OPTOELECTRONICS TECHNOLOGY PART IIB 4B10

Cribs to Tripos Examination 2004

1(a) This is primarily a bookwork question. A good answer should make the following points concerning the differences between Si and compound semiconductors such as GaAs and InP, and then discuss how it impacts technology.

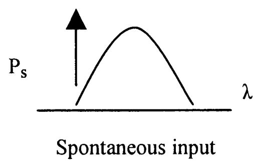
Si	GaAs
Cheap, plentiful	Relatively scarce
'Inert', non toxic	P loss > 350°C, As Loss > 450°C
Stable native oxide	Water soluble mixed oxides
Strong	Fragile
Huge demand	10^7 lasers/year
Optical 'purity' irrelevant	Must have good optical properties

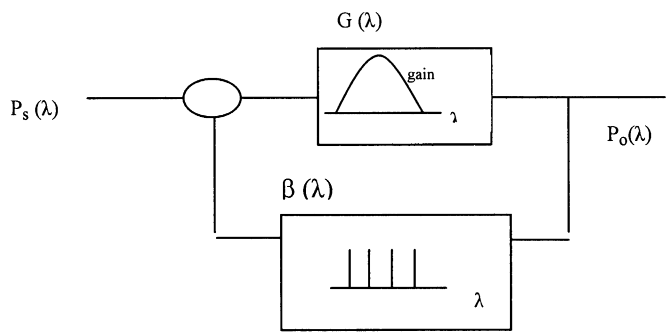
(b)(i) Again this is a bookwork question. Good answers should include detailed descriptions of the following measurements: layer thickness (such as using ball lap), atomic layer spacings (by X-ray diffraction), layer doping levels (by C-V and etching), emission wavelength and intensity (by electron or laser bombardment (PL)) and by constructing basic tests on very simple test lasers.

(b)(ii) A good answer should discuss techniques for patterning laser stripes and ridges, photolithography, wet and dry etching processes and techniques for oxide deposition including plasma deposition.

A discussion of metal contacts should highlight the different metal layers used to promote adhesion, act as barriers for gold diffusion. Comments on the need for the top contact material on each contact to be compatible with bonding procedures should be highlighted. A typical contact arrangement should be provided.

2(a) A good answer to this part should include a bookwork description of how the laser can be represented as





$$P_o(\lambda) = [P_s(\lambda) + \beta(\lambda)\, P_o(\lambda)]\, G(\lambda)$$

$$\Rightarrow P_o(\lambda) = G(\lambda)\, P_s(\lambda)\ \{1 - G(\lambda)\,\beta(\lambda)\}^{-1}$$

The answer should explain what physical properties are represented as $G(\lambda)$, $\beta(\lambda)$ and $P_s(\lambda)$ and highlight the impact that small changes in G and β can have.
An additional reflection can be considered as an additional feedback path.

(b) $$\Delta\lambda = \frac{\lambda^2}{2nL} \quad \Rightarrow \quad L = \frac{\lambda^2}{2n\,\Delta\lambda}$$

$$\Rightarrow L = \frac{1.3^2}{2 \times 3.2 \times 0.5 \times 10^{-3}} = 530\mu m$$

Change in emission wavelength $= \dfrac{d\lambda_m}{dT} \Delta T$

where $\dfrac{d\lambda_m}{dT} = \dfrac{dn}{dT}\dfrac{d\lambda_m}{dn} = \dfrac{dn}{dT}\dfrac{2L}{m} = \dfrac{dn}{dT}\dfrac{\lambda_o}{n_r}$

$\Rightarrow \quad \Delta T = \Delta\lambda \,/\, \{ \dfrac{\lambda_o}{n_r} \dfrac{dn}{dT} \}$

$= 10^{-6} / (1.3/3.2 \text{ x } 2\text{x}10^{-4}) = 0.012°C$

(c) This bookwork question should be answered with a description as to how the laser chip should have an anti-reflection coating placed on one facet, and then set in an external cavity. For continuous tuning the mode spacing should be changed in tandem with the grating angle, otherwise discrete tuning occurs.

3(a) Semiconductor optical amplifiers use stimulated emission to amplify the input optical signal. Anti-reflection coatings are applied to the device to avoid feedback and therefore oscillation.

The gain of the amplifier is dependent on the carrier density which depends on both injected current and injected optical signal. Time varying optical signals lead to a time dependent gain which distorts amplitude modulated data when the optical power is too high.

Able to estimate the saturation photon density by considering the steady state solution to the carrier rate equation, in combination with the definition of gain $G' = g(N - N_o)$, and by substituting out for the carrier density N

$G' = g(N - N_o) = g\tau_s I/eV - gN_o - g\tau_s \Gamma G'P$

And rearranging

$G' = G'_{linear}/(1+P/P_{sat})$ where $1/P_{sat} = \Gamma g \tau_s$ and $G'_{linear} = g(N - N_o)$

(b) To estimate amplifier gain the value for carrier density is required. Assuming again the steady state solution for carrier rate equation.

