UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN EXAMINATION 2005

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) (i) According to Bohr's theory of atomic structure the radius of the nth orbit of the electron in hydrogen atom

$$r_n = \frac{\varepsilon_0 n^2 h^2}{q^2 \pi m_0},$$

where symbols have their usual meanings. Show how the above relation is obtained stating clearly any the assumption made. (6 marks)

(ii) Calculate the radius of the first orbit of the electron in hydrogen. (4 marks)

(b) (i) Draw diagrams to show the atomic positions of a b.c.c. and an f.c.c. cubic lattices. (4 marks)

(ii) Find the nearest neighbour distance of an f.c.c. lattices in terms of their lattices constant. (3 marks)

(iii) Calculate the packing efficiency of an f.c.c. lattice. (4 marks)

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

(v) Calculate the distance between two planes in (iv) above in terms of the lattice constant 'a' (2 marks)

Question Two.

(a) Calculate:

(i) the ionisation energy of germanium. (3 marks)
(ii) the thermal energy at 300 K and (3 marks)
(iii) comment on the above results. (2 marks)

(b) (i) Distinguish between degenerate and non-degenerate semiconductors. (2 marks)

(ii) Verify whether or not a silicon sample doped with 2×10^{20} donors per m^3 is degenerate. (8 marks)

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

(iv) Draw the energy band diagram of the doped silicon sample, with a band gap of 1.1 eV. (3 marks)

Question Three.

(a) (i) Derive the following equation for the conductivity of a homogenous extrinsic semiconductor:

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

(9 marks)

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

(2 marks)

(b) (i) Calculate the resistivity of germanium at 300 K given that it has a carrier concentration of $2.5 \times 10^{19}\ \text{m}^{-3}$, $\mu_n = 0.38\ \text{m}^2 / \text{Vs}$,$\mu_p = 0.18\ \text{m}^2/ \text{Vs}$.

(3 marks)

(ii) The sample is now doped with donor a concentration of $4.41 \times 10^{20}\ \text{m}^{-3}$. Calculate the percentage decrease in resistivity due to the doping.

(6 marks)

(c) Write down the equation showing how the electrical conductivity in an intrinsic semiconductor varies with temperature. How would you use this to determine the band gap of the material.

(5 marks)

Question Four.

(a) (i) In a semiconductor, excess carriers are generated by irradiationon one face of a the sample. Write down the equation showing the variation of excess holes generated along the length of the sample and state what each symbol represents. (4 marks)

(ii) The gradients of quasi-Fermi levels in semiconductors determine the electron and current densities. Prove the validity of this statement for electron current density.

(9 marks)

[Hint: Use the expression for electron concentration under non- equilibrium condition in the Einstein relation for current density.]

(b) A silicon sample is doped with 10^{21} donors per m^3 (assume all the donors are ionized) and has a hole life time of 1 microsecond. Given that the electron and hole mobilities are 0.1325 m^2 V.s and 0.0450 m^2 V.s respectively:

(i) determine the photogeneration rate that will produce 2 x10^{19} excess pairs per m^3 in the steady state. (3 marks)

(ii) find the electron and hole concentrations of the doped sample and its conductivity in the steady state. (5 marks)

(iii) the position of the electron and hole quasi Fermi levels in the steady state.

(4 marks)

Question Five.

(a) With the help of necessary diagrams, distinguish between:

(i) a ***rectifying*** junction and an ***ohmic*** junction (2 marks)
(ii) an ***abrupt*** junction and a ***linearly graded*** junction. (3 marks)

(b) State what is meant by ***depletion region approximation*** in a p-n junction. (2 marks)

(c) From the following data of a silicon p-n junction,

$N_a = 10^{22}\,\mathrm{m^{-3}}$
$N_d = 10^{21}\,\mathrm{m^{-3}}$
$n_i = 1.5\mathrm{x}10^{16}\,\mathrm{m^{-3}}$
junction area = $0.2 \times 10^{-6}\,\mathrm{m^2}$.

calculate

(i) the built in voltage. (3 marks)
(ii) the depletion layer width. (4 marks)
(iii) the depletion layer capacitance. (4 marks)
(iv) the change in capacitance when the junction is reversed biased with 1 V. (3 marks)

(d) Justify the answer in (iv) above with your knowledge on the theory of parallel plate capacitors. (4 marks)

APPENDIX A

SOME USEFUL EQUATIONS.

$$E_I = 13.6\left(\frac{m^*}{m_0}\right)\left(\frac{\varepsilon_0}{\varepsilon_S}\right)^2$$

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

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

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

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

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

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

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

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

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