UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING

SUPPLEMENTARY 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) Explain how electrical conductivity occurs in metals, insulators and semiconductors based on the theory of ***energy band in solids.*** (6 marks)

(b) Calculate the density of states N_C and N_V of silicon at 300 K. Hence obtain the value of its intrinsic carrier concentration. (effective masses of electron and hole are 1.1 m_0 and 0.56 m_0 respectively) (12 marks)

(c) (i) A silicon sample having intrinsic carrier concentration of $1.3\text{x}10^{16}\,m^{-3}$ is doped with $5\text{x}10^{22}\,m^{-3}$ donor atoms. Find by how much the Fermi level shifts due to the doping. (4 marks)

(ii) Draw the resulting band diagram. (3 marks

Question Two

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

(ii) At 300 K pure silicon has a conductivity of 4.5×10^{-4} S/m . If the electron and hole mobilities are 0.14 m^2/ Vs and 0.05 m^2/ Vs, what is the density of electron-hole pairs at this temperature? (3 marks)

(iii) Calculate the conductivity of the sample in (ii) above when it is doped with 10^{23} atoms /m^3 of boron. What percentage of the current flow in the sample is carried by electrons alone? (8 marks)

(b) An intrinsic sample of silicon has conductivity 4.56×10^{-4} S/m . When it is irradiated its conductivity increases to 10×10^{-4} S/m. Irradiation stops immediately, and after 1 microsecond the conductivity becomes 5×10^{-4} S/m. Calculate the minority carrier lifetime in silicon. (12 marks)

Question Three.

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

(8 marks)

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

(i) the Hall constant (3 marks)
(ii) the carrier concentration of the sample. (3 marks)
(iii) the Hall mobility (3 marks)

(c) Semiconductor sample has resistance of 10 Ω at 364 K and 100 Ω at 333 K. Assuming that the change is due to temperature only, calculate the band gap of the sample.

[Given; conductivity varies as $\sigma = Ae^{-\frac{E_g}{2kT}}$, where A is a constant]. (8 marks)

Question Four

(a) Write down the equation for the density of states N(E)dE for electrons of mass 'm' with energy lying between E and E + dE. (2 marks)

(b) A metal of volume 1 cm^3 at 300 K has density of states distribution given as: $N(E)\,dE = 6.82 \times 10^{21} E^{1/2}\,dE$, where energy is measured from the bottom of the band. The number of electrons lying within a small energy level between $E_1 = 4.6$ eV and $E_2 = 4.601$ eV is 2.07×10^{15}. Determine:

(i) the fraction of states between E_1 and E_2 occupied by the electrons. (7 marks)

(ii) the position of the Fermi level and (6 marks)

(iii) the number of electrons between E_1 and E_2 at 0K. (2 marks)

(c) A photon of monochromatic wavelength 5000 Å is absorbed in a GaAs sample and excites an electron from the valance band to the conduction band.

(i) Calculate the photon energy. (3 marks)

(ii) Use the effective masses in the table appendix to find the kinetic energy of the electron and hole.

(5 marks)

Question Five.

(a) Derive the following expression for the built-in voltage across a p-n junction:

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

where N_d and N_a are donor and acceptor concentrations.

(8 marks)

(b) An abrupt p-n junction has acceptor concentration of 10^{24} m^{-3} and donor concentration of 10^{21} m^{-3} at 300 K. Calculate:

(i) the built-in voltage.
(ii) the depletion layer width.
(iii) the maximum electric field in the depletion region.
(iv) the depletion layer capacitance. (12 marks)

(c) (i) What is breakdown of a p-n junction? State two features of this phenomenon.
(3 marks)
(ii) Distinguish between Zener and Avalanche breakdown . (2 marks)

APPENDIX A

SOME USEFUL EQUATIONS.

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

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

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

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

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

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

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

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

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

APPENDIX B

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

Appendix C

Physical Constants.

Quantity	*symbol*	*value*
Speed of light	c	$3.00 \times 10^{8}\ ms^{-1}$
Plank's constant	h	6.63×10^{-34} J.s
Boltzmann constant	k	$1.38 \times 10^{-23}\ JK^{-1}$
Electronic charge	e	1.61×10^{-19} C
Mass of electron	m_e	9.11×10^{-31} kg
Mass of proton	m_p	$1.67 \times 10^{-27\ kg}$
Gas constant	R	$8.31\ J\ mol^{-1}\ K^{-1}$
Avogadro's number	N_A	6.02×10^{23}.
Bohr magneton	μ_B	$9.27 \times 10^{-24}\ JT^{-1}$
Permeability of free space	μ_0	$4\pi \times 10^{-7}\ Hm^{-1}$
Stefan constant	σ	$5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$
Atmospheric pressure		$1.01 \times 10^{5}\ Nm^{-2}$
Mass of $_2^4$He atom		6.65×10^{-27} kg
Mass of $_2^3$He atom		5.11×10^{-27} kg
Volume of an ideal gas at STP		$22.4 \times 10^{-3} m^3 mol^{-1}$