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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

SUMMER EXAMINATIONS, 2003

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 a Casio fx570w or fx570ms calculator is 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. (a) A power meter and 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*]

(b) The laser system shown schematically in Figure 1 below operates at a wavelength of 0.4μm. Only state 2 (the upper laser level) is pumped directly from the ground state (0 state) with a pump rate R_2 (cm^{-3} s^{-1}). The upper laser level has a lifetime $\tau_2 = 0.2\mu s$ and a spontaneous emission rate to state 1 (lower laser level) of 10^6 s^{-1} . 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:

i. What is the stimulated emission cross-section at line centre? [*3 marks*]
ii. What is the threshold gain coefficient? (Use the mirror reflectivity values shown in Figure 1 below). [*3 marks*]
iii. What is the pump rate R_2 that brings the laser to threshold? [*3 marks*]
iv. What is the cavity lifetime? [*3 marks*]

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

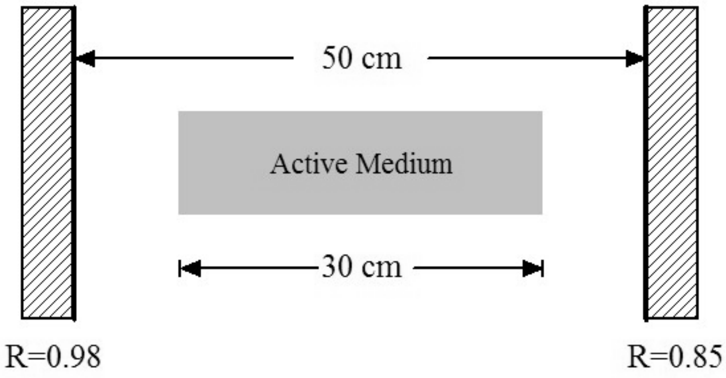

Figure 1:

2. (a) What is the physical significance of the following terms in the context of lasers?

- Longitudinal mode spacing
- Cavity lifetime
- Mode volume

[*6 marks*]

(b) A helium-neon laser (λ = 0.63 μm) operating in the fundamental Gaussian mode has mirrors separated by 0.3 m. The transition line-width $\Delta\nu$ = 1.5 GHz and the effective refractive index of the gain medium is 1. Assume that the gain medium fills the optical cavity. The output mirror is flat and the other mirror is spherical with a radius of curvature of 17 m. The reflection coefficient of the spherical mirror is 1 and the flat output coupling mirror has a reflectivity of 0.98. The spontaneous lifetime of the optical transition is 10^{-7} s.

i. What is the frequency difference between longitudinal modes in the optical resonator? [*2 marks*]
ii. Show that the resonator is stable. [*2 marks*]
iii. What is the threshold gain coefficient in cm^{-1}? [*2 marks*]
iv. What is the stimulated emission cross-section? [*2 marks*]
v. What is the spot size on the flat mirror? [*3 marks*]
vi. What is the Gaussian beam diameter at a distance of 20 m from the output mirror? [*3 marks*]

3. (a) Two spherical mirrors with radii of curvature 1 m and 2.5 m are available to form an optical cavity. Find the range of values of mirror separation L, which will make the cavity:

- Stable
- Marginally stable
- Unstable

[*6 marks*]

(b) A carbon dioxide laser (λ = 10.6 μm) employs an optical resonator using a spherical and a flat mirror. The fundamental Gaussian beam emerges from the resonator through the flat mirror with a beam diameter of 4 mm. The beam encounters a thin convex lens of focal length 0.3 m placed a distance of 1 m from the flat mirror. Determine the beam waist diameter of the focused beam at the other side of the lens and its location relative to the lens position. [*8 marks*]

(c) A circular aperture of 1 mm diameter is placed at the exact focused position of the beam in (b) above. What fraction of the incident power is coupled through this aperture? [*6 marks*]

4. (a) The Q-switching technique as applied to laser systems is capable of generating very large peak output powers. Give an outline of the technique and describe two typical Q-switching methods. [*5 marks*]

(b) A laser at λ = 1 μm, which is to be Q-switched, has an initial population inversion at 10^{18} atoms, a factor of 3 above the threshold value required for continuous wave (CW) oscillation in a high Q-cavity. The dominant photon loss within the cavity is coupling through one mirror to the outside world at a rate of 5×10^{7} s^{-1}. The population inversion after the Q-switched pulse is over is 6×10^{16} atoms.

i. Find the peak power output of the laser. [*5 marks*]
ii. Find the output energy in the Q-switched pulse. [*5 marks*]
iii. Estimate the pulse width. [*5 marks*]

SECTION B

5. (a) Draw a block-diagram representation of a repeaterless long-haul fibre optic communication system. Label each block and list two types of amplifier that may be used to maintain the signal strength in such a 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*]

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 Brewster angle? What value is the Brewster angle 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*]

7. (a) Why is silicon a poor emitter of light? [*4 marks*]

   (b) Why is the external quantum efficiency for a light emitting diode (LED) significantly less than the internal quantum efficiency? Give one solution to improving the external quantum efficiency. [*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) Illustrate the Responsivity as a function of wavelength for an ideal and a real photodiode and explain the differences. [*5 marks*]

(b) Describe the operation of the p-i-n photodiode, paying particular attention to the quantum efficiency and speed of operation. [*5 marks*]

(c) A photodiode having a circular active area of 1 cm radius has a responsivity of 0.55 A/W to light at 633 nm. The noise equivalent power for the photodiode is 2.5×10^{-12} W $\mathrm{Hz}^{-1/2}$. This photodiode is to be used in a LIDAR (Light detection and ranging) system in conjunction with a He-Ne laser having a non-divergent beam with 5 mW average output power. Assume no attenuation of the laser light, a bandwidth of 1 Hz and assume the target is a perfect diffuse reflector (i.e. reflected light is scattered uniformly in all directions) - what is the maximum target distance that can be measured in this system? What is the photocurrent produced? [*10 marks*]