UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING.

SUPPLEMENTARY EXAMINATION 2010

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES I

COURSE NUMBER: E321

TIME ALLOWED : THREE HOURS

INSTRUCTIONS: ANSWER ANY <u>FOUR</u> QUESTIONS .

EACH QUESTION CARRIES 25 MARKS

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

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QUESTION ONE.

(a) (i) Explain wave-particle duality of matter.

(ii) Calculate the de Broglie wavelength of:

(1) an object of mass 1 g

(2) a neutron.

Is it necessary to consider the wave nature of matter in both cases above? Explain.

(11 marks)

(b) (i) Distinguish between a boson and a fermion.

(ii) Write down the expression for the probability function f(E) that an energy state with energy E is occupied by an electron at temperature T. Find its values at T = 0 K, when the energy of the state is:

(1) less than E_F
(2) more than E_F

where E_F is the Fermi energy.

Sketch a graph of F(E) versus E at T = 0 K and T > 0 K. (8 marks)

(c) The probability that an energy state, with energy ΔE above Fermi level, is occupied should be the same as the probability that an energy state with energy ΔE below the Fermi level. Verify this using the probability function

(6 marks)

QUESTION TWO.

(a) On the basis of the theory of the energy bands in solids, explain how electrical conductivity occurs in metals, insulators ans semiconductors.

(10 marks)

(b) Explain what are non-degenerate and degenerate semiconductors clearly distinguishing between their properties.

(7 marks)

(c) The density of states in the conduction band and valance band of silicon is $2.5 \times 10^{25}\ m^{-3}$. Assuming that they are not functions of temperature, find the intrinsic carrier concentration of silicon at 300 K. The sample is now doped with 10^{23} phosphorus atoms m^{-3}. Calculate the majority and minority carrier concentrations. By how much the Fermi level is shifted by this doping?

(8 marks)

QUESTION THREE.

(a) (i) Show that for a homogenous extrinsic semiconductor the conductivity:

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

where n and p are the electron and hole concentrations and μ_n , μ_p are their respective mobilities.

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

(10 marks)

(b) Discuss briefly how the electrical conductivity of a semiconductor varies with temperature. State how the band gap of a material can be found experimentally using this information.

(6 marks)

(c) Calculate the resistivity of germanium at 300 K given that it has an intrinsic carrier concentration of $2.5\text{x}10^{19}\ \text{m}^{-3}$, $\mu_n = 0.38\ \text{m}^2/\text{Vs}$ $\mu_h = 0.18\ \text{m}^2/\text{Vs}$.
The sample is now doped with donor concentration of $4.41\text{x}10^{20}\ \text{m}^{-3}$. Calculate the decrease in resistivity in the sample. (9 marks)

QUESTION FOUR.

(a) What are excess carriers in semiconductors?
State three mechanisms and their respective causes that can restore equilibrium after excess carriers are generated in a semiconductor. (4 marks)

(b) A monochromatic light of frequency ν is allowed to fall on a semiconductor sample. Write down the expression for the intensity of light transmitted through the sample and state what each factor of the equation represent.

Draw a sketch of frequency versus absorption coefficient of light through a semiconducting material and explain each part of it with sufficient reasoning.

(10 marks)

(c) A 0.5 μm thick sample of GaAs is uniformly illuminated with monochromatic light of frequency $5.07 \times 10^{14}\ s^{-1}$. Absorption coefficient of the light is $4 \times 10^{4}\ cm^{-1}$. The power incident on the sample is 12 mW. Calculate:

(i) the power absorbed by the sample.
(ii) the power dissipated by the excess electrons to the lattice
(iii) the number of photons falling per second on the sample
(iv) the number of photons emitted per second from the electron- hole pair recombination. (11 marks)

QUESTION FIVE

(a) An abrupt silicon p-n junction has acceptor concentration of 10^{24} m^{-3} and donor concentration of 10^{21} m^{-3} at 300 K. Its area of cross section is 0.2 mm^2. 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. (13 marks)

(b) (i) Explain how an electric field is created in a p-n junction? (6 marks)

(ii) Draw sketches showing the electric field and the potential distributions across a p-n junction. (6 marks)

APPENDIX A

SOME USEFUL EQUATIONS.

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

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

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

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

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

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

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

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

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

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

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

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}
Electronic charge	q	1.602×10^{-19} C
Electron rest mass	m_0	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_0	1.257×10^{-6} H/m
Permittivity of free space	ε_0	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