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Cribs to Photonic Technology 3B6

Q.1 (a) Answers are primarily from book work.

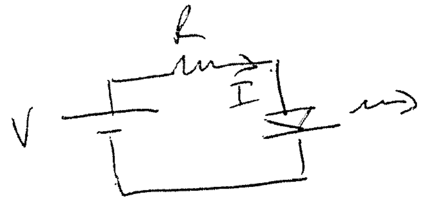
– LEDs may be used in certain applications because of advantages through low cost, broad linewidth allowing reduced speckle, eye safety issues, or because of operating wavelength requirements

A suitable answer might involve the description of surface and edge emitting light emitting diodes.

(b)

$$\eta = \eta_{int} \cdot \eta_{ext} = \frac{1/\tau_{rr}}{1/\tau_{rr} + 1/\tau_{nr}} \cdot 0.04$$

$$= \frac{2}{3} \cdot 0.04 = 0.0267$$



$$\Rightarrow \quad V = IR + V_F \quad \text{and} \quad P = \frac{hc}{\lambda}\eta\frac{I}{e}$$

$$\Rightarrow \quad I = \frac{Pe\lambda}{hc\eta} = \frac{0.5\times10^{-3} \times 1.6\times10^{-19} \times 650\times10^{-9}}{6.625\times10^{-34}\times 3\times10^{8} \times 0.0267}$$

$$= \underline{9.81\,\text{mA}}$$

$$V_F = \frac{hc}{e\lambda} = 1.91\ \text{V}$$

$$\Rightarrow \quad V = 25\times 9.81\times10^{-3} + 1.91 = \underline{2.15\ \text{V}}$$

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Q.1 (c) The linewidth can be written as

$$\delta\nu = 2kT/h. \quad \text{in terms of frequency}$$

$$\Rightarrow \delta\lambda = \frac{\lambda^2}{c}\frac{2kT}{h} = \frac{(650\times10^{-9})^2 \times 2\times1.38\times10^{-23}\times300}{6.625\times10^{-34}\times3\times10^{8}}$$

$$= \underline{18 \text{ nm}}$$

Q.1 (d)

$$\frac{P(T)}{P(T_1)} = \exp\left(\frac{T-T_1}{T_0}\right)$$

$$\rightarrow P(350) = P(300)\,.\exp\left(\frac{350-300}{100}\right)$$

$$= 0.5 \exp 0.5 \text{ mW}.$$

$$= \underline{\qquad\qquad}$$

Q. 2 (a) Bookwork answer.

A good answer should include the need for population inversion and optical feedback and the describe the major steps involved in achieving electrical and optical confinement.

(b) Bookwork answer for comments on the main terms within the equations and on any assumptions.

For derivation, assume $\frac{dn}{dt} = \frac{dP}{dt} = \phi$ and $\beta = 0$

$\therefore$ taking photon rate equation,

$$0 = P \left\{ g(n - n_0) - 1/\tau_p \right\}$$

$\Rightarrow$ for $P > 0$, $n = n_0 + \frac{1}{g\tau_p}$ $\Rightarrow$ constant

Taking the electron rate equation

$$I = \frac{neV}{\tau_s} = \frac{eV}{\tau_s}\left(n_0 + \frac{1}{g\tau_p}\right)$$

= threshold current.

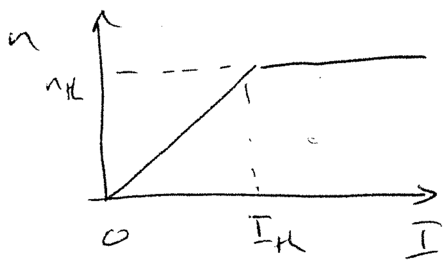
Q.2(b) Above threshold, the photon rate equation may be rewritten

$$P = \frac{\left(\frac{I}{eV} - \frac{n_{th}}{\tau_s}\right)}{g(n_{th} - n_0)}$$

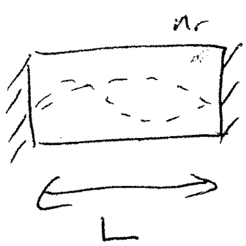
$$= \frac{I - I_{th}}{eV g (n_{th} - n_0)}$$

