GX900

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SEMESTER 1 EXAMINATIONS 2002 - 2003

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

Paper I Optoelectronics (EP408)

4EL3-EP441-1, 4EL4-AX402-1,
4BS2-EP442-1, 4BS2-AX404-1

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Time allowed : TWO hours.
Answer THREE questions.

Q.1 Given the equations

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3 \mu^3}{c^3} \quad ; \quad g_1 B_{12} = g_2 B_{21}$$

relating, in the usual notation, the Einstein coefficients for a transition between two levels in a medium of refractive index μ, derive the expression for the frequency dependent gain coefficient $k(\nu)$

$$k(\nu) = \frac{c^2 \; A_{21}}{8\,\pi\,\mu^2\,\nu^2}\,[N_1 \; - \; N_2]\,g(\nu)$$

where $g(\nu)$ is the lineshape function and $\int g(\nu)d\nu = 1$. [6 marks]

For the 632.8 nm line in neon, $A_{21} = 5\text{x}10^6$ s^{-1}, and the Doppler width of the transition under operating conditions is 1500 MHz. The laser mirrors have reflectivities 100% and 98% at this wavelength. Ignoring other losses, estimate the population inversion per unit volume required to achieve threshold of oscillation at the centre of the 632.8 nm line in a He-Ne laser having L = 0.30 m. [4 marks]

Q.2 Explain briefly how optical signals can be propagated in silica fibres of suitable construction. [2 marks]

Describe how these fibres form the basis for optical communications networks, and give an account of the effects which give rise to signal dispersion and signal loss (intrinsic and extrinsic) in such networks. [4 marks]

Describe in detail the technique of optical time domain reflectometry (OTDR) and indicate clearly what information it provides about an optical fibre installation. [4 marks]

Q.3. Write, with as much quantitative detail as you can, on two of the following topics ;

(a) Explain the difference between the Raman-Nath and Bragg regime for acousto-optic modulation and sketch briefly the operation of a modulator in each regime. [5 marks]

(b) Explain the operation of a Nd:YAG laser, including the energy level structure, construction details, diode laser pumping, and the mechanisms for Q-switching and mode-locking. [5 marks]

(c) Give a brief overview account of the operation of semiconductor diode lasers, in particular the development of improved optical and carrier confinement in such lasers. [5 marks]

(d) Give the properties required in a material in order to make a light emitting diode. Explain how the spectral region from 400 nm to 950 nm can be covered by suitable choices of semiconductor material and dopants and explain why the internal and external efficiencies are so different. [5 marks]

(e) Discuss the transverse and longitudinal mode structure of laser emission and the techniques used for mode control. [5 marks]

(f) Discuss the physics of the compact disc readout head, giving typical construction details, data format and reading mechanism, and the techniques used for tracking and focusing. [5 marks]

Q.4 Give an overview account of the principle of operation of optical detectors. Use examples of thermal, photo-emissive, photo-conductive, and junction-type detectors to illustrate your answer. [4 marks]
Explain what is meant by the detectivity (D*) of a general optical detector. [1 mark]

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. 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. [5 marks]

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

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

λ is measured in μm and T in degrees Kelvin.]

Q.5. Answer **TWO** of the following :

(a) A GaAs junction laser has a 300 μm cavity length and an effective absorption coefficient of 3.5×10^3 m^{-1} at the lasing wavelength. The refractive index of the material is 3.6 and the end facets are uncoated. Calculate the optical gain coefficient at the lasing threshold, and the frequency separation, in MHz, between adjacent longitudinal modes in the output spectrum. The laser is driven by a square wave current pulse. Give a simple physical explanation for the time delay before emission occurs and explain what determines the response time of the light output when the current is switched off.

[5 marks]

(b) 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) a He-Ne laser beam, with a beam area of 1 mm^2, output power 1 mW, and a beam divergence of 1 mrad.

(ii) a 100 watt tungsten lamp, 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} ; angle subtended by the sun at the earth = 10 mrad.]

[5 marks]

(c) A 1.2 m long Argon ion laser is operating at 514.5 nm in the Gaussian (TEM_{oo}) mode and has a beam diameter of 0.5 mm at the beam waist, which is close to the (plane) output mirror. Calculate the radius of curvature required for the 100% mirror in order to match the curvature of the beam. Calculate also (i) the beam diameter, and (ii) the radius of curvature of the wavefront, at a point which is 100 m from the laser. Estimate the beam divergence of this laser and the approximate spot size obtainable with a convex lens of 100 mm focal length.

[5 marks]

(d) Derive the line-shape function for Doppler-broadening of an atomic transition in a gas and use it to calculate the Doppler line-width for the Argon laser transition at 488 nm, assuming a gas discharge temperature of 3000 K.

[5 marks]

[Atomic mass of Argon = 40 kg $kmol^{-1}$; Universal Gas Constant = 8314 J $kmol^{-1}$ K^{-1}.]