UNIVERSITY OF CAMBRIDGE

ENGINEERING TRIPOS PART IIB

Friday 23 April 2004 2.30 to 4.00

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
i) Standard equations (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) Describe the major ways in which the properties of Silicon differ from those of compound semiconductors such as GaAs or InP, and explain how these affect the growth and processing techniques used to fabricate optoelectronic components. [40 %]

(b) A simple oxide stripe laser diode is to be fabricated from an epitaxial wafer containing all the optically active and contact semiconductor layers required for the device.

(i) Describe in detail what tests should be carried out on the wafer prior to processing to ensure that it is of the necessary quality for device fabrication.

(ii) Describe what typical processes will then be required for device fabrication, in particular explaining what issues surround the choice of contact materials. [60 %]

2 (a) Explain how a simple Fabry Perot laser diode may be represented functionally as a feedback based oscillator with a transfer characteristic of the following form:

$$P_O(\lambda) = \frac{P_S(\lambda)G(\lambda)}{1 - G(\lambda)\beta(\lambda)}$$

Define the terms and describe the assumptions made in this equation and its physical significance. How may additional reflections be represented using this model? [30 %]

(b) It is proposed to fabricate a multimode Fabry Perot laser diode to generate a comb of modes with a longitudinal mode spacing of 0.5 nm at a wavelength of 1.3 μm. What length should this device have if it has an effective refractive index of 3.2? If the refractive index varies with temperature by 2×10^{-4} /°C, how accurately must the laser temperature be controlled if the absolute wavelength of each of the modes is to vary by less than 0.001 nm? [50 %]

(c) Describe how the device in part (b) might be modified and placed in a grating external cavity to provide single longitudinal mode operation. How should the cavity be constructed if tuning of the wavelength is to be achieved? [20 %]

3 (a) Explain the operating principle of a semiconductor optical amplifier.

Amplitude modulated data is input to a semiconductor optical amplifier. Explain how the output becomes distorted for a sufficiently high photon density. Show that the saturation photon density is defined by confinement factor, gain and carrier lifetime:

$$P_{sat} = (\Gamma g \tau_c)^{-1}$$ [40%]

(b) A semiconductor optical amplifier has the following material and operating parameters

Gain	4.0×10^{-6} cm^{3}s^{-1}
Active layer width	24 nm
Transparency carrier density	1.5×10^{18} cm^3
Waveguide width	2 μm
Group refractive index	3.55
Injection efficiency	0.95
Carrier lifetime	320 ps
Gain peak wavelength	1310 nm
Confinement factor	0.05
Operating current	0.1 A
Length	1 mm

Estimate the gain of the amplifier when operating in a linear regime. Hence or otherwise, estimate the input power at which the gain drops by 3 dB. [50%]

(c) Comment on possible applications for semiconductor optical amplifiers with low input saturation powers. [10%]

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4 (a) Explain what is meant by the terms power margin, power budget, and power penalty in a fibre optic communications link. [15%]

(b) A 500km link is to be implemented using spans comprising the two fibre types below and low saturation power Erbium doped fibre gain blocks with 17dB gain.

	Fibre 1	Fibre 2	
Loss	0.2	0.31	dB/km
Dispersion	2	-4	ps/nm/km

Sketch a power and dispersion map for the link. What is the minimum number of amplifier stages that are required? How far apart should they be spread? [20%]

(c) The transmitter and receiver for the above link are specified as follows:

Transmitter:	
Wavelength	1550 nm
Transmitter power	0 dBm
Data format	balanced non-return to zero
Data rate	9953 MB/s
Receiver:	
Photodiode quantum efficiency	0.90
Receiver amplifier input impedance	50 Ω
Receiver bandwidth	7 GHz
Temperature	20 °C

Estimate the power incident on the receiver. Hence or otherwise estimate the power margin for a bit error rate of 10^{-9}, corresponding to an optical signal to noise ratio of 144. [40%]

(d) Additional wavelengths are to be added to increase capacity. What are the implications for power penalty and power budget? [25%]

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

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

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

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

$$\delta\lambda = \frac{\lambda^2}{2L n_r}$$

3. Semiconductor optical amplifiers

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

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

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

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

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

4. Receivers

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

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

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

5. Links

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

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

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

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

Answers to go with question papers

1:

2: (b) 530μm, 0.012°C

3: (b) 25 dB, 12 dBm

4: (b) 6, 72 km (c) 21 dBm, 4.7dB