OLLSCOIL NA hÉIREANN, CORCAIGH
THE NATIONAL UNIVERSITY OF IRELAND, CORK

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2011

B.E. DEGREE (ELECTRICAL & ELECTRONIC)

OPTICAL ELECTRONICS
EE4007

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Time Allowed: *3 hours*

FOUR QUESTIONS TO BE ANSWERED, AT LEAST TWO FROM EACH SECTION.
USE SEPARATE ANSWER BOOKS FOR EACH SECTION

The use of Departmental approved non-programmable calculators is permitted.
The use of Log Tables and Graph paper are permitted.

Physical Constants:

Free electron mass, m_0 = 9×10^{-31} kg
Planck's constant, h = 6.626×10^{-34} J s
Electronic charge, q = 1.602×10^{-19} C
Boltzmann's constant, k_B = 1.38×10^{-23} J K^{-1}
Room temperature = 300 K
Speed of light in free space, c = 3×10^{8} m s^{-1}

SECTION A

1. **a.** Using diagrams where appropriate, explain how a light emitting diode (LED) operates. Your answer should include a discussion the principles of operation a diode, and for the LED the relationship between light output power and voltage and current. It should also explain where the energy being carried away in the form of emitted light came from, with reference to the band structure of the material in the junction. **(8)**

b. A high brightness blue LED using an InGaN active region is forward biased to give a current of 350 mA with a drive voltage of 3.2V. Using a so-called integrating sphere all the light emitted can be detected and in this case a power of 500 mW at a wavelength of 450 nm was measured.

i) What is the external efficiency of this device **(4)**

ii) What is the wall plug efficiency **(2)**

iii) Explain the difference between the two values calculated above. **(2)**

c. The InGaN active region normally is a quantum well sandwiched between layers of GaN. Due to the piezoelectric nature of the material and the strain in the well the conduction and valance band profile looks as shown in the figure below, ignoring the effects of band bending due to any applied bias. For this figure sketch the form of the ground (lowest energy) state electron and hole wavefunctions and suggest what will happen to the wavelength of emission and the quantum efficiency of an LED as the well width is varied. Explain clearly your reasoning in all parts of your answer.

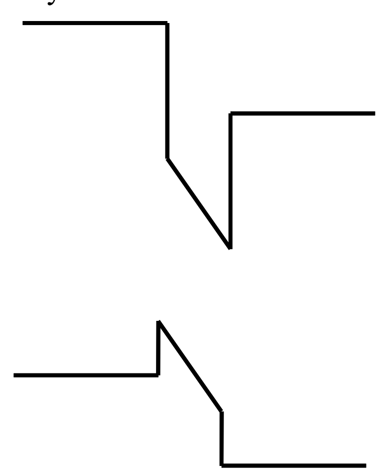

Figure Q1 **(4)**

2. **a.** Explain what is meant by doping and how this can modify the conductivity of a semiconducting material. **(4)**

b. As the temperature is increased from room temperature a semiconductor's conductivity may also change. Carefully explain the change in conductivity **(6)**

expected for:

i) An EXTRINSIC semiconductor

ii) An INTRINSIC semiconductor

e. At a time t=0 the profile of free carriers in an undoped semiconducting material with distance, x is given by:

