UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIA

Friday 7 May 2004 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:
Special datasheet (1 sheet)

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

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1 (a) Describe the principle of operation and typical structure of a surface-emitting light emitting diode. [40 %]

(b) A light emitting diode is to be used within a data communications link operating at a wavelength of 1.3 μm. The device has an internal quantum efficiency of 60 %. If the light emitting diode has an external quantum efficiency of 4 % and a forward resistance of 2 Ω, what voltage must be applied across the device to generate an output power of 5 mW? [25 %]

(c) If the non-radiative recombination lifetime in the diode is 3 ns, determine the radiative recombination lifetime and hence the overall carrier lifetime of the device. [20 %]

(d) Describe how the risetime of an optical pulse generated by a light emitting diode might be reduced by modifying the electrical modulation, and hence how this technique can be used to increase the achievable bit rate in communication applications. [15 %]

2 (a) Briefly explain why optical confinement and feedback are required to ensure efficient operation of diode laser structures. Illustrate your answer by sketching a typical simple stripe Fabry Perot laser diode. [35 %]

(b) A stripe Fabry Perot laser diode operates at a wavelength of 1.5 μm. By deriving an equation which relates longitudinal mode spacing to cavity length, determine the mode spacing if the device has an effective refractive index of 3.6 and a length of 400 μm. [25 %]

(c) The diode laser has a characteristic temperature, T_o, of 90 K and an activation energy of 0.7 times the bandgap energy. Under normal conditions, the device operates at a temperature of 20 °C and exhibits a threshold current of 40 mA. Determine what reduction in lifetime and increase in threshold current would occur if the operating temperature was to rise by 20 °C. [20 %]

(d) Explain what alternative transverse confinement structures could be used which would dissipate lower power and exhibit better temperature performance. [20 %]

3 (a) Explain why guided wave transmission over optical fibre is generally preferred to free space links for optical communications. Your answer should include the benefits and disadvantages of each approach. [25 %]

(b) It is proposed to develop an optical communications link to operate at a data rate of 1.25 Gbit s^{-1} using a step index optical fibre. The fibre to be used has a 50 μm core diameter, a core index of 1.458 and a cladding index of 1.450. The link is to employ an optical transmitter operating at a wavelength of 1300 nm.

(i) Describe the process by which such an optical fibre guides light.

(ii) Estimate the number of modes that the fibre supports at the 1300 nm operating wavelength

(iii) Describe dispersion mechanisms in optical fibres generally. Estimate the dispersion of the multimode fibre described above, indicating any assumptions that you make.

(iv) Calculate the maximum transmission distance achievable for this link. You may assume that the receiver will allow a maximum broadening of a single "one" to 1.5 times the bit period. [65 %]

(c) The IEEE Ethernet standard specifies a link length of up to 550 m at this data rate. Describe how the fibre might be modified to allow this distance to be achieved. [10 %]

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4 (a) Describe the main noise processes in an optical receiver. [20 %]

(b) Consider a long haul optical communications system which operates at a data rate of 10 Gbit s^{-1} and at a wavelength of 1535 nm. The circuit contained in the receiver front end consists of a conventional InGaAs p^+n photodiode connected to a high gain amplifier with an input impedance of 1 kΩ and a 10 GHz bandwidth. The photodiode has a quantum efficiency of 90 %, a dark current of 0.5 nA and a negligible capacitance. The operating temperature of the circuit is 25 °C.

(i) Calculate the responsivity of the photodiode.

(ii) The required bit error rate of the link is 10^{-12}. Calculate the quantum limited receiver sensitivity, indicating any assumptions that you make.

(iii) For an input power of 4 μW incident on the photodiode, calculate the signal to noise ratio at the output of the circuit. [45 %]

(c) The InGaAs p^+n photodiode is to be replaced by an avalanche photodiode (APD) with an excess noise figure of 0.3 and a dark current of 1 nA, with all other device parameters and circuit elements remaining the same.

(i) Briefly describe the operation of an APD.

(ii) Describe, without any calculations, how you would find the optimum signal to noise ratio for the APD circuit. [35 %]

END OF PAPER

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3B6 Photonic Technology 2004

Wave-particle view of light (photons)	$E = hf = hc/\lambda$
Photon-electron interaction	$eV_{band\text{-}gap} = hf$
Quantum efficiency: emission	$P = \eta hfI/e$
Quantum efficiency: detection	$I = \eta(e/hf)P$
Shot noise: Poisson distribution	$P(k \mid N) = \exp(-N).N^k/k!$
Conversion to dBm	Power in dBm = $10\log_{10}[P/1\text{mW}]$
LED linewidth	$\Delta\lambda \sim \lambda^2\, 2kT/hc$
LED temperature dependence	$P(T)/P(T_1) = \exp[-(T - T_1)/T_0]$
LED Ageing	$P(t) = P(0)\exp(-\beta t)$; $\beta = \beta_0 \exp(-E_a/kT)$
Laser: photon rate equation	$dP/dt = g(n - n_0)P - P/\tau_p + \beta n/\tau_s$
Laser: electron rate equation	$dn/dt = I/eV - n/\tau_s - g(n - n_0)P$
Laser: photon lifetime	$\tau_p = (\mu/c)\,\{\alpha + (1/2L)\ln(1/(R_1R_2))\}^{-1}$
Laser switch on delay	$\tau_{delay} = \tau.\ \ln\{[I - I_{bias}]/[I - I_{threshold}]\}$
Laser temperature dependence	$J_{th}(T) = J_0 \exp[T/T_0]$
LED Ageing	$t_{lifetime}\ \alpha\ \exp[E_a/kT]$
Optical fibre: numerical aperture (NA)	$NA = \mathrm{SIN}(\alpha) = (n_{core}^2 - n_{cladding}^2)^{1/2}$
Optical fibre: normalised frequency (V)	$V = \frac{2\pi a}{\lambda}(n_{core}^2 - n_{cladding}^2)^{1/2} = \frac{2\pi a}{\lambda} NA$
Number of modes in step index multimode fibre	$N \approx V^2/2$
Dispersion	$\tau_{out}^2 = \tau_{in}^2 + \tau_{dispersion}^2$
Shot noise	$\overline{i_{shot}^2} = 2eIB$
Thermal noise: resistor	$\overline{i_{thermal}^2} = 4kTB/R$; $\overline{v_{thermal}^2} = 4kTRB$
APD excess noise figure	$F = M^x$