PHOTONICS TECHNOLOGY, 3B6, 2012: OUTLINE ANSWERS

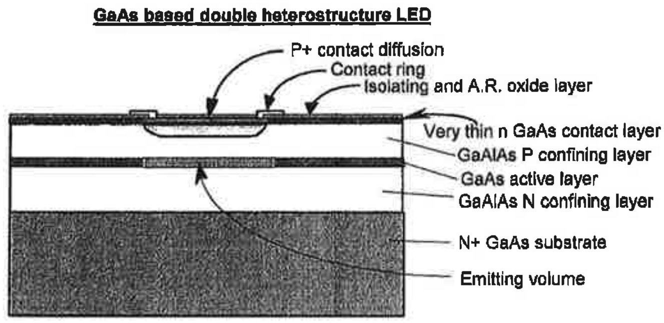
Q1 (a) The answer is primarily bookwork and should highlight the direct dependence of emission wavelength on material bandgap. The material composition itself therefore must be selected for specific applications.

A good answer would include descriptions of the use of specific compound materials to allow the engineering of the emission wavelength.

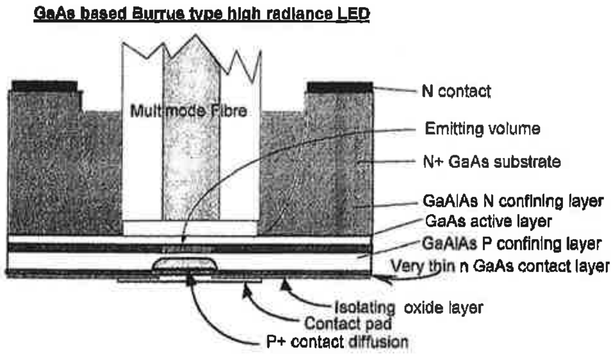
The answer should explain the impact that direct and indirect bandgap materials have on emission efficiency and hence why direct bandgap materials are preferred.

(b) This again is primarily bookwork. A good answer should provide detailed descriptions of surface- and edge-emitting light emitting diodes. This might include:

1 SURFACE EMITTING LED STRUCTURES



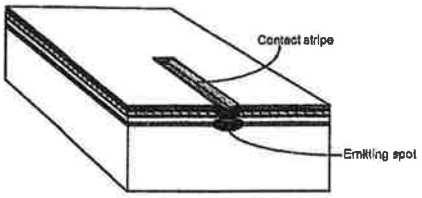
A good answer should explain the basic principles of the structure and comment on the different materials used for short and long wavelengths, and also the Burrus structure.

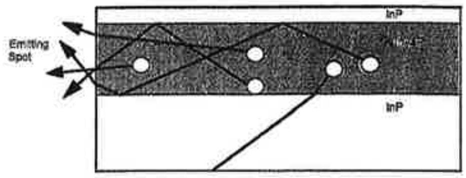


The Burrus diode has much of the substrate etched away: this allows high coupling into a multimode fibre, sometimes a spherical micro-lens is interposed as well. In addition, the heat generation is close to the p surface which can be bonded directly to a heatsink and the contact metal also reflects some light back upwards into the fibre. Similar devices are made using the InP/GaInAsP materials system for operation at longer wavelengths.

2 EDGE EMITTING LEDS

A typical answer should explain the structure of the device, detailing the action of the heterostructure.





The answer should include typical advantages and disadvantages of the light emitting diodes for example that the surface emitting device generates well defined circular beams and is easy to use while the edge emitting device has much greater radiance, and is better at coupling light into single mode fibres.

