain how ***Hall voltage*** is produced in a rectangular uniformly doped n - type semiconductor. (Draw necessary diagrams)

(6 marks)

(b) A Hall voltage of 6 mV was obtained in a semiconductor sample of length 2 cm and a thickness of 0.4 cm when a current of 75 mA was flowing along its length. Magnetic field applied across its length was 5 x10^{-5} weber cm^{-2} and the applied voltage was 1.5V Calculate:

(i) the Hall constant
(ii) the carrier concentration of the sample.
(iii) the Hall mobility

(9 marks)

(c) An intrinsic semiconductor sample has a resistance of 10 ohms at 364 K and 100 ohms at 333 K. If this change is caused by temperature variation, calculate band gap of the sample.

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.

(3 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.

(5 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}]

(4 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)

(iii) How far does the equilibrium product $n_0 p_0$ differ from the non-equilibrium np product?

(3 marks)

[μ_n = 1325 $cm^2 V^{-1} s^{-1}$. μ_p = 450 $cm^2 V^{-1} s^{-1}$; Eg of Si = 1.1 eV. T = 300K

Question Five

(a) Explain how an electric field is created when a p - type and an n - type semiconductor 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. (8 marks)

(c) A p-n junction is formed between an n- type p-type silicon having donor and acceptor concentration of $10^{15}/cm^3$ and $4x10^{18}/cm^3$ respectively.

- (i) Calculate the built-in potential. (3 marks)
- (ii) The zero bias depletion region width (4 marks)
- (iii) Maximum electric field in the depletion region at zero bias (2 marks)
- (iv) Depletion region width for a reverse bias of 3 V (2 marks)

(take T = 300K; intrinsic concentration of silicon = $1.5x10^{10}/cm^3$)

APPENDIX A

SOME USEFUL EQUATIONS.

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

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

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

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

$$V_i=\frac{kT}{q}\ln\frac{N_aN_d}{n_i^{\,2}}$$

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

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

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

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

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
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

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
Valence band N_V (cm^{-3})	6.0×10^{18}	1.02×10^{19}	7.0×10
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}	1.79×1
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