Crib for Paper 4B10, 2003 **Optoelectronic Technology**

Q.1(a) This is primarily a bookwork question though good answers could take several different approaches. In terms of growth techniques for compound semiconductor crystals, answers could include descriptions of the Bridgeman or Liquid Encapsulated Czochralski techniques. As the growth of wafer layers is critically dependent on the quality of the crystal substrate, it is important to characterise this. Characterisation techniques might include; doping and mobility, resistivity, etch pit density etc. Details of these tests will be expected for a good answer.

(b) Again, this part of the question is primarily bookwork. LPE allows rapid growth and hence is suitable for large throughput manufacturing of components with modest layer tolerances. MOVPE allows high quality growth, suitable for forming quantum well structures. A good answer would provide specific details of the advantages and disadvantages of each approach.

(c) This is also a bookwork question. A good answer will highlight the key challenges in fabricating the laser structures and how the use of LPE can lead to different buried heterostructure lasers from MOVPE.

Q.2(a) This bookwork-based answer should highlight the use of antireflection coatings in semiconductor amplifiers to prevent lasing. A good answer should also explain techniques to minimise polarisation dependence, to maximise coupling efficiency from amplifiers to optical fibres, and to reduce the impact of optical noise

(b) After the first bookwork part, assume dn/dt = 0

$$\Rightarrow \quad 0 = (I/eV) - (n/\tau_s) - \Gamma g(n - n_o)L/E$$

but the material gain $g_m = g(n - n_o)$, so,

$$g_m = g\ \{ (I\tau_s)/(eV) - \tau_s \Gamma g_m L/E\} - gn_o$$

$$\Rightarrow g_m = ((gI\tau_s/eV) - gn_o)/(1+\tau_s\Gamma gL/E)) = g(I\tau_s/eV - n_o)/(1+L/L_s)$$

where $L_s = E/g\Gamma\tau_s$

(c) The saturation intensity is L_s but $E = hc/\lambda$, so,

$$\Rightarrow \quad L_s = hc/\lambda g\Gamma\tau_s = 24\ \mathrm{mW/\mu m^2}$$

The amplifier may be optimised primarily in terms of the saturation intensity by varying g and Γ. However a trade-off typically exists between the gain and saturation power. Clearly the saturation power (as opposed to intensity) is also optimised by transverse waveguide design.

Q.3(a) A bookwork part where a good answer would include notes on:

- Gain spectrum: comments on the energy distribution of charge carriers in conduction/valence bands
- Round trip gain condition: need for unity roundtrip gain for oscillation, i.e. material gain = overall total losses
- Round trip phase condition: the roundtrip signal must add constructively with the original signal at any given point in cavity.
- Cavity length: generally this must be long enough to allow multiple modes to exist within the gain spectrum, while the wavelength satisfies the condition that there is an integer multiple of half wavelengths between the cavity facets.
- External reflections: These add additional effective cavities. The modes of the cavities can be adversely affected by additional feedback paths (a good answer would introduce the feedback model).

(b) The modes are selected by the effective round trip gain dependence on wavelength. The mode positions are therefore also a function of temperature.

The dependence of gain peak wavelength on temperature can be given by

$$\partial\lambda_g/\partial T = 0.3 \text{ nm}/^{o}\text{C}$$

$=>$ gain peak shift in 20^{o}C, $= 6$ nm $= \Delta\lambda_g$

The mode spacing $\Delta\lambda_m = \lambda^2/(2n_rL) = 1.2$ nm

However the change in mode emission wavelength $= \Delta\lambda_m + (\partial\lambda_m/\partial T)\ \Delta T$

$=> (\partial\lambda_m/\partial T)\ \Delta T = \Delta\lambda_g - \Delta\lambda_m$

But $(\partial\lambda_m/\partial T) = (\partial n/\partial T).(L/2m) = (\partial n/\partial T).(\lambda_o/n_r)$

$=> dn/dt = (\Delta\lambda_g - \Delta\lambda_m)/\ \Delta T).(n_r/\lambda_o) = 5.1 \times 10^{-4}\ /^{o}C$

(d) A DFB laser has a wavelength which depends on the internal fixed grating and hence the temperature dependence of wavelength is governed by index so that

$$\Delta\lambda_{dfb} = (\partial n/\partial T).(\lambda_o/n_r).(\Delta T) = 4.8 \text{ nm}$$

Q.4(a) A bookwork question where a good answer should provide a detailed description of a heterostructure pin photodiode giving details of the optimum arrangements of the layer structure, including comments on doping. The answer should highlight the role of the material in determining the detection properties as a function of wavelength and contrast the properties of direct and indirect bandgap materials.

(b) Here a good answer should describe techniques to reduce photodiode area and note the trade-offs between sensitivity and high speed. Comments on thickness optimisation and balancing of transit time and capacitance limits should also be included. Good answers should include descriptions of air-bridges for ultrahigh speed operation.

(c) The frequency dependence is given as $H(\omega) = 1/[(1+j\omega\tau_t).(1+j\omega RC)]$

$$=> \quad |H(\omega)| = 1/[(1+j\omega^2\tau_t^2).(1+j\omega^2R^2C^2)]^{1/2} = 1/1.39$$

The required rms current, $I_{rms} = 1\ mV/2\ /\ \ 50\ \Omega = 10\ \mu A$

=> The required rms optical power = 12 μW