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NATIONAL UNIVERSITY OF IRELAND
UNIVERSITY COLLEGE
GALWAY

SEMESTER 1 (WINTER) EXAMINATIONS 2000/2001

B.Sc. (Honours)
Applied Physics and Electronics
Experimental Physics
Physics & Computing

Paper I: Optoelectronics (EP408)

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Time allowed : TWO hours.
Answer THREE questions.

Q.1 In the case of one of the laser types given below, describe with as much quantitative detail as possible (i) the energy level structure in the active medium, (ii) the method used to obtain population inversion, (iii) the spectral characteristics of the output, and (iv) the physical construction and typical output power. State, giving your reasons, whether the output can be Q-switched or spectrally tuned. Survey the principal applications of the laser you have chosen and describe one application in detail.

(a) CO_2 laser
(b) He-Ne laser or Argon ion laser
(c) Semiconductor diode laser
(d) Nd-YAG or ruby laser.

Q.2 Write, with as much quantitative detail as you can, on two of the following topics;

(a) Acousto-optic techniques for modulating the intensity of optical beams.

(b) The mechanisms which cause broadening of optical transitions in gas discharges.

(c) Semiconductor diode lasers. Explain how the wavelength, mode structure, and beam divergence are influenced by the construction details.

(d) Optical Time Domain Reflectometry for optical fibre characterisation.

(e) The main requirements for the active medium in a light emitting diode. Explain how the spectral region from 450 nm to 1.5 μm can be covered by suitable choices of semiconductor material and dopants.

Q.3 Answer two of the following :

(a) Explain briefly the difference between radiometric and photometric units for light measurement. Estimate the radiance (in W cm $^{-2}$ sr $^{-1}$) of the following three sources :
(i) He-Ne laser with beam area 1 mm^2, output power 1 mW, and beam divergence 1 mrad.
(ii) a 100 watt lamp, of diameter 5 cm, at a distance of 1 m from the lamp.
(iii) the Sun, at a point on the Earth's surface.
(Solar constant = 1350 W m^{-2})

(b) When an electric field **E** is applied along the optic axis (the z-axis) of a crystal of $LiNbO_3$ (a uniaxial material), the refractive indices at λ = 632.8 nm for light polarised along the x and y axes are :

$$n_x = n_o + \beta E$$
$$n_y = n_o - \beta E$$

where n_o = 2.29 is the refractive index in zero field, and β = 1.9 x 10^{-10} m V^{-1}. Explain clearly how a $LiNbO_3$ crystal could be used to make an amplitude modulator for light of wavelength 632.8 nm and calculate the voltage for 100% modulation.

(c) Calculate the Doppler-broadened line-width for the 632.8 nm line on the He-Ne laser, assuming a laser discharge temperature of 120 °C. If the cavity length is 30 cm, in approximately how many longitudinal modes will the laser oscillate? Calculate the coherence length for this laser. What must the length of the cavity be to ensure that only one longitudinal mode can oscillate. (Molar mass of neon = 20.2 kg $kmol^{-1}$)

(d) Explain what is meant by the mode structure of a laser output beam. Sketch the intensity pattern for a few low-order transverse modes and describe in detail the TEM_{00} mode. Write down expressions for the radius of curvature and beam waist radius of this mode as a function of distance from the point of minimum beam waist. In what circumstances might these formulae be used ? Using a 10 cm focal length lens, to what diameter can a TEM_{00} beam from an argon ion laser (at 514 nm), with a diameter at the minimum beam waist of 1mm, be focussed in the diffraction limit ?

Q.4 Explain how optical signals may be propagated in silica fibres of suitable construction. Give an account of the various loss mechanisms in such fibres. Describe the various effects in fibres which limit their frequency response in optical communications and indicate how these limitations are overcome. List briefly the types of sources and detectors which are typically used in optical fibre communications systems.

An LED source launches 500 μW into a 30 km long fibre whose attenuation coefficient is 1 dB km^{-1}. Assuming an end-connector allowance of 3 dB and a system safety margin of 6 dB, calculate the power, in dBm, which a detector placed at the other end of the fibre must be capable of detecting.

Q.5 Give a general overview account of the principles of operation of the different types of optical detectors in general use.

An IR detector is to be used to monitor temperature changes in a flat plate 30 cm square (assumed to be a black body emitter, with emissivity = 1) which is located 3 m away from the detecting system. If the plate is at 100 °C, at approximately what wavelength is the peak of the blackbody emission spectrum ?

A narrow-band filter with peak transmission of 50%, centre wavelength of 2.3 μm, and bandwidth 0.1 μm, is mounted in front of the detector element which has an area 1x1 mm^2. A region of the target is imaged onto the detector using a lens (f = 50 mm, diameter 25 mm) placed 51 mm from the detector. Estimate the infrared power reaching the detector in the selected spectral band. Suggest a detector for this application.

The spectral radiance of a black-body at temperature T is given by

$$L_\lambda = \frac{1.192 \times 10^4}{\lambda^5}\left[\frac{1}{\exp(1.439 \times 10^4/\lambda T) - 1}\right] \mathrm{W\ cm^{-2}\ sr^{-1}\ \mu m^{-1}}$$