UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

MAIN EXAMINATION:	2014/15
TITLE OF PAPER:	SOLID STATE ELECTRONICS
COURSE NUMBER:	EE429
TIME ALLOWED:	3 HOURS

INSTRUCTIONS:

ANSWER ANY FOUR (4) OUT OF FIVE (5) QUESTIONS.

EACH QUESTION CARRIES 25 MARKS.

MARKS FOR DIFFERENT SECTIONS ARE SHOWN ENCLOSED IN SQUARE BRACKETS.

THIS PAPER HAS FIVE (5) PAGES INCLUDING THIS PAGE.

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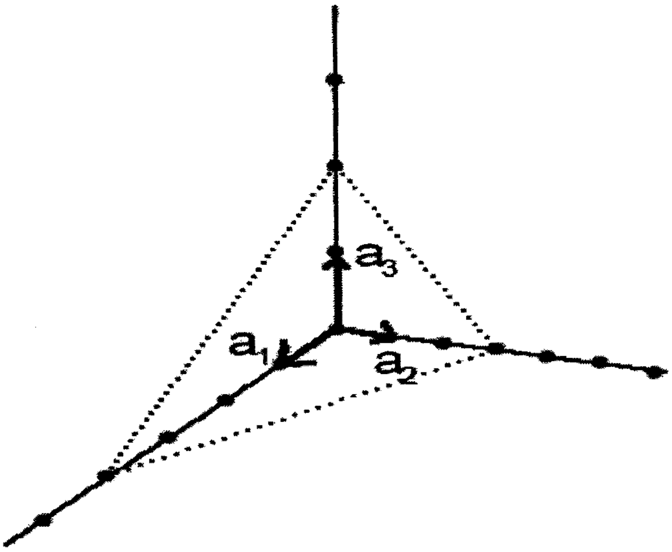
Question 1 (25 marks)

a) Calculate the surface density of atoms on a surface plane that cuts the BCC lattice diagonally. The lattice constant of the BCC is ***a* = 0.5nm** (= 5 Å). [3]

b) Determine the Miller indices for the plane on the figure [2]



c) Calculate the "Bohr radius" for He. [3]

d) A photon with a wavelength of 3.091×10^{-7} m strikes an atom of hydrogen. Determine the velocity of an electron ejected from the excited state, *n = 3*. [5]

e) Determine the minimum potential that must be applied to an α -particle so that on interaction with a hydrogen atom, a ground state electron will be excited to *n = 6*. [5]

f) Determine the wavelength of radiation emitted by hydrogen atoms upon electron transitions from n=6 to n=2. [4]

g) What is the energy gap (in eV) between the electronic states n=3 and n=8 in a hydrogen atom? [3]

Question 2 (25 marks)

In a solid, many atoms are brought together to form a crystal. With the aid of a diagram, illustrate the formation of a silicon (Si) crystal from isolated Si atoms. In your illustration:

Consider only two (2) Si atoms.

- Draw the complete diagram, of the energy levels in Si as a function of inter-atomic spacing. [7]

  On the diagram:
  - show the number of states and number of electrons. [7]
  - indicate the band gap. [2]
  - show the electronic configuration of the atom and how it corresponds to the energy levels. [5]
  - explain the diagram [4]

Question 3 (25 marks)

a) A Si sample is doped with 10^{17} Boron atoms/cm^3. [6]
   i. What is the electron concentration n_0 at 300 K?
   ii. What is the resistivity?

b) A Ge sample is doped with 3×10^{13} Sb atoms/cm^3. Using the requirements of space charge neutrality, calculate the electron concentration n_0 at 300 K. [6]

c) A new semiconductor has $N_c = 10^{19}$ cm^{-3}, $N_v = 5 \times 10^{18}$ cm^{-3}, and $E_g = 2$ eV. If it is doped with 10^{17} donors (fully ionized):
   i. calculate the electron, hole, and intrinsic carrier concentrations at 627 ^{0}C. [10]
   ii. Sketch the simplified band diagram, showing the position of E_F. [3]

