ENGINEERING TRIPOS PART IIA

Thursday 28 April 2011 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 (2 pages)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	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 three major processes by which electrons and photons interact. On this basis, explain what requirements exist if lasing action is to be achieved in a laser diode device, indicating what structures are required for efficient operation. [20%]

(b) A Fabry Perot laser diode has a cavity length, L, and a reflectivity, R, at each facet. If the scattering loss is α, show that the photon lifetime, τ_p, is given by

$$\tau_p = \frac{\mu}{c}\left\{\alpha + \left(\frac{1}{L}\right)\ln\left(\frac{1}{R}\right)\right\}^{-1}$$

where μ is the refractive index and c is the free space speed of light. [30%]

Hence derive an equation for the differential quantum efficiency, and explain why typically this parameter is relatively insensitive to operating temperature. [25%]

(c) A laser diode, operating at a wavelength of 1.5 μm, has a temperature invariant differential quantum efficiency of 90% and threshold current of 20 mA at a temperature of 20 °C. If the temperature is increased to 40 °C, calculate the current required for the laser to generate 5 mW of total optical power if the characteristic temperature, T_0, is 70 K. [25%]

2 (a) Describe in detail the structures and operation of edge emitting and surface emitting LEDs, indicating design features which enhance efficiency. Explain the relative advantages and disadvantages of the structures, indicating the most common applications for the devices. [40%]

(b) An edge emitting LED, operating at 800 nm wavelength, is driven from a voltage source through a 10 Ω series protection resistor. If the device has a quantum efficiency of 5%, determine the voltage required at the source to generate 1 mW of optical power. [25%]

(c) If the radiative lifetime in the device is 2 ns, and the external quantum efficiency is 10%, determine the overall risetime of the device. [20%]

(d) What is the optical spectral width of the device at a temperature of 20 °C? [15%]

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3 (a) Describe the limiting factors for the operating bandwidth of a *p+n* photodiode and explain how a *pin* structure can be used to remove some of the uncertainties in designing a high bandwidth component. [25%]

(b) Sketch the construction of mesa and planar diffused *p+n* photodiodes. [15%]

(c) A transimpedance receiver circuit has been constructed to operate with an input signal of wavelength 1310 nm. The photodiode has a depletion capacitance of 20 pF and a quantum efficiency of 0.85 . The operational amplifier has a gain of 500 but can otherwise be considered to be ideal. The transimpedance has a resistance of 120 Ω and a stray capacitance of 0.1 pF. The circuit is operated at a temperature of 37 °C.

(i) Calculate the maximum bandgap of the photodiode in units of eV. [10%]

(ii) Calculate the low frequency transfer function (defined as the output voltage / input optical power in units of $V\ W^{-1}$). [15%]

(iii) Calculate the bandwidth of the circuit. [15%]

(iv) Calculate the sensitivity of the receiver, in units of dBm, assuming that an acceptable BER performance requires a signal to noise ratio of at least 20 dB. You may assume that the noise performance of the circuit is limited by thermal noise. [20%]

4 (a) What are the ways in which signal quality can degrade in single mode fibres? Explain how these effects influence how optical fibre transmission systems are operated. [25%]

(b) A step index single mode fibre is to be designed with a core refractive index of 1.51 and a cladding refractive index of 1.50 . Calculate the maximum core diameter for the fibre to remain single mode at a wavelength of 1550 nm. Describe how optical fibre is manufactured. [20%]

(c) The fibre is to be used in a transmission link operating at a data rate of 10 Gbit s^{-1} . The laser transmitter generates a fibre coupled power of 2 mW and operates with a linewidth of 0.2 nm. The link contains three optical splices, each with a loss of 0.3 dB, and two connectors, each with a loss of 0.5 dB. The fibre has an attenuation of 0.23 dB km^{-1} and a dispersion of 16 ps nm^{-1} km^{-1} . The receiver sensitivity is -23 dBm. The link is required to operate with a margin of 2 dB.

(i) Determine whether the link is dispersion or attenuation limited and state its maximum transmission length. You may assume that the receiver can tolerate pulse broadening of 50% of a bit period. [35%]

(ii) Describe how the link length could be increased to 1000 km. [10%]

(iii) Describe how the link capacity could be increased to 100 Gbit s^{-1}. [10%]

END OF PAPER

3B6 PHOTONIC TECHNOLOGY 2011

This data sheet is designed to provide an *aide-memoire* on certain physical and device-orientated aspects of optoelectronics. It will be issued for the 3B6 exam.

Note: e = charge of an electron, e = exponential

Wave-particle view of light (photons)	$E = hf = hc/\lambda$
Photon-electron interaction	$eV_{band\text{-}gap} = hf$
Diode equation	$I = I_0(\mathrm{e}^{\frac{eV}{nkT}} - 1)$
Quantum efficiency: emission	$P = \eta hfI/e$
Quantum efficiency: detection	$I = \eta(e/hf)P$
Conversion to dBm	Power in dBm = $10\log_{10}[P/1\mathrm{mW}]$
LED linewidth	$\Delta\lambda \sim 2kT\lambda^2/hc$
LED power temperature dependence	$\dfrac{P(T)}{P(T_1)} = \mathrm{e}^{-\left(\frac{T-T_1}{T_0}\right)}$
LED power time dependence (ageing)	$P(t) = P(0)\mathrm{e}^{-\beta t}$ $\beta = \beta_0\,\mathrm{e}^{-\frac{E_a}{kT}}$
Laser: photon rate equation	$\dfrac{dP}{dt} = g(n-n_o)P + \beta\dfrac{n}{\tau_s} - \dfrac{P}{\tau_p}$
Laser: electron rate equation	$\dfrac{dn}{dt} = -\dfrac{n}{\tau_s} + \dfrac{I}{eV} - g(n-n_o)P$

Laser: photon lifetime

$$\tau_p = \left(\frac{\mu}{c}\right)\frac{1}{\alpha + \frac{1}{2L}\ln\frac{1}{R_1R_2}}$$

Laser switch on delay

$$\tau_{delay} = \tau_s \ln\left[\frac{I - I_{bias}}{I - I_{threshold}}\right]$$

Laser threshold temperature dependence

$$J_{th}(T) = J_0 \, e^{\frac{T}{T_0}}$$

Laser Ageing

$$t_{lifetime} \propto e^{\frac{E_a}{kT}}$$

Optical fibre: numerical aperture (NA)

$$NA = \sin(\alpha) = (n_{core}^2 - n_{cladding}^2)^{1/2}$$

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

$$\overline{i_{shot}^2} = 2eIB$$

Shot noise: Poisson distribution

$$P\langle k|N\rangle = \frac{e^{-N} . N^k}{k!}$$

Thermal noise: resistor

$$\overline{i_{thermal}^2} = 4kTB / R \; ; \; \overline{v_{thermal}^2} = 4kTRB$$

APD excess noise factor

$$F = M^x$$