Date: May 7, 2014; 10.30 am – 12.30 pm

Total = 40 marks

EPL – 336 (Semiconductor Optoelectronics)

ALL problems are compulsory. Answer all sub-parts of the same question in one sequence.
NOTE: **FULL** credit will be awarded only if the right answer is obtained for the right reason, **NO** credit wil be given if the calculations are not completed and proper units not mentioned even if correct formulae have been used.

1. Choose the correct answer in the following questions.
Note: A wrong answer will result in negative marking of 1 mark. [2×5=10]

(A) In Rutherford's famous set of experiments, the fact that some alpha particles were deflected at large angles indicated that
(a) the nucleus was positive.
(b) charge was quantized.
(c) the nucleus was concentrated in a small region of space.
(d) most of the atom is empty space.

(B) If we set the potential energy of an electron and a proton to be zero when they are an infinite distance apart, then the lowest energy a bound electron in a hydrogen atom can have is
(a) 0.
(b) −13.6 eV.
(c) any possible value.
(d) any value between −13.6 eV and 0.

(C) Which type of bond holds the molecules of the DNA double helix together?
(a) Covalent bond.
(b) Ionic bond.
(c) Van der Waals bond.
(d) None of the above.

(D) Laser light of wavelength 800 nm is incident on a GaAs based photoconductive device biased with 25V. The lifetime of the EHPs generated is ~ 1.0 ps. What would be the central wavelength of radiation emitted when the EHPs are traveling under the acceleration of the bias voltage?
(a) 300μm
(b) 30μm
(c) 400nm
(d) 100 μm

(E) With increasing temperature of an extrinsic semiconductor, the most pronounced effect is on..........?
(a) Majority carriers
(b) Minority carriers
(c) Junction capacitance
(d) none of the above

2. **Bandgap and Photodetection**
(a) Determine the maximum value of the energy gap which a photoconductive semiconductor can have, if it is to be sensitive to yellow light of wavelength 600 nm.

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(b) A photo-detector of area is 5×10^{-2} cm^2 is irradiated with yellow light, whose intensity is 2 mW cm^{-2}. Assuming unit internal quantum efficiency, calculate the number of EHPs generated per second.
(c) From the known energy gap of the semiconductor GaAs, calculate the primary wavelength of photons emitted from this crystal as a result of electron-hole recombination.
(d) Will a silicon CMOS photo-detector be sensitive to the radiation from a GaAs laser? Explain.

[1+3+1+2=7]

3. **CMOS and CCD image sensors**

Consider the basic principle of operation of the CMOS and CCD image sensors.
(a) What constitutes the signal in the CMOS and CCD sensors? Explain the differences in their operational methods with relevant figures.
(b) Considering the above sensors, which one is faster for a given number of megapixels? Explain.

[6+2=8]

4. **Photoconductive Detector**

An *n*-type Si photoconductor has a length l = 100 μm and cross-sectional area A = 10^{-4} mm^2. The applied bias voltage to the photoconductor is 10 V. The recombination time is 1.0 μs.
(a) Find an analytical expression for photoconductive gain and calculate its value.
(b) For the detector above to operate with the above gain, do the metal semiconductor junctions at the electrode have to be Schottky type or Ohmic type? Explain.

[5+3=8]

5. **Quantum Well Heterostructure Devices**

Consider a quantum well in a semiconductor heterostructure, and assume, for simplicity, an infinite potential energy quantum well with dimensions d along x, and D_y and D_z along y and z directions. The energy of an electron with respect to the bottom of the well is then given by

$$E = \frac{h^2 n^2}{8m_e^* d^2} + \frac{h^2 {n_y}^2}{8m_e^* {D_y}^2} + \frac{h^2 {n_z}^2}{8m_e^* {D_z}^2}$$

where n, n_y and n_z are quantum numbers having values 1,2,3..
Assume that the well has d = 10 nm, $D_z = D_y$ = 2μm, and $m^*_e = 0.067 m_0$.
(a) Calculate the minimum energy.
(b) What would n_y need to be to get the same energy as the first term of the above expression?
(c) What is the separation δE between the energy levels for motion in the y and z plane?

[3+2+2=7]

Useful Information:

Physical Constants: $h = 6.626\times10^{-34}$ Js ; $k = 1.381\times10^{-23}$ JK^{-1} ; $e = 1.6\times10^{-19}$ C ; $m_0 = 9.1\times10^{-31}$ kg; $c = 3\times10^{8}$ ms^{-1}

Table 1: Typical properties of selected semiconductors at room temperature

	a (nm)	E_g (eV)	χ (eV)	N_c (cm^{-3})	N_v (cm^{-3})	n_i (cm^{-3})	ε_r	μ_e (cm^2 V^{-1} s^{-1})	μ_h (cm^2 V^{-1} s^{-1})
Ge (DI)	0.5650	0.66 (I)	4.13	1.04×10^{19}	6.0×10^{19}	2.3×10^{13}	16	3900	1900
Si (DI)	0.5431	1.11 (I)	4.05	2.8×10^{19}	1.2×10^{19}	1.0×10^{10}	11.8	1450	490
InP (ZB)	0.5868	1.35 (D)	4.50	5.2×10^{17}	1.1×10^{19}	3×10^{7}	12.6	4600	150
GaAs (ZB)	0.5653	1.42 (D)	4.07	4.7×10^{17}	7×10^{18}	2.1×10^{6}	13.0	8500	400
AlAs (ZB)	0.5661	2.17 (I)	3.50	1.5×10^{19}	1.7×10^{19}	10	10.1	200	100

Data combines from a number of sources. I and D represent indirect and direct bandgap. DI, diamond crystal; ZB, zinc blende; *a*, lattice constant; *n*, refractive index. (Note that there are variations in the values of certain properties among books *e.g.* n_i for Si, ε_r for GaAs *etc.* Most commonly used or recent values have been selected.)

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