(c) (i) The light emitting diode equation can be shown to be

$$I = e P \lambda / (h c \eta_i \eta_e)$$

The circuit equation is V= forward voltage + I x R

$$= [hc/e\lambda] + e P \lambda / (h c \eta_i \eta_e) \times R$$

$$= \underline{1.61 \text{ V}}$$

(ii) The light emitting efficiency may be shown to be

$$\eta_i = (1 / \tau_{rr})/((1 / \tau_{rr})+(1 / \tau_{nr}))$$

$$\Rightarrow \tau_{nr} = \tau_{rr} \eta_i / (1 - \eta_i) = 4.67 \text{ ns}$$

The overall response time, $\tau = 1/ ((1 / \tau_{rr})+(1 / \tau_{nr})) = 1.4$ ns

$\Rightarrow$ The bit rate B = 1/(1.4 τ) = <u>510 MHz</u>

(iii) The linewidth is assumed to be dominated by *thermal effects* so that the range of emission energies is given by

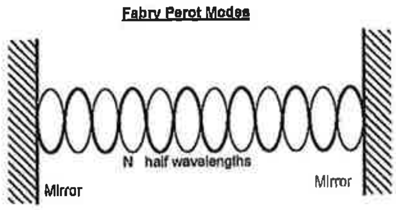
$$\Delta E = 2kT = h|\Delta f| = (hc/ \lambda^2).|\Delta\lambda|$$

$$\Rightarrow T = hc. |\Delta\lambda|/(2k \lambda^2) = 359 \text{ K or } 76\ ^{o}\text{C}$$

2 (a) A good answer, which is largely bookwork, should include the following:

A Fabry Perot cavity is formed by two reflectors set a distance L apart. This ensures that while light can leave the cavity as a laser beam, it can also be recycled, thus maintaining lasing action. The optical field oscillates at such a wavelength that nodes occur at both reflectors. As a result a series of different wavelengths λ_m can be supported by such a cavity where

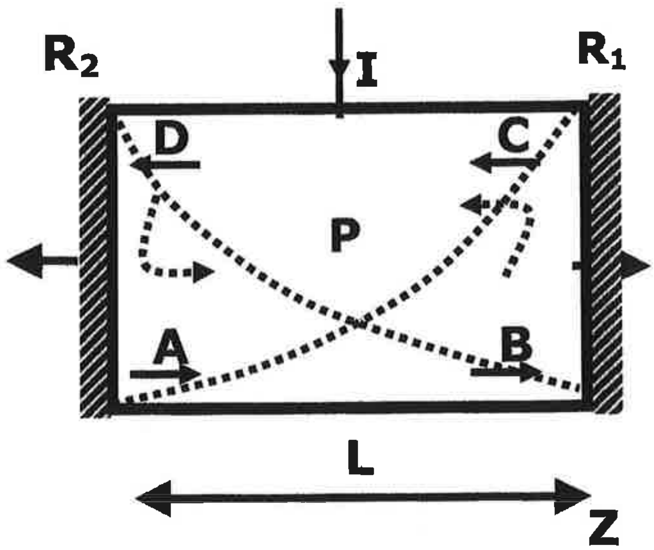
$$\lambda_m = 2L/m.$$



(The wavelength spacing therefore is $\Delta\lambda = \lambda^2/2L$). It should be noted however that wavelengths are only generated if electronic transitions occur with the necessary energy spacing. However a range of optical lasing modes can be generated simultaneously if a range of energy levels are available.

Comments on advantages and disadvantages should include the simplicity and low cost features of the device structure, whereas its multimode nature limits applications, for example in long haul communications where dispersion is important.

(b)



The photon lifetime of the laser cavity can be readily determined by considering the amplification of laser light as it propagates along the laser cavity.

Assume that stimulated emission encounters a gain per unit length (due to stimulated amplification), G, and a loss per unit length due to scattering and absorption, α, as it passes along the laser. The gain G in practice creates extra photons to compensate for those photons lost as the signal travels over a distance of unit length.