Below threshold $n = \frac{I \tau_s}{eV}$

$\therefore$ carrier and photon characteristics may be drawn as follows:



Q.2(c) Modes are generated according to the structure of the Fabry Perot laser cavity



i.e. $\frac{m\lambda}{2} = n_r L$

Q. 2 (c) cont.

But $f = \frac{c}{\lambda}$ $\Rightarrow$ $\frac{mc}{2f} = n_r L$

$$\Rightarrow f = \frac{mc}{2n_r L}$$

$\Rightarrow$ mode spacing in frequency, δf

$$= \frac{c}{2n_r L}$$

But $\delta f = \left|\frac{c}{\lambda^2}\right| \delta\lambda$ $\Rightarrow$ $\delta\lambda = \frac{\lambda^2}{\cancel{c}} \cdot \frac{\cancel{c}}{2n_r L}$

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

3. (a) Bookwork

	Advantages	Disadvantages
1300nm	Low loss window Low (can be zero) dispersion Low cost optical sources available (FPs – VCSELs) Low linewidth sources available (DFBs) SOAs available.	But not the lowest No low noise amplifier
1550nm	Lowest loss window ~~Bla~~ Low NF fibre amplifier (EDFA) High performance optical sources (DFBs, EAMs, MZIs) High capacity WDM systems	Fairly high dispersion (~17ps/nm/km

– Main applications for 1550nm window is high capacity telecommunications. Unamplified spans of ~100km possible ~~&~~ with amplified systems of ~5000km possible. Single channel rates of 10Gb/s possible with WDM enabling 1Tb/s aggregate rates.

– Main application of 1300nm is datacommunications where ~~Bi~~ unamplified systems dominate. Typical lengths are 100s m though 40km is possible. Typical links are single wavelengths. Most links are <2Gb/s but 10Gb/s possible.