$N = \tau\eta I/eV = 320\text{x}10^{-12}\text{x}0.95\text{x}0.1/(1.6e^{-19} \text{ x } 24\text{x}10^{-7}\text{x}2\text{x}10^{-4}\text{x}0.1) = 3.96\text{x}10^{18}\text{cm}^{-3}$

$\text{Gain} = 0.05\text{x}4\text{x}10^{-6} \text{ x } (3.96 - 1.5) \text{ x}10^{18} = 4.91\text{x}10^{11}$ /s

So gain per unit distance: $= 4.91\text{x}10^{11} \text{ x } 3.55/ 3\text{x}10^{10} = 58.10$ /cm

Signal gain for an amplifier of length L: Gain = exp (GL)

10 log10 (exp (58.10 x 0.1) = 25.23dB

Able to estimate the output saturation photon density from equation derived in part (a)

$1/P_{sat} = 0.05 \text{ x } 4\text{x}10^{-6} \text{ x } 320\text{x}10^{-12} = 6.40\text{x}10^{-17} \text{ cm}^3$

Calculate photon energy $hf = 6.626\text{x}10^{-34} \text{ x } 3\text{x}10^{10} / 1310\text{x}10^{-7} = 1.52\text{x}10^{-19}$ J

Convert to optical power

$v_g \text{ AP hf} = 3\text{x}10^{10}/3.55\text{x}2\text{x}10^{-4}\text{x}24\text{x}10^{-7}\text{x}1.52\text{x}10^{-19}/6.40\text{x}10^{-17} = 9.63\text{mW} = 9.84\text{dBm}$

Input saturation power = Output saturation power – linear gain – 3dB

9.84 – 25.23 – 3 = – 12.4 dBm

(c)

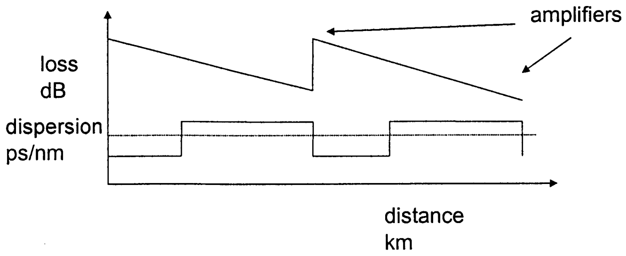
A low input saturation power amplifier is liable to distortion but may be used as a preamplifier at a receiver to improve power sensitivity and also in nonlinear applications which exploit gain saturation, such as wavelength conversion and nonlinear regeneration.

4(a)

Power budget is the power difference between the transmitter and receiver. This will accommodate losses in the system, any power penalties incurred during transmission, and allow a power margin for component specifications
Power penalty is the reduction in power budget due to signal degradation from e.g. noise, distortion, dispersion
Power margin is the part of the power budget which is not allocated to losses or penalties which is provided to accommodate variations in component specification

(b)

The power and dispersion map sketch should indicate the placement of the two fibre types with one amplifier afterwards for each span:



The low saturation erbium fibre amplifiers require low input power so the first fibre spans precede the first gain block. The order of the two types of fibre is not critical here. Dispersion is to be balanced for each span so fibre with higher dispersion will be half (2/4) the length of the low dispersion fibre from the ratios of the dispersion. The magnitude of the dispersion defines the relative lengths of fibres. The gain of the amplifier defines length of span loss. So for one amplified span the gain and loss are equal;

$17 = L\ (\ 0.2 \times 2/3\ +\ 0.31\ \times 1/3\ ) \Rightarrow L = 71.83$ km

No of spans = 500/71.83 = 6.9 i.e. require at least 6 amplifiers

(c) Estimating the power after the last amplified span:
Uncompensated loss for length : 500 – 6 x 71.83 = 69.01 km
So uncompensated loss = 69.01 (0.2 x 2/3 + 0.31 x 1/3) = 16.33dB uncompensated loss
so for 0dBm transmitter power: 0 – 16.33 = – 16.33 dBm at the receiver

To estimate power margin at 10^{-9} error rate, need to know the receiver sensitivity.
BER = 10^{-9} giving Q = 6 and therefore SNR = $4Q^2$ = 144
Solving the SNR equation as a quadratic in terms of photocurrent I :

$I^2/SNR - I\,2eB - 4kTB/R = 0$

where

$1/SNR = 0.00694$

$-2e\,B = -2.24\times10^{-9}$

$-4kTB/R = -2.26\times10^{-12}$

Giving one positive root for detected current = 17.9μA
Detected power = I hf/ηe = 17.9 x 1.24/1.55/0.9 = 15.9μW
giving P_{ones} = –17.98 dBm
so P_{ave} = – 20.98 dBm as mean power is half peak for balanced NRZ
Power margin = –16.33 – – 20.98 = 4.7dB

(d) Additional wavelengths will include additional losses due to mux and demux reducing the power budget. Power penalty may be enhanced through e.g. four wave mixing, and imperfect dispersion matching.