Therefore the stimulated light A starting at one facet will be incident on the opposite facet with an optical power

$$B = \exp\{(G - \alpha)L\}\, A$$

At that point part of the signal is reflected with a coefficient R and the signal then passes back amplified by 1 the same amount as above and again reflected by the initial facet. Lasing action will occur in the nett round trip gain of the signal is unity i.e. if

$$\exp\{(G - \alpha)L\}.R_1\exp\{(G - \alpha)L\}.R_2 = 1$$

$$=> \quad G = \alpha + (1/2L)\ln(1/(R_1R_2))$$

This value of G is equal to the ratio of photons lost as the signal travels a unit length and hence the proportion of photons lost per unit time is simply the gain G times the speed of light in the laser material, v_g. As a result the average time for which one photon will remain in the cavity is given by

$$\tau_p = 1/Gv_g$$

$$= 1/\{v_g\{\alpha + (1/2L)\ln(1/R_1R_2)\}\}$$

(c) Above threshold the differential efficiency is simply the proportion of photons leaving the cavity through the facets over the total number of photons. It is equal therefore to the loss through the facets divided by the total loss; i.e.

$$\eta_D = \frac{\ln(1/(R_1R_2))/(2L)}{\alpha + \ln(1/(R_1R_2))/(2L)}$$

(d)

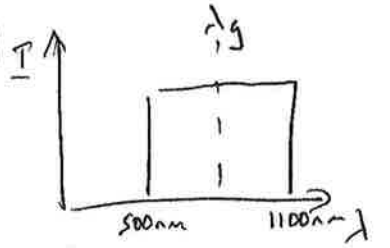
$$\delta\lambda = \frac{\lambda^2}{2nL} => L = \frac{\lambda^2}{2n\delta\lambda} = 310\ \mu\text{m}$$

$$\eta = \frac{\frac{1}{L}\ln(\frac{1}{R})}{\alpha + \frac{1}{L}\ln(\frac{1}{R})} = \frac{1}{1 + \alpha L/\ln\frac{1}{R}}$$

$$=> R = \left[\exp\left\{\alpha L/(\frac{1}{\eta} - 1)\right\}\right]^{-1} = 8\%\ [power]$$

3. (a) Bookwork.

(b)



λ_g certainly should > 500nm or no energy absorbed.

Photon energy @ wavelength λ = $\frac{hc}{\lambda}$

So for $\lambda < \lambda_g$ energy absorbed $= \frac{hc}{\lambda}$ but e, h generated will relax via phonon emission to useable energy of $\frac{hc}{\lambda_g}$ $\Rightarrow$

$hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_g}\right)$ will be lost.

So if λ_g is at a long wavelength, then for short λ photons, a lot of energy is lost. If λ_g is too short, long λ photons will not be absorbed.

The optimum λ_g will be somewhere between the two extremes of the spectrum.

(c) (ii) $I = I_o\left(e^{\frac{eV}{nkT}} - 1\right)$

$$\frac{I_{ph} + I_o}{I_o} = \exp\left(\frac{eV}{nkT}\right)$$

$$V_{oc} = \frac{nkT}{e}\ln\left(\frac{I_{ph} + I_o}{I_o}\right)$$

$$= \frac{1 \times 1.38\times10^{-23} \times 75}{1.602\times10^{-19}}\ln\left(\frac{0.185 + 2\times10^{-6}}{2\times10^{-6}}\right)$$

$$= 0.074\ \text{V}$$

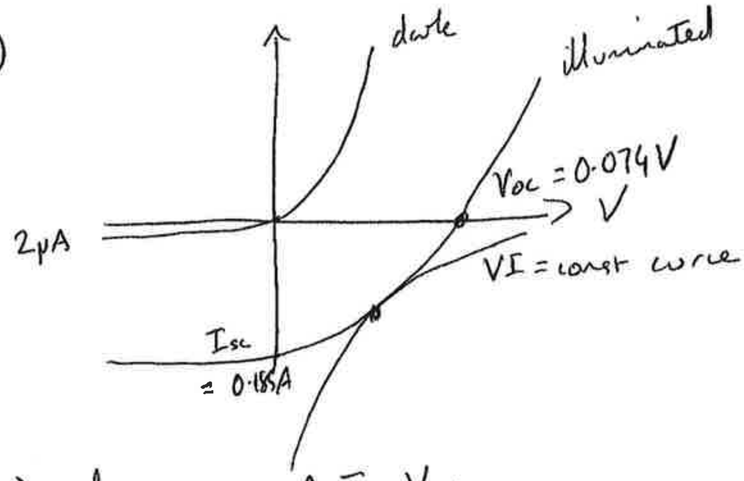
(i) $I_{ph} = \eta e\, {}^{P}/_{hc/\lambda}$

