UNIVERSITY OF SWAZILAND.

FACULTY OF SCIENCE.

DEPARTMENT OF ELECTRONIC ENGINEERING.

MAIN EXAMINATION 2007/2008.

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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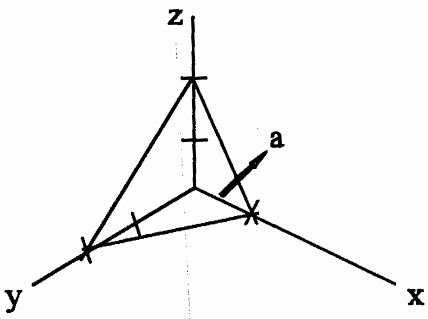
Question One.

1.1 (a) Draw a unit cell of a face centred cubic lattice showing the atomic positions of lattice constant 'a'. (2 marks)

(b) Calculate the number of lattice points in the cell. (1 marks)

(c) Find the nearest neighbour distance of the lattice. (3 marks)

1.2 Find the Miller indices of the plane shown below. (3 marks)



1.3 Find the distance between two neighbouring planes in question (B) above if the lattice constant is 6 Å. (2 marks)

1.4 Find the nearest neighbour distance of a diamond lattice in terms of its lattice constant. (3 marks)

1.5 If the position of one atom in a diamond lattice is (1/4, 1/4,1/4), write down the positions of atoms that make up a tetrahedron.

(3 marks)

1.6 (a) Write down the Fermi - Dirac distribution for a system of fermions at temperature T K. (1 mark)

(b) Find its values:

i. At T = 0K for energy < the Fermi energy.
ii. At T = 0K for energy > the Fermi energy.
iii. At T = 0K for energy = the Fermi energy. (3 marks)

(c) Draw a sketch showing the variation of the distribution function versus energy for T =0K and T > 0K. Comment on the results. (5 marks)

Question Two.

2.1 With appropriate examples explain how conductivity of a silicon sample increases with doping. (6 marks)

2.2 Show that the density of electrons in the conduction band of a semiconductor:

$$n_0 = 2\left(\frac{2\pi m kT}{h^2}\right)^{3/2} \exp\left[-\frac{E_C - E_F}{kT}\right]$$

where symbols have their usual meanings.

[Show all steps clearly and assume that (E_c - E_F) >> kT].

[Given : $\int_0^\infty \exp(-nx)x^{1/2}dx = \frac{1}{2n}\sqrt{\pi}$] (12 marks)

2.3 A silicon sample is doped with 10^{17} cm^{-3} arsenic atoms. All dopants are ionized.

(a) What is the equilibrium hole concentration at 300 K? (2marks)

(b) Where is the Fermi level relative to the centre of the band gap? (3 marks)

(c) Draw the resulting band diagram. (2 marks)

Question Three.

3.1 (a) What are excess carriers in semiconductors? (2 marks)

(b) State three mechanisms and their respective causes that can restore equilibrium after excess carriers are generated in a semiconductor. (3 marks)

(c) Distinguish between low level and high level injection in semiconductors. (4 marks)

(d) Verify if addition of $10^{12}\,cm^{-3}$ electron - hole pairs into a silicon sample doped with $10^{15}\,cm^{-3}$ donors at 300K is a low level or high level injection. (6 marks)

3.2 A silicon sample is doped with $10^{15}\,cm^{-3}$ donors.

(a) Calculate the excess electron and hole concentrations required to increase the sample conductivity by 15%.

(b) What carrier generation rate is required to maintain these excess concentrations?

Take $\mu_P = 0.3\,\mu_n$, $\tau_P = 10^{-6}$ s and T=300K. (10 marks)

Question Four.

4.1 Define the following terms with reference to carrier transport in semiconductors:

(a) Mean free path.
(b) Relaxation time.
(c) Mobility. (6 marks)

4.2 (a) Use data given in the appendix to calculate the hole relaxation time in germanium. (4 marks)

(b) Given that the thermal velocity of a hole is 1.9×10^{7} m s^{-1}, calculate its mean free path. (2 marks)

4.3 (a) The conductivity of an extrinsic semiconductor sample is given as:

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

where symbols have their usual meanings. Use this expression to show that the maximum conductivity of the sample:

$$\sigma_{\max} = 2qn_i\sqrt{\mu_n \mu_p}$$

(8 marks)

(b) Calculate the maximum resistivity of GaAs at 300K. (5 marks)

Question Five.

5.1 (a) Draw the energy band diagram of a p - n junction,

(i) under thermal equilibrium,
(ii) under forward bias and
(iii) under reverse bias. (6 marks)

(b) Answer the following questions:

(i) Name the major charge transfer mechanism responsible for the current flow under forward and reverse bias conditions.
(ii) What happens to the device if the forward bias approaches the built-in potential?
(iii) What is the significance of the quasi Fermi levels?
(iv) What does the splitting of the quasi Fermi levels in the neutral regions represent?
(v) By how much the Fermi level splits on application of a bias voltage of V_a volts?

(5 marks)

5.2 An abrupt germanium p-n junction of area 0.2 mm^{-2} has dopant densities of $10^{22}\,m^{-3}$ and $3x10^{24}\,m^{-3}$ in the n and p regions respectively. For zero applied bias:

(a) Calculate the positions of the quasi Fermi level in the n and p regions. (4 marks)

(b) Find the value of the built-in potential from your result in 1 above. (2 marks)

(c) Calculate the built-in potential using appropriate equations and compare it with your result in 2. (4 marks)

(d) Calculate the depletion layer width. (4 marks)

[Take T= 300 K and n_i for germanium = $2.5x10^{19}\,m^{-3}$]

Appendix A

SOME USEFUL EQUATIONS.

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

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

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

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

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

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

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

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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