Chromatic Dispersion

Due to signal never being purely monochromatic and the refractive index (phase index) of silica being a function of λ, pulses will broaden temporally as they propagate along the fibre. If the broadening is great, intersymbol interference occurs leading to increased Bit Errors & eventually the complete failure of the system.

Attenuation

In order to discriminate between '0' or '1' logic levels, a sufficiently large signal (compared to the noise floor) is required. For a given data rate a certain power at the receiver is required for a given bit error rate. The total losses in a system (including margin) cannot therefore exceed the difference in launch & receiver powers in dBm.

[4]

Using 7 dB for loss in fibre.

Using $BLD\Delta\lambda \leq \frac{1}{4}$

(n.b. assumption → allow bit to broaden by $\frac{1}{4}$ bit slot time - could be $\frac{1}{2}$ but doesn't chnge result in end.)

(use $\frac{1}{2}$ instead of $\frac{1}{4}$)

	Disp limit	Loss Limit	
1.35 μm	50 km (25 km)	17.5 km	cat over ⇒
1.55 μm	3.33 km (1.6 km)	35 km	

so best to use 1.35 μm for loss limited transmission up to 17.5 km link length (10)

To send @ 10 GBits/sec.

i) DFB @ 1.35 or 1.55. 1.55 better as (2) 35 km link length possible. (2)

ii) WDM system → 10 multiplexed 1 GBit transmitters @ ~ 1.35 μm (2)

Dispersion Limits.

$$BLD\Delta\lambda \leq \frac{1}{4} \Rightarrow L = \frac{1}{4 B D \Delta\lambda}$$

$B = 1 \times 10^9$

$L = ?$

$D = 1$ @ 1.35, 15 @ 1.55 (ps/nm.km)

$\Delta\lambda = 5$ nm

1.35 μm $\quad L = \dfrac{1}{4 \times 1 \times 10^9 \times 5 \times 10^{-12}}$ (km)

$= \dfrac{1}{20 \times 10^{-3}}$ (km)

$= 50$ km (n.b = 25 km if assume ½ Bit slot broadening).

1.55 μm $\quad L = \dfrac{1}{4 \times 1 \times 10^9 \times 5 \times 15 \times 10^{-12}}$ (km).

