UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

MAIN 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

ESSENTIAL DATA ND FORMULAE YOU MAY NEED ARE ATTACHED TO THE END OF THIS PAPER/.

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Question One.

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

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

Does your result agree with the conductivity of silicon at room temperatures? Explain. (2 marks)

(b) (i) Define "Fermi energy" E_F of a system of fermions. (2 marks)

(ii) Write down the equation for the Fermi function. (2 marks)

(iii) Find the values of the Fermi function at absolute zero temperature for the cases

1. Energy less than E_F and
2. Energy more than E_F

Draw a sketch of the Fermi function versus energy of the system for temperatures $T = 0$ and $T > 0$. Comment on the physical meaning of your observation. (6 marks)

(c) (i) Distinguish between a primitive and a non-primitive unit cell of a crystal. (2 marks)

(ii) For an fcc structure write down:

1. lattice points per cell
2. volume of a primitive cell in terms of the lattice constant ***a.***
3. Nearest neighbour distance In terms of the lattice constant ***a.***

(3 marks)

(iii) Draw diagrams to show the (110) and (111) planes of a cubic lattice.

Find the distance, in terms of ***a*** , between two consecutive (111) planes (3 marks)

[25]

Question Two.

(a) For an intrinsic semiconductor the relation $np = n_i^2$, where symbols have their usual meanings, holds. Is this relation true for a doped semiconductor as well? Explain. (3 marks)

(b) Silicon has a band gap of 1.1 eV. Calculate the values of the effective density of states in the conduction and valance bands of silicon at 300K. Use these values to get its intrinsic carrier concentration. (11 arks)

(c) A silicon sample is uniformly doped with a donor concentration of $5x10^{15}$ cm^{-3} and an acceptor concentration of $1.1x10^{16}$ cm^{-3}. Assume that all dopant atoms are ionized.

(i) Calculate the electron and hole equilibrium concentrations n_o and p_o
(ii) Determine the position of the Fermi level in the sample.
(iii) draw the resulting band diagram of the sample. (11 marks)

[25]

Question Three.

(a) (i). Define "mobility" and "mean free path"of a charge carrier. (2 marks)

(ii) The hole diffusion coefficient in a silicon sample is 12 $cm^2 s^{-1}$. Determine:

1. the carrier mean free path and

2. the carrier drift velocity in a field of 200 V cm^{-1}.

Also calculate the energy gained by the carrier in the mean free path.
T = 300K.

(12 marks)

(b) (i) Distinguish between "drift" current and "diffusion" current in a semiconductor. (2 marks)

(ii) Write down the equations for the electron and hole current densities in a sample where both drift and diffusion occur. (2 marks)

(iii) Assuming that electron and hole mobilities are independent of dopant concentrations, calculate the maximum resistivity in gallium arsenide at 300K. Compare this with its intrinsic value. (7 marks)

[25]

Question Four.

(a) (i) Explain why a semiconducting material is transparent to some incident radiation. (4 marks)

(ii) Distinguish between low level and high level injections in a semiconductor. (2 marks)

(iii) The gradients of quasi-Fermi levels in a semiconductor determine the currents. Prove the validity of this statement for electro current density. (9 marks)

(b) A sample of n-type silicon has a dark resistivity of 1 KΩ - cm at 300 K. The sample is then illuminated uniformly to generate 10^{21} electron-hole pairs per cm^3 per second. The hole life time in the sample is 1 μs.

(i) Verify whether it is high level or low level injection.

(ii) Calculate the percentage change in its conductivity after illumination. (10 marks)

[25]

Question Five.

(a) (i) Explain how a built- in potential difference is produced across a p-n junction. (4 marks)

(ii) Draw the energy band diagrams of a p-n junction under forward and reverse bias conditions. (4 marks)

(iii) Show that the built potential across the junction is:

$$V_i = \left(\frac{kT}{q}\right)\ln\left(\frac{N_d N_a}{n_i^2}\right)$$, where symbols have their usual meanings.

(8 marks)

(b) A p-n junction is made if n-type germanium of donor density 10^{16} cm^{-3} and p-type germanium of acceptor density 3×10^{18} cm^{-3} . If the intrinsic carrier concentration of germanium is 2.5×10^{13} cm^{-3} ,
calculate:

(i) the position of the Fermi levels in the p and n type regions. (4 marks)

(ii) the built - in potential using appropriate equations. (2 marks)

(iii) the width of the depletion region (3 marks)

[25]

Appendix

Some Useful Equations

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

$$n(x) = n_i \exp(E_{FN} - E_i) / kT$$

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

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

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

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

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

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

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

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

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

TABLE 4.2
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