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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2008

B.E. DEGREE (ELECTRICAL)
HIGHER DIPLOMA IN PHYSICS

OPTICAL ELECTRONICS
EE4007

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Time Allowed: *3 hours*

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

SECTION A

1. (i) A power meter and an optical spectrometer are employed to monitor the output of a laser. Describe in detail the main characteristics of the emerging radiation recorded by both instruments as the laser medium is pumped from below to above threshold.

[*8 marks*]

(ii) The laser system shown schematically in Fig.1 below operates at a wavelength of 0.4 microns. Only state 2 (the upper laser level) is pumped directly from the ground state (0 state) with a pump rate R_2 $(cm^{-3}/\text{sec.})$. The upper laser level has a lifetime $\tau_2 = 0.2\mu\text{sec}$ and a spontaneous lifetime of 10^{-6} sec. Atoms in state 1 have a lifetime of 50*ns*. The transition line width is 60 *GHz* and the laser medium fills the optical cavity in the manner shown. Assuming steady state conditions:

(a) What is the stimulated emission cross-section at line centre?

[*3 marks*]

(b) What is the threshold gain coefficient? (Use the mirror reflectivity values shown in Fig.1 below).

[*3 marks*]

(c) What is the pump rate R_2 that brings the laser to threshold?

[*3 marks*]

(d) What is the cavity lifetime?

[*3 marks*]

(Assume the refractive index of the active laser medium is unity)

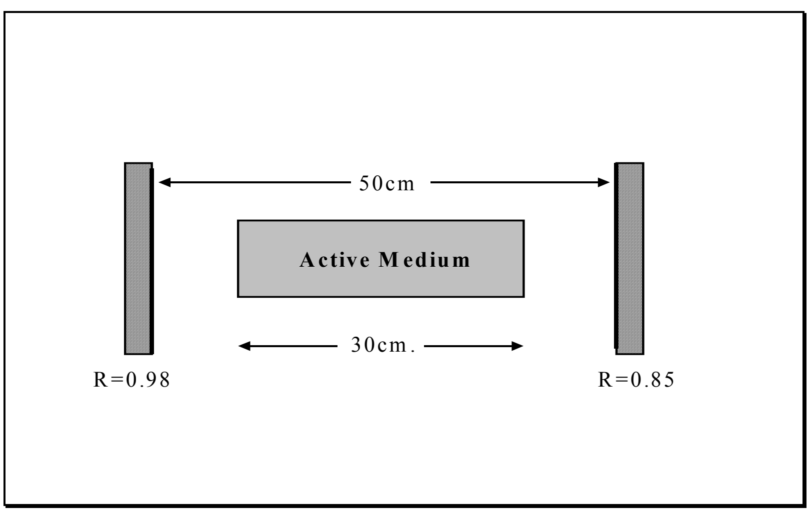

Fig.1.

2.

(a) In the context of lasers, what is the <u>significance</u> of the following terms?

- Threshold gain-coefficient
- Cavity lifetime
- Mode volume

(use appropriate equations and diagrams to illustrate your answer in each case)

[6 *marks*]

(b) Write the equation that describes the stability condition for optical resonators and draw the stability diagram in terms of the *g-parameters*.

[2 *marks*]

(c) Starting with the familiar equations for Gaussian beam propagation, derive an equation for the beam waist in the case of the *confocal* resonator. Express your answer in terms of the length of the resonator and the wavelength of the radiation.

[4 *marks*]

(d) An optical resonator is formed using large radius of curvature mirrors separated by a distance *L*. Assume that both mirrors have the same radius of curvature (*R*) and that the relation $R/L = 10$ applies. Determine the percentage increase in mode volume of this resonator in comparison to the confocal resonator of similar length.

[8 *marks*]

3.

Two concave mirrors of radii of curvature 1*m* and 1.5*m* form an optical cavity. Find the range of values of mirror separation (*L*) which will make the cavity:
(a) Stable.
(b) Unstable.
(c) Marginally stable.

[12 *marks*]

A Gaussian beam from a laser operating at 1.06 microns wavelength is focused with a 0.3*m* focal length lens. The beam emerges from the laser through its output mirror with a beam waist diameter (at the $1/e^2$ intensity points) of 3 *mm* and the lens is 1*m* from the output mirror. Calculate the diameter of the focused beam and its exact location (to the nearest mm) relative to the lens position.

[8 *marks*]

4.

(a) In relation to laser safety matters, define the following terms:

- Designated Laser Area (*DLA*).

- Maximum Permissible Exposure (*MPE*).
- Nominal Hazard Zone (*NHZ*).

[6 *marks*]

(b) List the three main control measures to prevent exposure to dangerous levels of laser radiation.

[4 *marks*]

(c) Apart from exposure to the beam, list other possible non-beam hazards associated with laser systems, and provide some general guidelines for the design of Class 3B and Class 4 laser facilities.

