OLLSCOIL NA h-ÉIREANN

THE NATIONAL UNIVERSITY OF IRELAND

COLAISTE NA h-OLLSCOILE, CORCAIGH

UNIVERSITY COLLEGE, CORK

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B.E. DEGREE (ELECTRICAL)

HIGHER DIPLOMA IN PHYSICS

OPTOELECTRONICS (EE4007)

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3 hours

Five Questions to be answered, at least two from each section.
USE SEPARATE ANSWER BOOKS FOR EACH SECTION

The use of approved electronic calculators is permitted.

Mass of a free electron: $m_o = 9.0 \times 10^{-31}$ Kg

$h/2\pi = 1.05\ 10^{-34}$ Js

charge of an electron: $e = 1.6\ 10^{-19}$ C

Questions follow overleaf/...

SECTION A

Q.1. Lasers can be classified into so-called 3-level and 4-level systems. Discuss this statement paying particular attention to the configuration of the energy levels involved, and to the input pump power requirements to achieve threshold conditions in each case. Starting with the familiar simplified 4-level rate equations:

$$\frac{dN_2}{dt} = R_p - \frac{N_2}{\tau_2} - KnN_2 \qquad \text{and} \qquad \frac{dn}{dt} = KN_2(n+1) - \frac{n}{\tau_c}$$

show, using certain simplifying assumptions, that the cavity photon numbers can be expressed in terms of a normalised pumping rate ($r = R_p/R_{th}$) and the mode number.

In particular, show (a) that the photon numbers build-up dramatically with pump rate as threshold is approached, and (b) that the population inversion is clamped at the threshold value.

Q.2. By considering the process of amplification of an electromagnetic wave of intensity I_ν with an inverted atomic system, show that the gain coefficient, $\gamma(\nu)$, where ν is the frequency, can be expressed in the following manner:

$$\gamma(\nu) = \frac{1}{I_\nu}\frac{dI_\nu}{dz},$$

where the distance z is measured along the direction of propagation. Hence, show that the gain coefficient is proportional to the population inversion and determine the multiplying constant.

The cavity shown below is utilised with a He/Ne laser, $\lambda = 0.6328\mu m$.

(i) Is the cavity stable?

(ii) What is the Gaussian beam waist at the plane mirror?

(iii) What is the beam radius at the curved mirror?

(iv) Comment on the polarisation state of the output radiation.

(v) What is the longitudinal mode spacing? ($c = 3\times10^8 ms^{-1}$)

(vi) Assuming zero internal losses, what is the minimum gain coefficient for laser action? (Assume mirrors M1 and M2 have power reflectivities of 0.995 and 0.98, respectively)

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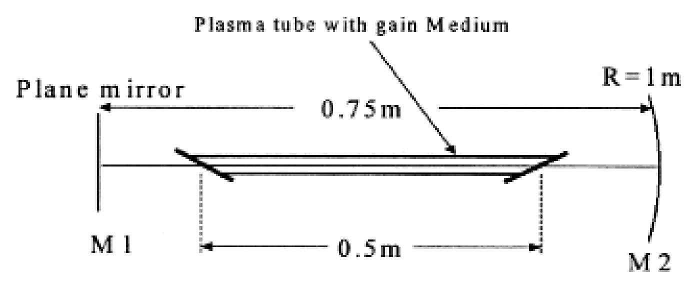
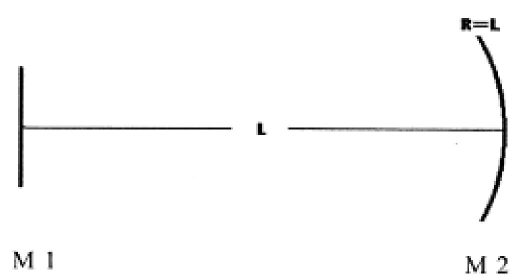


Q.3. Write (a) the stability equation for an optical cavity, and (b), the equations for Gaussian beam propagation, namely, the equations for beam size and radius of curvature.

Two concave mirrors of radii of curvature 9m and 10m form an optical cavity. Determine the mirror spacings for which the cavity is stable.

An almost hemispherical cavity can alter the spot size on the curved mirror by a small displacement ε, of the plane mirror from the exact hemispherical condition (shown below). Derive an expression for the variation of this spot size in terms of the displacement ε (assume $\varepsilon \ll L$).



