UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF ELECTRONIC ENGINEERING.

MAIN EXAMINATION 2006/2007.

TITLE OF PAPER: ELECTRONIC MATERIALS & DEVICES I

COURSE NUMBER: E321

TIME ALLOWED : THREE HOURS

ANSWER ANY FOUR QUESTIONS . ALL QUESTIONS CARRY EQUAL MARKS

THIS PAPER IS NOT TO BE OPENED UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR.

**Question One**

(a) (i) State the three postulates Neil Bohr presented in his theory to explain the structure of atoms. (3 marks)

(ii) State what is meant by "ionization energy' of an atom. (2 marks)

(iii) According to Bohr's theory, the total energy of an electron in the n$^{th}$ of the hydrogen atom is:

$$E_n = \frac{-q^4 m_0}{8\varepsilon_0^2 n^2 h^2}.$$

An electron makes a transition from n = 2 to n = 1 state in the hydrogen atom. Calculate the energy released during this transition. ( 5 marks)

(iv) If the energy is released in the form of light, what is its wavelength? ( 3 marks)

(b) (i) Draw a unit cell of an bcc lattice. ( 2 marks)

(ii) State with reason whether or not the unit cell you have drawn is primitive or non-primitive. ( 2 marks)

(iii) One of the planes in a cubic crystal has intercepts 1,2 and 3 units along its axes. Find the miller indices of this plane. ( 2 marks)

(iv) Calculate the spacing between two such planes if the lattice constant is 2 Å ( 2 marks)

(c) Explain briefly how electrical conductivity occurs in metals and as compared to that in insulators. (4 marks)

**<u>Question Two</u>**

(a). (i) Write down the equation for the density of states N(E)d(E) for a system of electrons. (1 mark)

(ii) If f(E)d(E) is the distribution function of the electrons what is the total energy of the system? (1 mark)

(iii) Calculate the effective density of states in the conduction band of silicon at 300 K. (Assume effective mass of electron is equal to its rest mass)

(5 marks)

(b) Using appropriate expressions for the effective density of states, $N_C$ and $N_V$, show that: the relation np = $n_i^2$, is valid for both extrinsic semiconductor and intrinsic semiconductors.

$$n_0 = N_C \exp\left[-\frac{E_C - E_F}{kT}\right]$$

(8 marks)

(c) A uniformly doped silicon sample has a donor concentration of $5 \times 10^{15}$ cm$^{-3}$ and an acceptor concentration of $1.1 \times 10^{16}$ 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.

[ given: $n_i = 1.5 \times 10^{10}$ cm$^{-3}$] (10 marks)

**Question Three**

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

(5 marks)

(b) A Hall voltage of 6 mV was obtained in a semiconductor sample of length 2 cm, thickness of 0.4 cm and width 0.8 cm, when a current of 75 mA was flowing along its length. Magnetic field applied across its length was 5 x$10^{-5}$ weber $cm^{-2}$ and the applied voltage was 1.5V Calculate:

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

(9 marks)

(c) (i) Define the terms ***mean free path*** and ***carrier mobility*** of a semiconductor.

(4 marks)

(ii) The hole diffusion coefficient of a silicon sample is 12 $cm^2s^{-1}$. An electric field of 200 $Vcm^{-1}$ is applied to the sample. Determine the:
***mobilty, relaxation time,*** and ***drift velocity*** of holes in the sample.

(7 marks)

Take T = 300K

**Question Four**

(a) Discuss ***photo-generation of excess carriers*** in the semiconductor sample.
Sketch a diagram showing the variation of the optical absorption coefficient of the sample with photon energy.

(5 marks)

(b) Distinguish between the following recombination processes in semiconductors

(i) direct and indirect
(ii) radiative an non- radiative

(4 marks)

(c) Excess holes generated at one end of a semiconductor sample by irradiation, diffuse along its length after the irradiation source is switched off. Write down an expression showing how the hole concentration varies with length of the sample. State what each symbol represent

(4 marks)

(d) A silicon sample doped with $10^{15}$ donors $cm^{-3}$ is illuminated producing $2 \times 10^{13}$ $cm^{-3}$ excess pairs.

(i) Calculate the non-equilibrium electron and hole concentrations, n and p.

(4 marks)

(ii) Find the position of the electron and hole quasi- Fermi levels.

(4 marks)

(iii) Calculate the change in conductivity of the sample. (4 marks)

**Question Five**

(a) Draw energy band diagrams of p - type and n - type semiconductor samples

(i) when they are separate. (2 marks)
(ii) when they are joined together to form a p-n junction (2 marks)

(b) Sketch diagrams to show (i) the electric field and (ii) the potential distributions in an abrupt p-n junction. (6 marks)

(c) Distinguish between a rectifying junction and an ohmic junction (4 marks)

(d) An abrupt silicon p-n junction of area of cross section 0.2 $mm^2$ 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.

(11 marks)

## APPENDIX A

SOME USEFUL EQUATIONS.

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

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

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

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

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

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

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

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

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

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

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

# 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, $N_C$ ($cm^{-3}$) | $1.04 \times 10^{19}$ | $2.8 \times 10^{19}$ | $4.7 \times 10^{17}$ |
| Valence band $N_V$ ($cm^{-3}$) | $6.0 \times 10^{18}$ | $1.02 \times 10^{19}$ | $7.0 \times 10^{18}$ |
| Electron affinity (eV) | 4.01 | 4.05 | 4.07 |
| Energy gap, $E_g$ (eV) | 0.67 | 1.12 | 1.43 |
| Intrinsic carrier concentration, $n_i$ ($cm^{-3}$) | $2.4 \times 10^{13}$ | $1.5 \times 10^{10}$ | $1.79 \times 10^{6}$ |
| 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 |
|---|---|---|
| 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 | $\mu_o$ | 1.257 × $10^{-6}$ H/m |
| Permittivity of free space | $\varepsilon_o$ | 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 | $\lambda$ | 1.24 $\mu$m |