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

COLÁISTE NA hOLLSCOILE, CORCAIGH
UNIVERSITY COLLEGE, CORK

AUTUMN EXAMINATIONS, 2006

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

OPTICAL ELECTRONICS
EE4007

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Dr. A.P. Morrison

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.
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) Write coupled rate equations for the population inversion and the photon number for an idealized 4-level laser system (assume that the relaxation from the lower laser level is so fast that the approximation $N_1 \approx 0$ applies). Justify the inclusion of the various terms appearing in your equations.

[6 *marks*]

(b) Under steady state conditions show that the population inversion (above the threshold value for laser oscillation) remains clamped at the threshold value.

[4 *marks*]

(c) A $Nd^{3+}:YAG$ laser has the following parameters: $\lambda = 1.06\mu m$, $t_{spon.} = 0.55ms$, $\Delta\nu = 120GHz$ and refractive index $n = 1.82$. Assuming a cavity lifetime (τ_c) of $20ns$, find the threshold population inversion density.

[6 *marks*]

(d) Determine the power in Wcm^{-3} given off by spontaneous emission just below threshold in (c) above.

[4 *marks*]

(Velocity of light $= 3\times10^{8}\ ms^{-1}$, Planck's constant $h = 6.62\times10^{-34}\ J-s$)

2. Lasers are normally divided into 3-level and 4-level systems. Discuss this statement and draw appropriate energy level diagrams to illustrate your answer. Estimate the relative pump power requirements to achieve population inversion in each case.

[4 *marks*]

A Helium-neon laser ($\lambda = 0.6328\mu m$) operating in the fundamental transverse mode has mirrors separated by 0.3 m. The transition line-width $\Delta\nu$ (full width at half-height) is 1.5 *GHz* and the cavity mirrors have power reflection coefficients of 0.995 and 0.98.

(a) What is the frequency difference between longitudinal modes in the resonator?

[2 *marks*]

(b) How many longitudinal modes are within $\pm\Delta\nu/2$ of line centre?

[3 *marks*]

(c) The energy of the upper pumped state is 20.6 electron volts above the ground state. What is the quantum efficiency of the laser?

[3 marks]

(d) Find the stimulated emission cross-section at line-centre given that $A_{21} = 6.5\times10^{6}$ $\sec^{-1}$ (A_{21} represents the Einstein coefficient for spontaneous emission).

[3 *marks*]

(e) What is the cavity lifetime in nanoseconds?

[5 *marks*]

(Use the following information: electronic charge $= 1.602 \times 10^{-19} C$, Planck's constant $= 6.62 \times 10^{-34}\ J-s$, velocity of light $= 3 \times 10^{8}\ ms^{-1}$)

3. Write the two fundamental equations for Gaussian beam propagation in free space, and derive an expression for the beam size at either mirror of the confocal resonator in terms of the wavelength and the mirror separation.

[4 *marks*]

Given two mirrors of radius of curvature 1m and 1.5m, find the range of values of mirror separation L, which will make a stable cavity.

[5 *marks*]

A Gaussian beam from an argon ion laser operating at 514nm is focused with a 50cm focal length convex lens. The beam emerges from the laser with a beam waist (defined at the $1/e^2$ points of the intensity profile) diameter of 2mm and the lens is 1m from the position of the waist. Calculate the exact location of the focused spot (in mm.) and its size relative to the lens position.

[7 *marks*]

A circular aperture of 200 microns in diameter, concentric with the beam, is placed at the exact focused position. What fraction of the incident power is coupled through this aperture?

[4 *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 $\lambda = 1.0\mu m$, which is to be Q-switched, has an initial population inversion at 10^{18} atoms, a factor of 5 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 $5 \times 10^{7} s^{-1}$. 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) Calculate the link margin for the system specified in the diagram below. [*8 marks*]

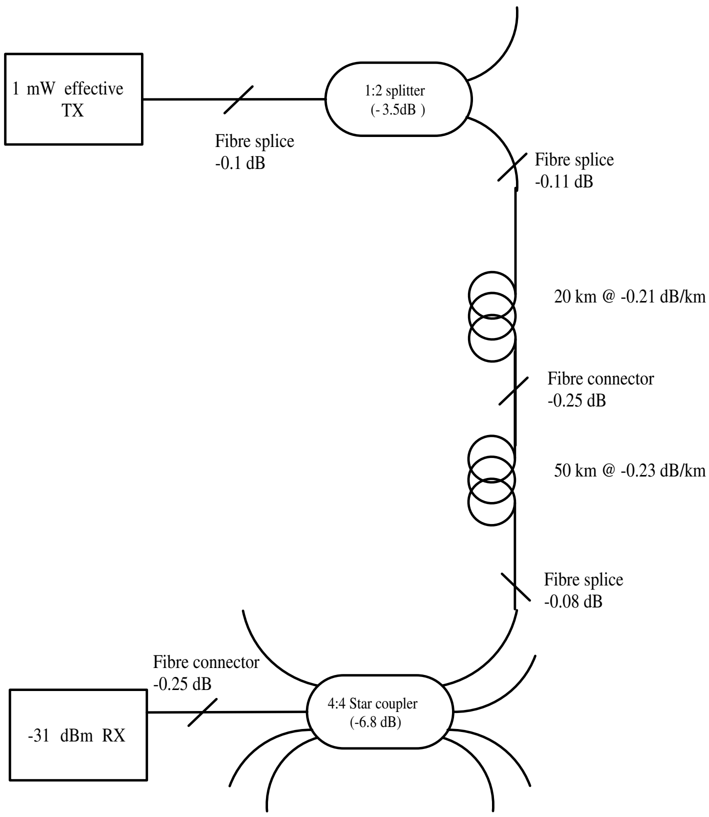

Figure 1:

(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) List five differences between Light-emitting diodes (LEDs) and Laser diodes.

[*4 marks*]

(b) Show using diagrams the physical effect compressive strain and tensile strain has on a mismatched epi-layer. Is the epi-layer lattice constant greater or smaller than that of the substrate for tensile strain to occur?

[*4 marks*]

(c) List suitable semiconductor materials for light emission at wavelengths around 650 nm, 780 nm, and 1300 nm. (one of each).

[*3 marks*]

(d)) A GaAs/AlGaAs LED has an activation barrier of energy E_d = 0.6 eV to long-term degradation. If the prefactor in the Arrhenius equation describing the degradation rate is C = 250 hour^{-1}, find the time after which the ouptut radiant power will fall to half its initial value, assuming room temperature (25° C) operation.

[*9 marks*]

8. (a) Explain the term Noise Equivalent Power (NEP) with reference to semiconductor photodetectors. [*5 marks*]

(b) Describe the process of impact ionization as applied to avalanche photodiodes. How does this provide internal gain? What is the advantage of internal gain in the photodiode? [*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 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*]