Q.4. Describe the technique of Q-Switching as applied to laser systems.
During the pumping process, and prior to opening the Q-switch, show that no advantage is to be gained by applying pump power for longer than a few lifetimes of the upper state. (Assume the pumping takes place at a constant rate).

With the Q-switch opened at $t = 0$, use the pair of coupled equations:

$$\frac{dN}{d\tau} = -2n\frac{N}{N_{th}} \text{ and } \frac{dn}{d\tau} = n\left(\frac{N}{N_{th}} - 1\right),$$

to derive expressions for:

(a) The number of photons in terms of the inversion.
(b) The output power of the Q-Switched pulse.
(c) The energy in the pulse.

Where N is the population inversion, n is the cavity photon numbers, N_{th} is the threshold inversion and $\tau = t/\tau_c$ is the time in units of cavity lifetime (τ_c).

SECTION B

Q. 5.

The spontaneous emission rate (r_{spon}) in a semiconductor can be simply described by:

$r_{spon} = A\, n\, p$

where n and p are the sums of the background and excited carrier densities for electrons and holes respectively, i.e. $n = n_o + \Delta n$ and $p = p_o + \Delta p$, and A is the material dependent recombination constant.

(i) Show that for the case of minority carrier injection ($n_o > p_o$) that the recombination life-time τ is given by $\tau = 1/(A\, n_o)$ while for strong injection ($\Delta n > n_o, p_o$) $\tau = 1/(A\, \Delta n)$

[continued over/...]

(ii) Calculate the recombination life-times for a GaAs and Si n^+p homojunction light emitting diode (LED) for a doping density of $5x10^{18}$ cm^{-3} on the n^+ side. Hence calculate the internal quantum efficiency of each diode if the non-radiative life-time is 2 $x10^{-9}$ s for each material. (A = $1.79x10^{-15}$ cm^3 $s^{-1}$and $7.21x10^{-10}$ cm^3 s^{-1} for GaAs and Si respectively.

(iii) With reference to your answer in section (ii) briefly explain the physical reasons why the recombination life-times are so different and hence why Si makes such a poor LED.

(iv) Give two reasons why the external efficiency will differ from the internal quantum efficiency for a LED.

Q.6

Consider a GaAs p-n^+ junction light emitting diode (LED) with the following parameters at 300 K:

Electron Diffusion Coefficient:	$D_n = 25\ cm^2/s$
Hole Diffusion Coefficient:	$D_p = 12\ cm^2/s$
n-Doping:	$N_d = 5x10^{17}\ cm^{-3}$
p-Doping:	$N_a = 1x10^{16}\ cm^{-3}$
Electron diffusion length:	$L_n = 5x10^{-4}$ cm
Hole diffusion length:	$L_p = 3.46x10^{-4}$ cm
GaAs Band-Gap:	$E_g = 1.42$ eV

(i) Sketch the band diagram of the p-n^+ junction both in equilibrium and in forward bias. For the forward bias condition indicate clearly where you would expect most photons to be generated and indicate how the minority carrier densities vary throughout the junction.

(ii) Justify the use of quasi Fermi levels in the forward biased diode by comparing approximate values for the life-times of electron/hole relaxation by phonon emission and electron-hole recombination.

(iii) This LED is to be used to generate an optical power of 1 mW. If the total area of the diode is 1 mm^2 and has an external efficiency of 20%, calculate the forward bias required.

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(iv) Briefly describe two factors that reduce the external efficiency for this LED and make suggestions of how the LED's design could be altered to improve the efficiency.

Q.7

(i) Give three reasons why the long haul transmission of data is performed using optical fibres and explain the preferred use of 1.3 μm and 1.55 μm wavelengths.

(ii) Explain the phenomena of modal and material dispersion in reference to digital data transmission in optical fibres.

(iii) Using sketches explain what are meant by lateral, transverse and longitudinal modes of a semiconductor laser. What implications do these modes have for the use of semiconductor lasers in optical fibre communication.

(iv) In what way do compact disc lasers differ from telecommunications lasers and explain why.

(v) Describe which semiconductor materials are used for telecommunication lasers and compact disc lasers.

Q.8

(i) Explain how (i) carrier confinement, (ii) optical confinement and (iii) optical feedback are achieved in a double heterojunction (DH) laser.

(ii) Sketch a series of curves showing how the gain in the DH laser's active region varies with energy and injected carrier density.

(iii) Derive expressions for the density of states for a bulk semiconductor and a quantum well and draw sketches of the results.

(iv) Explain the advantages of quantum well active regions in lasers over bulk active regions.