$$= \frac{0.85 \times 1.602\times10^{-19} \times 0.3}{\frac{6.626\times10^{-34} \times 3\times10^{8}}{900\times10^{-9}}}$$

$= 0.185\text{A}$

$= I_{sc}$

(iii)



(iv) $P_{max} = A\, I_{sc} V_{oc}$

$= 0.7 \times 0.185 \times 0.074V$

$= 9.6\ mW.$ $(\sim 3\%$ efficient)

4.(a) Bookwork.

To include

- SI MMF. Cheap. V. low bandwidth. Easy to use. Low speed applications (incl. endoscopes, e.g. POF comms in vehicles)
- GI MMF. Relatively expensive. Moderate bandwidth. Easy to use. Often used in building LANs
- SI SMF. Cheap. V. high bandwidth. Difficult to handle. - Telecoms.

(b)

$$V = \frac{2\pi a}{\lambda}\left(n_{co}^2 - n_{cl}^2\right)^{1/2} = 2.4 \text{ at cut off}$$

$$\Rightarrow a = \frac{V\lambda}{2\pi\left(n_{co}^2 - n_{cl}^2\right)}$$

(core radius)

So want to ~~maximise~~ minimise $(n_{co}^2 - n_{cl}^2)$ to maximise a

So choose $n_{co} = 1.52$, $n_{cl} = 1.51$

$$\Rightarrow a = \frac{2.4 \times 1.55\,\mu m}{2\pi\sqrt{(1.52^2 - 1.51^2)}} = 3.4\,\mu m$$

Diameter: $2a = 6.8\,\mu m$

Fibre will be at cut off ie very close to 1st order mode being excited.

(c). Power budget = launch power − sensitivity − margin (in dB)

= 2 dBm − (−30 dB/m) − 3 dB

= 29 dB.

Attenuation limit = $\frac{29 \text{ dB}}{0.6 \text{ dB/km}}$ = 48.3 km.

Dispersion $t_o^2 = t_i^2 + t_{disp}^2$

t_{in} = 800 ps ⇒ $t_o|_{max}$ = 1600 ps.

⇒ $t_{disp}^2 = 1600^2 - 800^2$

t_{disp} = 1386 ps.

= $D \, \Delta\lambda \, L_{disp}$.

L_{disp} = ~~1386 ps~~ $\frac{1386 \text{ ps}}{15 \text{ ps/nm.km} \times 3 \text{ nm}}$.

= 30.8 km. (dispersion limit)

So maximum link length limited by dispersion to 30.8 km.

d) i) To increase length, need to reduce dispersion ⇒ reduce Δλ. Use DFB where Δλ < 0.1 nm. (could use DCF but not cost-effective).

ii) then need to remove ~~dispers~~ attenuation limit so use EDFAs (note ~~→~~. Length of 310 km would require ~ (310 − 48) × 0.6 dB

= 157 dB of gain (approx 5 EDFAs distributed throughout link)

3B6 Photonic Technology

No changes were required for the exam.

Numerical Answers

1. (c) i) 1.61V, ii) 510 MHz, iii) 359 K
2. (d) 8%
3. (c) i) 0.185 A, ii) 0.074 V, 0.185 A, iv) 9.6 mW
4. (b) 6.8 μm, 30.8 km