(b). Bit period, $T = \frac{1}{2.5 \times 10^9} = 400\,ps$

Dispersion

$$\Delta t_{out}^2 = \Delta t_{in}^2 + \Delta t_{disp}^2 \qquad (1)$$

Assume $\Delta t_i = T = 400\,ps$

$$\Delta t_{disp} = D\,L\,\Delta\lambda \qquad (ps)$$

$$= 2.5 \times L \times 3$$

$$= 7.5\,L \qquad (ps) \text{ where } L \text{ is in km} \qquad (2)$$

from (1) $\Delta t_{disp}^2 = \Delta t_{out}^2 - \Delta t_{in}^2$

But for dispersion limit $\Delta t_{out} = 1.5\,\Delta t_{in}$

$= 600\,ps$

$$\Rightarrow \Delta t_{disp}^2 = 600^2 - 400^2 \; ps^2$$

$$\Rightarrow \Delta t_{disp} = 447.2\,ps$$

from (2) $7.5L = 447.2\,ps$

$$\Rightarrow L = \frac{447.2}{7.5} \; \cancel{ps} \; km$$

$$= 59.6\,km$$

Attenuation

Power budget $= P_{launch} - P_{receiver}$

$= 3\,dBm - (-19\,dBm)$

$= 22\,dB$

Attenuation length limit $= \frac{22}{0.5} = 44\,km$

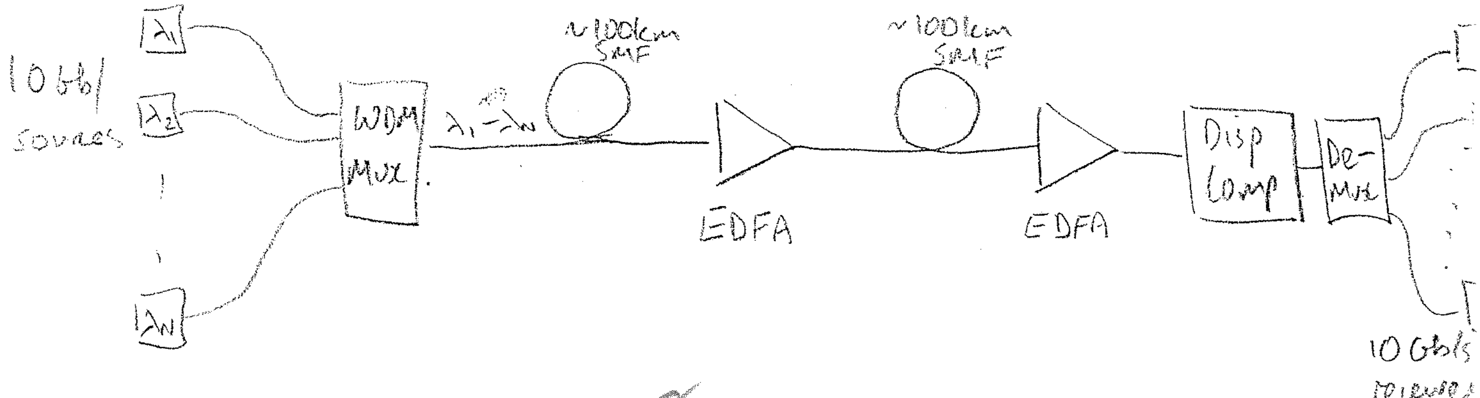
(6) To increase link length beyond the attenuation limit it is necessary to use optical amplifiers. The best amplifier is the EDFA as it has high gain and a near quantum limited noise figure. This would require a change of operating wavelength to 1550nm. Achievable fibre spans between amplifiers are ~ 100km

To increase the data rate beyond the currently available single channel data rate of 10Gb/s it is necessary to multiplex. The best way of doing this is via wavelength division multiplexing.

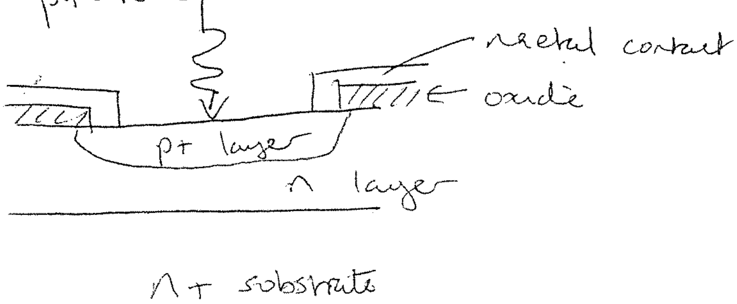
Thirdly, the 200km length is beyond the dispersion limit and so some form of dispersion compensation will be necessary.

The simplest way is to use dispersion compensating ~~shifted~~ fibre (DCF)

The system would therefore look something like



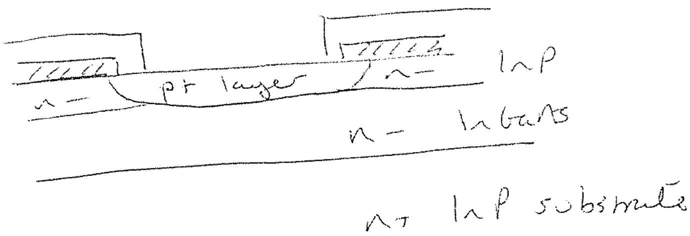
4(a) Basic p+-n structure



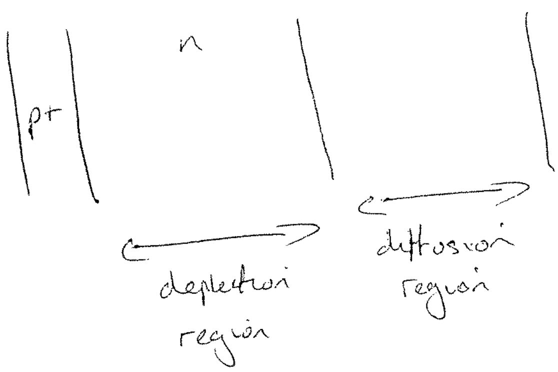
p+ layer formed by diffusion in simplest diodes forming planar homojunction photodiode

More complicated structures (acceptable in answer) include heterojunction devices.

e.g.