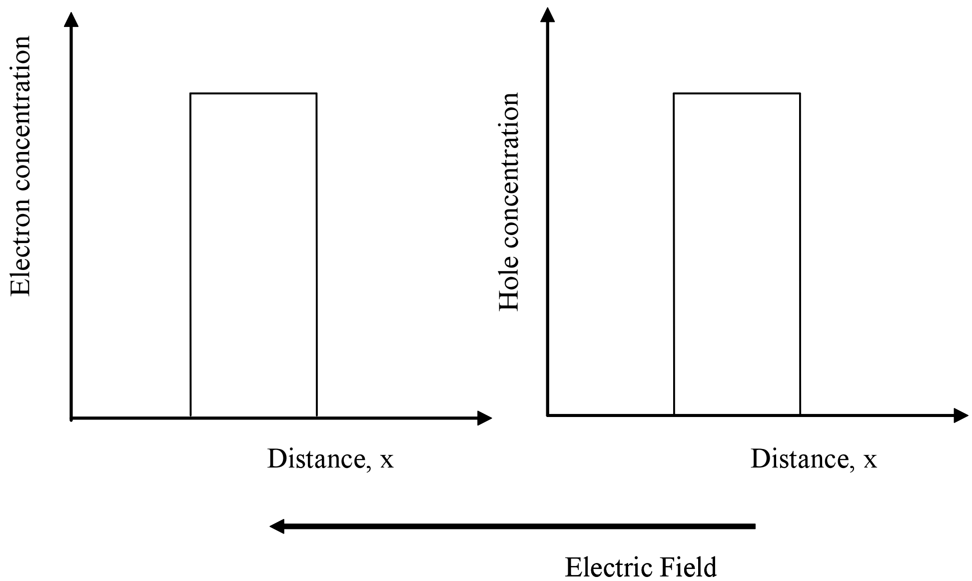

Figure Q2

The indicated electric field applies both to the electrons and holes where appropriate. Indicate how the concentration profiles of excess electrons and holes will evolve with time under the following assumptions, using diagrams and brief notes as appropriate:

i) Only diffusion occurs

ii) Only drift occurs

iii) Only recombination occurs

In each case your answer should highlight any similarities and differences between the behaviour of electrons and holes.

[Note: It is recognised that the three processes could not occur separately in practice. However, the aim here is to test understanding of the properties of each process in isolation] **(10)**

3. **a.** i) Explain briefly why a cavity is required in order to achieve laser action

ii) Show that the optical gain per unit length at laser threshold, g_{th}, is equal to.

$$g_{th} = \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

Where R and L are the mirror reflectivities and cavity length respectively. **(6)**

b. A graded index separate confinement heterostructure (GRINSCH) semiconductor laser structure operates at a glass fibre optics communications wavelength.

i) Calculate the mirror reflectivity, assuming it is simple given by Fresnel reflection,

ii) Hence using your own assumption for the cavity length estimate the threshold gain for the device. **(5)**

c. For your laser in part (b) calculate the wavelength spacing between the allowed laser modes. **(4)**

d. Briefly describe why multimode behaviour can occur in a semiconductor laser and suggest one method to prevent it. **(5)**

SECTION B

4. (a) Draw and label a block-diagram representation of a broadcast optical communication system. [*4 marks*]

   (b) Explain the following terms:

      i. Modal distortion
      ii. Polarisation mode dispersion
      iii. Bit-error rate
      iv. Fibre attenuation
      v. Link margin

   [*5 marks*]

   (c) A semiconductor laser operating at 1.55 μm is used in a digital optical communications network. If the average power from the laser is 5 dBm and the data rate is 10 Gb/s, how many photons are there per bit of information? [*6 marks*]

   (d) To increase the maximum length of a fibre optic link, is it more advantageous to use a lower loss fibre, use a more powerful transmitter or a more sensitive receiver? Justify your answer. [*5 marks*]

5. (a) Describe in *detail* the main causes of attenuation in silica glass fibres. [*7 marks*]

   (b) Describe *three* factors influencing the choice of source and fibre for short-haul (local-area) optical communications networks versus long-haul optical communications networks. [*7 marks*]

   (c) Explain *briefly* the following:

      i. Optical time domain reflectometry (OTDR)
      ii. Dense wavelength division multiplexing (DWDM)
      iii. Dispersion-shifted fibre

   [*6 marks*]

6. (a) Calculate the reflectance at normal incidence for a ray of light striking a plane glass surface. (refractive index for air = 1, glass = 1.5). What is the value of the reflection coefficient? [*4 marks*]

   (b) What is meant by s-polarisation and p-polarisation? [*4 marks*]

   (c) What is the definition of the Brewster angle? What value does the Brewster angle have for the air/glass interface? [*4 marks*]

   (d) If air/glass/air were used to form a symmetric slab waveguide, what thickness should the glass be to guarantee single mode operation at a wavelength of 650 nm? [*4 marks*]

   (e) What is the critical angle for the waveguide described in part (d)? [*4 marks*]