Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE6212 Semiconductor Materials

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

Data provided:

electron mass, $m_0 = 9.11 \times 10^{-31}$ kg

electron charge, e or q, $=1.60 \times 10^{-19}$ C

Rydberg unit of energy, $R_y = 13.61$ eV

Bohr radius of hydrogen atom, $a_0 = 5.29 \times 10^{-11}$ m

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

or 4.135×10^{-15} eV.s

reduced Planck's constant $\hbar = 1.055 \times 10^{-34}$ J.s

or 6.582×10^{-16} eV.s

GaAs electronic properties

band-gap at 300K = 1.424 eV

electron effective mass, $m_e=0.063m_0$

heavy hole effective mass, $m_{hh}=0.51m_0$

1. **a.** The elements gallium (Ga), germanium (Ge) and arsenic (As) have numbers 31, 32 and 33 in the periodic table of the elements. Explain the similarities and differences between the semiconductor materials Ge and GaAs with respect to the following aspects:

(i) crystal structure;
(ii) F_{002} structure factor;
(iii) covalence bonding /ionicity;
(iv) size of bandgap;
(v) type of bandgap;
(vi) average atomic number;
(vii) lattice parameter;
(viii) density.

(8)

b. Sketch a three-dimensional view of the unit cell of a gallium arsenide crystal with all atoms in the cell. Label the directions of the basic unit cell vectors. Mark the [110] and the [-$\bar{1}$10] directions. Calculate for a lattice parameter of a=0.5653nm

(i) the atomic number density in units of atoms/nm^3,
(ii) the atomic areal density of the (001) surface in atoms/nm^2,
(iii) the spacings of the {113} lattice planes.

(7)

c. Calculate and compare the Ga-N bond lengths in cubic gallium nitride (a_{cub}=0.452nm) and hexagonal gallium nitride (a_{hex}=0.319nm, c_{hex}=0.519nm).

(5)

2. **a.** Name all possible symmetry elements of a cubic crystal (apart from the identity operation). For each, identify where they are and how many there are. **(6)**

b. (i) Draw a sketch of the diamond lattice.

(ii) How many atoms are there per unit cell?

(iv) In your sketch, indicate all tetragonal interstices. Which of them are occupied by atoms? **(5)**

c. All possible unit cells can be divided into 7 crystal systems, 14 Bravais lattices and 230 space groups of increasing symmetry. While most semiconductors are either cubic or hexagonal in bulk form, during epitaxy the unit cells can adopt different shapes of reduced symmetry.

(i) Define what a crystal system is.

(ii) Define what a Bravais lattice is.

(iii) Explain what space centering means.

(iv) Explain why there are fewer than twenty Bravais lattices.

(v) Why is there no tetragonal *F* lattice? **(5)**

d. Dislocations are common extended defects in semiconductors. Define what the Burgers vector is and use it to explain the difference between an edge and a screw dislocation. **(4)**

3. **a.** The electron density in a heavily n-doped semiconductor at low temperature may be written as

$$n = \sqrt{\tfrac{1}{2} N_c N_d} \exp\left[-(E_c - E_d)/(2k_B T)\right] \qquad \text{(equation 1)}$$

Describe how you can extract the magnitude of the energy level of the donor relative to the conduction band edge using a series of conductivity measurements. **(5)**

b. Provide a sketch of the cross-section through an n-channel MOSFET device as typically used for high-speed switching or high-frequency amplification. Name all terminals. Indicate the sign and strength of doping levels in all relevant regions. Explain what the critical device dimensions are for use as an amplifier and why. **(6)**

c. With the help of a suitable sketch, explain the difference between a type-I and a type-II band alignment between two semiconductors. Which is better for application as light-emitting device, and why? **(5)**

d. Name the two physical principles that the function of every LASER system relies on, and the corresponding components to be found in all LASER systems. **(4)**

4. **a.** Derive the drift velocity for electrons in a semiconductor. Describe all assumptions, concepts, and parameters. **(12)**

b. Describe how the mobility of a material may be modified by the choice of material and synthesis methods. **(4)**

c. The total electron (hole) current density is given as the sum of the electron (hole) drift and diffusion. Comment upon the magnitude of the drift and diffusion current densities with regard to majority and minority carrier densities. **(4)**

5. **a.** Using schematic diagrams describe absorption, spontaneous and stimulated emission processes in a semiconductor, and define their rates.

(6)

b. Describe how the application of a current to a p-i-n diode may result in the transition from optical loss to gain for incident photons of energy greater than the band-gap in the intrinsic region. Describe what is meant by a "transparency current".

(4)

c. Calculate the binding energy and radius of the n=1 and n=2 excitons in a semiconductor which has:

an effective electron mass of $m_e = 0.28m_0$,

an effective hole mass of $m_h = 0.5m_0$,

relative permittivity $\varepsilon_r = 7.9$.

Comment on whether these excitons are stable at room temperature.

(5)

d. Describe the relevance of the Mott transition in a semiconductor with regards to excitonic effects.

Estimate the Mott densities for GaAs (exciton radius =13nm) and GaN (exciton radius = 3nm)

(5)

6. **a.** Describe, using equations and schematic diagrams, the first three confined electronic levels and their wave-functions within an infinite quantum well. Making an infinite well approximation, calculate the e1-hh1 transition energy for a 10nm GaAs quantum well.

(7)

b. Describe the effects of a finite potential barrier on the confinement energies, and wave-functions.

(2)

c. Draw schematic diagrams of the electronic density of states changes for 3D, 2D, 1D and 0D electronic systems. Briefly describe how such electronic density of states may be realised in semiconductor structures.

(8)

d. Through band-structure engineering, describe strategies to maximise the gain in a single quantum well laser structure.

(3)

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