[4 *marks*]

(d) A helium-neon laser ($\lambda = 0.6328\mu m$) has an output power of 10 mW and an output beam diameter of $2mm$ ($1/e^2$ intensity points). A spectator located $100m$ from the laser in an outdoor laser display show receives an accidental eye exposure (corresponding to the natural "blink-reflex" of the eye) to the beam. The *MPE* in terms of beam irradiance is $2.54 mWcm^{-2}$ for accidental viewing of visible radiation. Assuming that the radiation emerging from the laser propagates as a Gaussian beam, perform a simple computation to ascertain if the spectator has exceeded the *MPE*.

[6 *marks*]

SECTION B

5. (a) Calculate the link margin for the system specified in the diagram below. [*8 marks*]

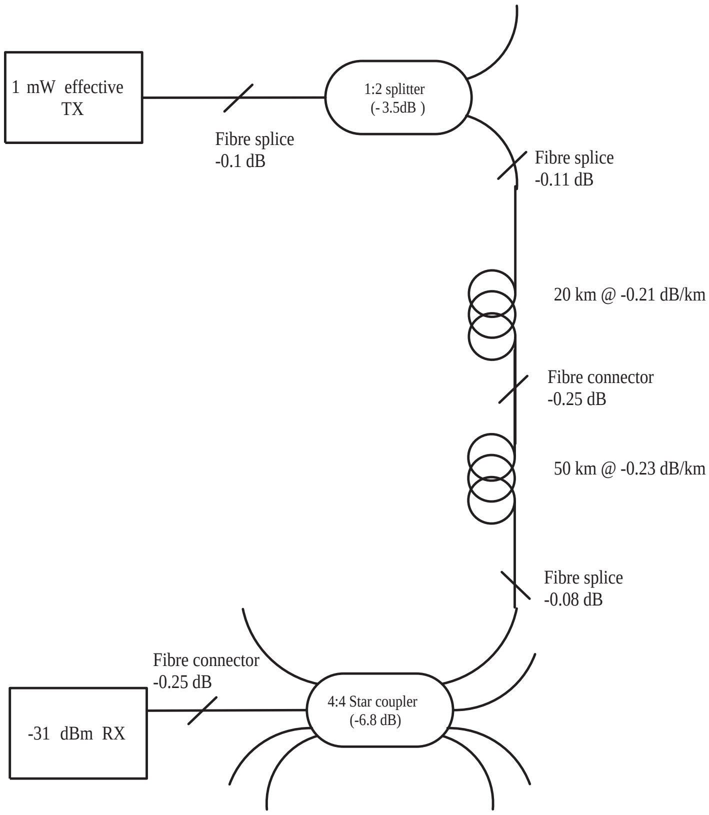

Figure 1:

(b) Explain the following terms:

i. Modal distortion
ii. material dispersion
iii. soliton
iv. Fibre attenuation
v. Link margin

[*5 marks*]

(c) If the material dispersion for silica is 110 ps/nm.km at 820 nm and 15 ps/nm.km at 1.5 μm determine whether it is more advantageous to use an 820 nm LED having a spectral linewidth of 10 nm or a 1550 nm LED having a 60 nm spectral width. Justify your answer numerically. What will be the total pulse spreading for each LED if the link length is 25 km? [*7 marks*]

6. (a) It is required to design an integrated optic directional coupler with two thirds of the power going to one output port and one third to the other. The coupling length is given as 3 cm. What should be the length of the coupling region?

[*7 marks*]

(b) A fibre has an NA = 0.2588. A light source is coupled to this that will emit 75 % of its light into a 60° full-cone angle, 50 % into a 30° cone and 25 % into a 15° cone. What is the coupling efficiency when this source and fibre are connected?

[*6 marks*]

(c) A fibre has a core refractive index of 1.5 and a cladding refractive index of 1.49, and a core diameter of 50 μm. Consider the guided ray travelling at the steepest angle with respect to the fibre axis. How many reflections are there per meter for this ray? [*7 marks*]

7. (a) Draw the simplified band diagram for Silicon and GaAs. Label the Γ, X and L valleys, the heavy-hole band, the light-hole band and the split-off band. [*4 marks*]

(b) Outline three advantages of III-V semiconductors over silicon in the design and fabrication of light emitting diodes. [*6 marks*]

(c) A single quantum well double heterostructure laser diode is to operate at λ = 855 nm. The quantum well is infinitely deep and the well material has a bandgap energy of 1.2 eV. If the electron effective mass and the heavy-hole effective mass were both one tenth of the free electron mass, what width should the quantum well be to provide the required emission wavelength? [*10 marks*]

8. (a) Outline the main factors affecting the extraction efficiency of light from an LED

[*4 marks*]

(b) Describe with the aid of diagrams two techniques for improving the extraction efficiency from an LED. [*4 marks*]

(c) Describe the use of GaP as an LED material for green, yellow and red light emission. [*6 marks*]

(d) Explain concisely the operation of biased p-n junction LEDs and outline their main advantages and disadvantages.

[*6 marks*]