ENGINEERING TRIPOS PART IIA

Thursday 22 April 2010 9.00 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 operation of a surface emitting light emitting diode (SELED), explaining the principle of conversion of electrons to photons. Using a diagram by way of illustration, explain how the structure of the device is designed to maximise its efficiency. [30%]

(b) Explain how the generation of light within an SELED is affected by increasing temperature, and how thermal effects can be reduced within the device. [25%]

(c) A SELED, operating at a wavelength of 850 nm, is to be driven from a voltage source with an internal resistance of 2 Ω. If the SELED has internal and external quantum efficiencies of 65% and 4%, respectively, at 20 °C, determine the required voltage generated by the source to deliver an output power of 1 mW. (Assume that the SELED also has an internal resistance of 0.5 Ω.) [25%]

(d) Assume that T_0 for the SELED is 80 K. Hence determine the voltage required from the source to generate 1 mW output power when the device temperature increases to 70 °C. [20%]

2 (a) Explain why optical feedback, in conjunction with stimulated emission, is normally required for successful laser operation. [20%]

(b) Describe in detail the operation and structure of a Fabry Perot ridge laser diode and explain how the cavity affects the wavelengths at which the device lases. [25%]

(c) Hence derive an equation for the mode spacing, in terms of wavelength, of a Fabry Perot laser. Calculate the mode spacing for a device with a cavity length, L, of 0.3 mm, an effective refractive index, μ, of 3.6 and an operating wavelength, λ, of 1.5 μm. [25%]

(d) By considering the cavity, show that the photon lifetime in the laser can be written as

$$\tau_p = \left(\frac{\mu}{c}\right)\frac{1}{\alpha + \frac{1}{2L}\ln\frac{1}{R_1 R_2}}$$

where c is the free space speed of light, μ is the effective refractive index, α is the optical scattering loss and R_1 and R_2 are the mirror reflectivities. Explain how the value of the photon lifetime can affect the laser performance. [30%]

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3 A photonics engineer has been tasked to design a solar cell. The engineer has been given three possible materials to work with:

Material	Bandgap Wavelength	Quantum Efficiency
Material #1	400 nm	0.2
Material #2	1000 nm	0.8
Material #3	1400 nm	0.95

(a) Using band diagrams, explain how a solar cell operates. Briefly contrast how a solar cell is operated compared with a photodiode. [15%]

(b) Sketch a graph of solar irradiance against wavelength (you may assume that the peak irradiance is at a wavelength of 400 nm). Based on this graph and the table above, state with reasons which material is the best to use in the solar cell. [25%]

(c) In a test, a 1.3 m^2 solar cell constructed from the material that you have chosen in (b) is illuminated with light at its bandgap wavelength at an intensity of 1.2 kW m^{-2}. The solar cell is found to have an ideality factor of 1.0, a dark current of 20 μA, a shape factor of 0.6 and is operated at a temperature of 320 K.

(i) Calculate the maximum photocurrent that the solar cell can generate. [10%]

(ii) Using the diode equation, calculate the open circuit voltage and the short circuit current. [20%]

(iii) Sketch the I-V curve for the solar cell for both illuminated and non-illuminated states. Mark important values on the curves. [15%]

(iv) Mark the optimum operating point on the illuminated I-V curve and calculate the maximum power that can be generated. [15%]

4. (a) Describe the two main sources of signal degradation in optical fibres. Discuss how these degradation mechanisms affect the choice of operating wavelength in optical communications systems. [20%]

(b) A step index multimode fibre is constructed with a core index of 1.52 and a cladding index of 1.51. Calculate the maximum bit rate that it is possible to transmit over a 100 m length of this fibre, assuming that the receiver circuit can tolerate a 50% broadening of a single input “1”. [20%]

(c) Describe, explaining the principle involved, how the construction of the multimode fibre described in (b) can be modified to allow data rates in excess of 1 Gbit s^{-1}. [10%]

(d) A transimpedance amplifier (TIA) receiver is to be constructed using a photodiode, with a depletion capacitance of 20 pF and a quantum efficiency of 90%, connected to an amplifier with a voltage gain of 50 and a 200 Ω transimpedance resistor, which has a stray capacitance of 0.5 pF. The receiver circuit needs to operate with a signal to noise ratio of at least 20 dB and at a temperature of 27 °C. The input wavelength to the photodiode is 1.55 μm.

(i) Sketch the receiver circuit. [10%]

(ii) Calculate the receiver bandwidth. [15%]

(iii) Calculate the receiver sensitivity. You may assume that thermal noise is the most important noise process in the receiver for low optical input power levels. [25%]

END OF PAPER

3B6 PHOTONIC TECHNOLOGY 2010

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	$P\langle k \mid N\rangle = \frac{e^{-N} . N^k}{k!}$
Thermal noise: resistor	$\overline{i_{thermal}^2} = 4kTB / R \; ; \; \overline{v_{thermal}^2} = 4kTRB$
APD excess noise factor	$F = M^x$

Numerical Answers

Q.1 (c) 1.53 V, (d) 1.58 V
Q.2 (c) 1 nm
Q.3 (c) (i) 1006 A, (ii) 1 kA, 0.489 V, (iv) 295 W
Q.4 (b) 333 Mb/s, (d) (ii) 884 MHz, (iii) -26.2 dB