ENGINEERING TRIPOS PART IIA

Friday 11 May 2007 9 to 10.30

Module 3B6

PHOTONIC TECHNOLOGY

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

Attachment: Photonic Technology Data Sheet

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 (a) Describe the major processes by which electrical carriers and photons interact in semiconductor materials, explaining how they are used in optoelectronic components. [30%]

(b) A light emitting diode (LED) is to be constructed for operation at a wavelength of 1.3 μm.

(i) What structure might be used in the LED if it is to generate a beam that is particularly suitable for coupling into single mode optical fibres? [20%]

(ii) What bandgap should the semiconductor material in the active region have? [10%]

(iii) At a temperature of 20 °C, the LED material has a non-radiative lifetime of 3 ns. What must its radiative lifetime be limited to, if the overall response time of the LED is to be 2 ns? [10%]

(iv) On this basis, what must the external quantum efficiency of the device be if the overall quantum efficiency is to be 3%? [15%]

(v) The LED is to be operated at a current of 500 mA. What characteristic temperature should it have, if the output optical power must only reduce by 7 mW when the temperature is increased from 20 °C to 80 °C? [15%]

2 (a) Describe the structure of a Fabry Perot laser diode, explaining its advantages and disadvantages for general photonic applications. [30%]

(b) By considering the gain and loss encountered by light within a Fabry Perot laser cavity, and explaining any assumptions made, show that the photon lifetime may be written as

$$\tau_p = (\mu/c)\ \{\alpha + (1/L)\ \ln(1/R)\}^{-1}.$$

Give a clear definition of all the symbols used in the expression. [30%]

(c) Hence also derive an equation for the differential quantum efficiency of the Fabry Perot laser diode. [20%]

(d) A Fabry Perot laser is to be constructed to operate at a wavelength of 1.5 μm, with an effective refractive index of 3.6 and a scattering loss of 20 cm^{-1}. If the mode spacing of the device is to be 1 nm, determine the facet reflectivity required if the differential quantum efficiency is to be 80%. (Assume for this part of the question that the facet reflectivities are equal.) [20%]

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3 (a) Describe how a photoconductor can allow the detection of radiation at wavelengths in the mid-IR range (wavelengths of 2-10 μm). Explain the concept of photoconductive gain. [20%]

(b) Consider an optical communications system, carrying Ethernet signals, which operates at a data rate of 1.25 Gbit s^{-1} and uses a transmitter operating at a wavelength of 1300 nm. The receiver front end is to contain a photodetector connected to a high gain amplifier with a 250 Ω input impedance and a 1 GHz bandwidth. The operating temperature of the receiver is 20 °C.

(i) Two possible photodetectors are under consideration for use in the receiver circuit: a *pin* photodiode and an avalanche photodiode. Discuss the advantages and disadvantages of the two components for this application. Describe the noise processes that will occur in the receiver circuit using these two photodetectors. [20%]

(ii) The *pin* photodiode has a quantum efficiency of 85% and a dark current of 1 nA. Calculate the signal to noise ratio at the output of the circuit for an optical input signal power of 3.16 μW. [25%]

(iii) The *pin* photodiode is replaced by an avalanche photodiode with a quantum efficiency of 85%, a dark current of 10 nA and an excess noise factor $F = M^{0.5}$, with all other circuit parameters remaining the same. Find the optimum value of avalanche gain and the resulting output signal to noise ratio. [35%]

4 (a) Explain why optical fibres are the transmission medium of choice for very high data rate communications. Describe the construction, with approximate dimensions, of step-index multimode fibre, graded-index multimode fibre and step-index single mode fibre types for this application. [25%]

(b) The numerical aperture of a step-index optical fibre is given by the expression:

$$\mathrm{NA} = \sqrt{n_1^{\,2} - n_2^{\,2}}\ .$$

where n_1 and n_2 are the core and cladding refractive indices, respectively. Derive this expression from first principles and explain its significance. [25%]

(c) A step-index optical fibre is to be manufactured from two glasses which have refractive indices of 1.45 and 1.43. Design the fibre core dimension so that it is single mode at a wavelength of 1550 nm. [10%]

(d) The fibre in (c) above is found to have an attenuation of 0.3 dB km^{-1} and a dispersion of 18 ps nm^{-1} km^{-1}. It is to be used as part of an optical communication system operating at a data rate of 10 Gbit s^{-1}. The transmitter has an optical bandwidth of 0.1 nm and launches an average power of 2 dBm into the fibre. An optical amplifier, with a gain of 12 dB, is to be placed half way along the link. The link contains two fibre connectors, each with a loss of 0.4 dB, and three fibre splices, each with a loss of 0.2 dB. The receiver has a sensitivity of –28 dBm and the system is required to have a margin of at least 3 dB. Calculate the maximum link length that is achievable using this fibre. You may assume that electronic dispersion equalisation is used in the receiver such that the dispersion limit is reached when a single "one" is broadened by the fibre to 3 times its original width. [40%]

END OF PAPER