Question 4 (25 marks)

An abrupt Si p-n junction ($A = 10^{-4}$ cm^2) has the following properties at 300 K.

p side	n side
$N_a = 10^{17}$ cm^{-3}	$N_d = 10^{15}$ cm^{-3}
$\tau_n = 0.1$ µs	$\tau_p = 10$ µs
$\mu_p = 200$ cm^2/V-s	$\mu_n = 1300$ cm^2/V-s
$\mu_n = 700$ cm^2/V-s	$\mu_p = 450$ cm^2/V-s

a) The junction is forward biased by 0.5 V.
   i. What is the forward current? [16]
   ii. What is the current at a reverse bias of -0.5 V? [2]

b) What is the total depletion capacitance at -4 V? [7]

Question 5 (25 marks)

A Si p-n junction with cross-sectional area $A = 0.001\ \text{cm}^2$ is formed with $N_a = 10^{15}\ \text{cm}^{-3}$, $N_d = 10^{17}\ \text{cm}^{-3}$. Calculate the:

a) Contact potential V_0. [4]

b) Space-charge width at equilibrium (zero bias). [6]

c)

- i. Current with a forward bias of 0.5 V. Assume that the current is diffusion dominated. Assume $\mu_n = 1500\ \text{cm}^2/\text{V-s}$, $\mu_p = 450\ \text{cm}^2/\text{V-s}$, $\tau_p = \tau_n = 2.5$ ms. [11]
- ii. Which carries most of the current, electrons or holes, and why? [2]
- iii. If you wanted to double the electron current, what should you do? [2]

APPENDIX A - PHYSICAL CONSTANTS AND SOME USEFUL FORMULAS

Electron charge, $q = 1.60217657 \times 10^{-19}$

$1\ eV = 1.60217657 \times 10^{-19}$ J

Boltzmann's constant, $k = 1.831 \times 10^{-23}\ J/K$

Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-12}\ F/m = 8.85 \times 10^{-14}\ F/cm$

Relative permittivity of Si $\varepsilon_r = 11.8$

Electron rest mass, $m = 9.109 \times 10^{-31}\ kg$

Velocity of light $C = 3 \times 10^8$ m/s

Planck's constant (reduced), $\hbar = 1.0546 \times 10^{-34}\ J/s$

Planck's constant, $h = 6.626 \times 10^{-34}\ J/s$

$1\ nm = 10^{-9}\ m = 10\ \text{Å}$ (atomic units)

Intrinsic concentration for Si at room temperature, $n_i = 1.5\ x\ 10^{10}\ cm^{-3}$

Momentum $p = mvr = n\hbar$, where n is the n^{th} orbit.

Electrostatic force between 2 point charges of charge q, separated by distance r is $\frac{q^2}{4\pi\epsilon_0 r^2}$

Equilibrium electron concentration, $n_0 = n_i\, e^{\left(\frac{E_F - E_i}{kT}\right)} = N_C\, e^{\left(-\frac{E_C - E_F}{kT}\right)}$

Equilibrium hole concentration, $p_0 = n_i\, e^{\left(\frac{E_i - E_F}{kT}\right)} = N_V\, e^{\left(-\frac{E_F - E_V}{kT}\right)}$

Ideal diode saturation current density, $J_0 = qn_i^2\left(\frac{D_p}{N_d L_p} + \frac{D_n}{N_a L_n}\right)$

Equilibrium value of the space charge width, $W = \sqrt{\frac{2\epsilon V_0}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$

Mobility and doping for Si at 300 K:

Impurity concentration (cm^{-3})	10^{14}	10^{15}	10^{16}	10^{17}	10^{18}
$\mu_p\ (cm^2/V\text{-}s)$	590	580	500	350	100
$\mu_n\ (cm^2/V\text{-}s)$	1500	1400	1200	700	350