UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

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Friday 29 April 2005 2.30 to 4

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Module 4B10

OPTOELECTRONIC TECHNOLOGIES

*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:*
*Standard equations sheet (1 page)*

**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) Explain how polycrystalline GaAs is initially formed from its constituent elements, and then how a high quality pure crystal is grown using the Liquid Encapsulated Czochralski technique. [30%]

(b) What basic processing of the crystal is carried out to form a substrate wafer, and what tests are carried out on the substrate wafer before beginning further processing to form photonic components? [30%]

(c) The wafer is to be used for laser diode construction. Describe in detail what growth techniques might be used to form the epitaxial layers of the laser diode, explaining their relative advantages and disadvantages. [40%]

2 (a) How might a Bragg reflector be implemented in a semiconductor laser? Describe with the aid of sketches how a distributed Bragg grating can be used to select a single optical frequency. [30%]

(b) How is the manufacturing complexity and the performance of a distributed feedback laser affected by:

(i) The use of a first or second order grating?
(ii) The use of a quarter wavelength phase shift?
(iii) The reflectivity of the facets? [30%]

(c) A distributed feedback laser with a characteristic temperature 80 K is to be used without temperature stabilisation with the following transmitter specifications:

| | |
|---|---|
| Maximum laser temperature | 85 °C |
| Maximum forward current | 90 mA |
| Maximum peak-to-peak modulation current | 50 mA |
| Optical extinction ratio | 10 dB |

(i) Assuming that the slope efficiency of the laser does not vary significantly, estimate the maximum and minimum value of threshold current over an operating range of 20 °C to 85 °C. [20%]

(ii) Suggest reasons as to why the slope efficiency would be expected to reduce at higher temperatures. [10%]

(iii) Describe the control electronics required to ensure the transmitter operates at constant mean power and constant extinction ratio for non-return-to-zero data modulation. [10%]

(TURN OVER

3 (a) Explain what is meant by transparency current density and threshold current density in a semiconductor laser. [10%]

(b) The threshold current density can be expressed as a sum of the transparency current density and terms dependent on waveguide loss α and cavity length *L*:

$$J_{th} = J_o + \frac{v_g e d \alpha}{g \tau_s} - \frac{v_g e d.\log(R_r R_f)}{2 g \tau_s}.\frac{1}{L}$$

Explain the meaning of the parameters. How can this relationship be used to measure the losses in Fabry-Perot laser diodes? [30%]

(c) A laser with the following parameters is fabricated for pumping an Erbium doped fibre amplifier.

| | |
|---|---|
| Transparency current density | 1 kA/cm$^2$ |
| Waveguide loss | 5 cm$^{-1}$ |
| Waveguide width | 3 μm |
| Gain rate | $10^{-7}$ cm$^3$/s |
| Active layer thickness | 10 nm |
| Transparency carrier density | $10^{18}$ cm$^{-3}$ |
| Rear facet reflectivity | 80% |
| Front facet reflectivity | 1% |
| Internal injection efficiency | 100% |
| Oscillating wavelength | 980 nm |
| Refractive index | 3.4 |

(i) How long must the laser cavity be to ensure an overall differential slope efficiency of at least 1 W/A? [25%]

(ii) What current density is required to give 200 mW total output power? [25%]

(iii) The series resistance is measured to be 1Ω. Estimate the proportion of electrical input power which is converted to optical output power at that current. How is the remaining power dissipated? [10%]

4 (a) Sketch the structure for a high speed p-i-n photodiode for operation at 1.5 μm wavelength. Identify the mechanisms which impact the photodiode responsivity. [20%]

(b) A photodiode is connected to a component analyser with input impedance of 50 Ω. The optical responsitivity is measured to have a half power cut off frequency of 1 GHz. The capacitance of the photodiode is independently measured to be 2 pF.

(i) What design changes might be implemented to reduce the capacitance? [10%]

(ii) What is the new half power cut off frequency if the capacitance is reduced to 500 fF? [30%]

(iii) What further design changes may be made to increase the cut off frequency? [10%]

(c) A p-i-n receiver is to be used in a long haul wavelength division multiplexed link which uses optical amplification at regular intervals. Identify the other photonic components required in the link and identify the aspects of the performance these components will have on signal quality after the receiver. [30%]

END OF PAPER

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## Standard Equations

1. Light Emitting Diode

$$P = \eta I \frac{hc}{e\lambda}$$

$$\frac{P(T)}{P(T_1)} = \exp\left(-\frac{(T_1 - T)}{T_o}\right)$$

$$P_T(t) = P_T(0)\ \exp(-\beta t)$$

$$\beta = \beta_o \exp(-E_a / kT)$$

2. Laser Diode

$$\frac{dn}{dt} = -g(n - n_o)P - \frac{n}{\tau_s} + \frac{J}{ed}$$

$$\frac{dP}{dt} = g(n - n_o)P + \frac{\beta n}{\tau_s} - \frac{P}{\tau_p}$$

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

$$\delta\lambda = \frac{\lambda^2}{2Ln_r}$$

3. Semiconductor optical amplifiers

$$\frac{dn}{dt} = \frac{I}{eV} - \frac{n}{\tau_s} - \Gamma g(n - n_o)P$$

$$\frac{dP}{dt} = \Gamma\beta\frac{n}{\tau_s} + \Gamma g(n - n_o)P$$

$$Power_{out} = \frac{c}{n_r}\frac{hc}{\lambda}AP_{out}$$

$$G' = g(n - n_o) \quad [\mathrm{s}^{-1}]$$

$$G = \frac{n_r}{c}G' \quad [\mathrm{m}^{-1}]$$

4. Receivers

$$\frac{dV}{dL} = \eta\frac{e}{hf}\cdot\frac{R}{(1 + j\omega RC)(1 + j\omega\tau)}$$

$$\langle\sigma^2_{Shot}\rangle = 2eIB_e$$

$$\langle\sigma^2_{Thermal}\rangle = \frac{4kTB_e}{R}$$

5. Links

$$OSNR = \frac{i^2_{Signal}}{\sum\langle\sigma^2\rangle}$$

$$\tau_{output} = \sqrt{\tau_{input}^{\ 2} + \sum_{i=1}^{n}\tau_{system}^{\ 2}}$$

$$Q = \frac{i_{ones} - i_{zeros}}{\sqrt{\sigma^2_{ones}} + \sqrt{\sigma^2_{zeros}}}$$

$$BER = \frac{1}{Q\sqrt{2\pi}}\exp\left(\frac{-Q^2}{2}\right)$$

Numerical Answers to 4B10

Q.2 (c)(i) 35 mA, 15.5 mA
Q.3 (c)(i) 1280 μm, (ii) 8.31 kA/cm$^2$, (iii) 40%
Q.4 (b)(ii) 2.16 GHz