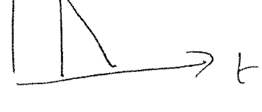


(b) The impulse response of a p+n photodiode is relative complicated as it consists of contributions from both the depletion and diffusion region

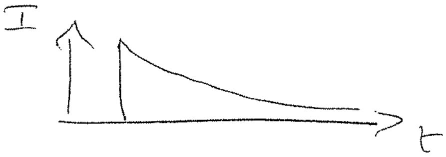


In the depletion region the main carrier transport mechanism is drift in the induced E field

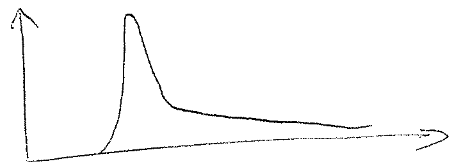
The impulse response is



The response ~~to~~ in the diffusion region is much slower than the depletion region with timescales of the order of the carrier recombination time

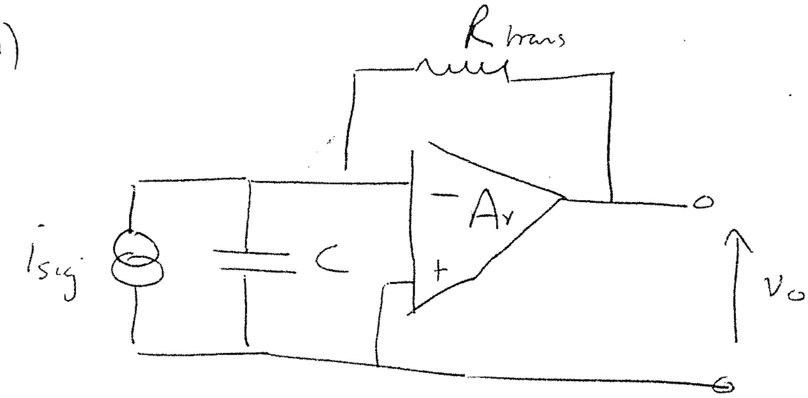


So composite ~~two~~ response is



The pin photodiode ~~[illegible]~~ overcomes the problem of the long tail. The pin structure ensures that the intrinsic region is fully depleted if the bias is high enough. This ensures that the pulse response is determined by the drift of the photocarriers and there are no problems associated with diffusion

(c) (i)



- Assuming ~~A~~ amplifier has broader bandwidth than circuit limit ie assume C of photodiode is limiting factor

$$\frac{V_o(s)}{i_{sig}(s)} = \frac{R_{trans}}{1 + sR_{trans}C/A_v}$$

$$\Rightarrow \quad \omega_{3dB} = \frac{1}{R_{trans}C/A_v} \gg 2.5\times10^9 \times 2\pi$$

$$\Rightarrow \quad R_{trans} \ll \frac{A_v}{C \times 2\pi \times 2.5\times10^9}$$

$$\ll \frac{60}{0.8\times10^{-12} \times 2\pi \times 2.5\times10^9}$$

$$\ll 4.78\ \mathrm{k\Omega}$$

(ii) Assuming thermal noise is the limiting noise process and the circuit operates at 300K. Other noise processes mainly arise from shot noise (from photocurrent and dark current) and excess noise in amplifier.

$$\text{Require} \quad \frac{\langle i_{sig}\rangle^2}{\langle i_n\rangle^2} = 12\text{dB} \quad (\text{NB electrical})$$

$$= 15.85$$

NB optical

$$i_{sig} = \frac{\eta e}{hc/\lambda} P_{sig}$$

$$= \frac{0.8 \times 1.602\times10^{-19}}{6.63\times10^{-34} \times 3\times10^{8} / 1550\times10^{-9}} P_{sig}$$

$$= 0.999 \, P_{sig}$$

$$\langle i_n \rangle^2 = \frac{4kTB}{R} = \frac{4\times1.38\times10^{-23} \times 300 \times 2.5\times10^{9}}{4.78\times10^{3}}$$

$$= 8.671\times10^{-15} \, A^2$$

Minimum P_{sig} (ie sensitivity) when

$$\frac{\langle i_{sig} \rangle^2}{\langle i_n \rangle^2} = \frac{(0.999 \, P_{sig})^2}{8.671\times10^{-15}} = 115\times10^{12} \, P_{sig}^2$$

$$= 15.85 \quad \text{(from earlier)}$$

$$\Rightarrow \quad P_{sig}^{B} = \sqrt{\frac{15.85}{115\times10^{12}}}$$

$$= 371.1 \, nW$$

$$= -34.3 \, dBm$$