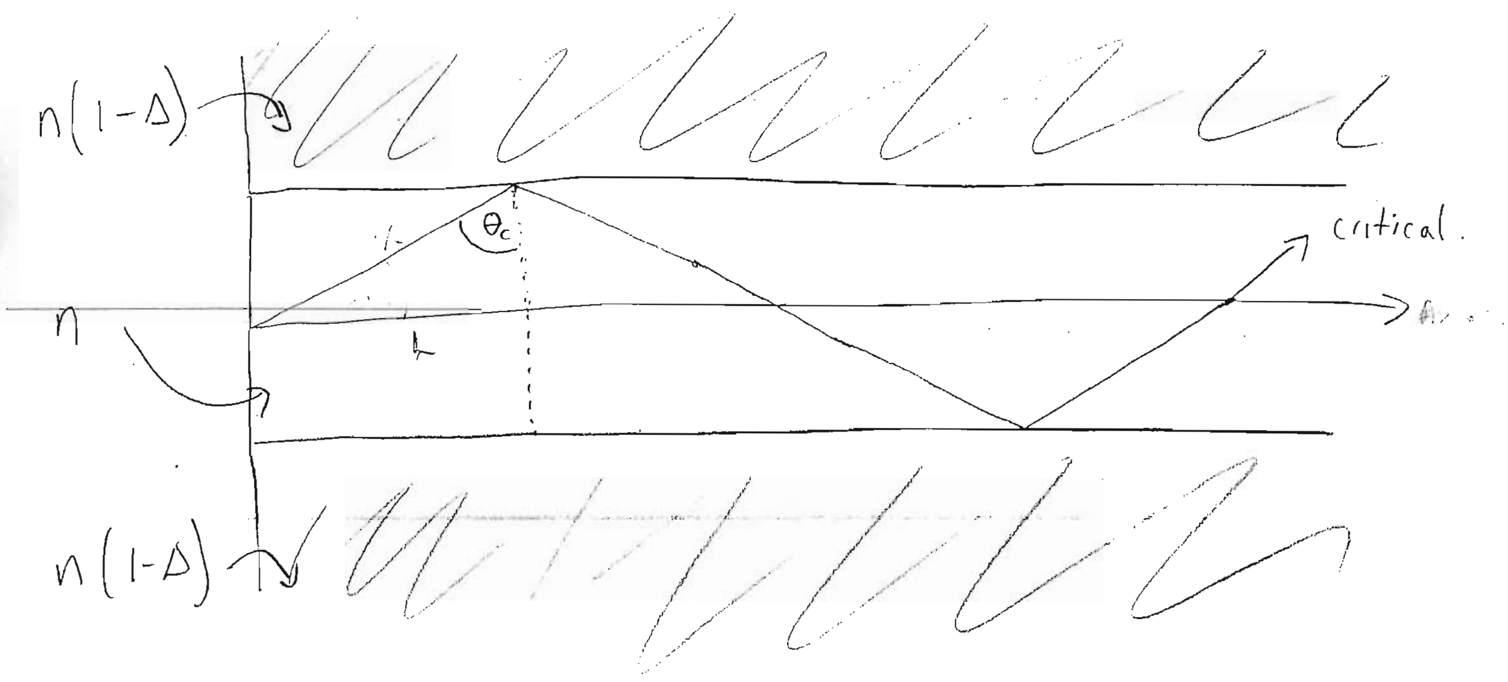
$= 3.33$ km.

Loss Limit

7 dB loss.

@ 1.35 $\quad$ 0.4 dB/km $\Rightarrow$ 17.5 km

@ 1.55 $\quad$ 0.2 dB/km $\Rightarrow$ 35 km.



For meridional ray

$$t_{meridional} = \frac{L}{v_1} = \frac{Ln}{c}.$$

for critical ray, fibre length $L \rightarrow$ signal travels $\dfrac{L}{\sin\theta_c}$

$$t_{critical} = \frac{Ln}{c\sin\theta_c}$$

Differential $= t_{critical} - t_{meridional}$

$$\delta t = \frac{Ln}{c\sin\theta_c} - \frac{Ln}{c}$$

Snells Law defines $\sin\theta_c = \dfrac{n(1-\Delta)}{n}$

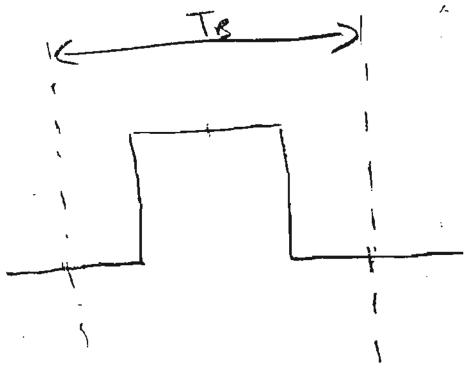
$$\delta t = \frac{Ln}{c(1-\Delta)} - \frac{Ln}{c}$$

$$= \frac{Ln - Ln(1-\Delta)}{c(1-\Delta)}.$$

$$\delta t = \frac{Ln\Delta}{c(1-\Delta)}.$$

[5]

Bit slot & Allowed Broadening.



$T_B = \frac{1}{B}$ $\quad$ B = Data rate.

Assume broadening to be $T_B/4$

(may be $T_B/2$ ....)

$$\delta t \leq \frac{T_B}{4} \leq \frac{1}{4B}$$

$$\frac{1}{4B} \leq \frac{Ln\Delta}{c(1-\Delta)}.$$

$$L \leq \frac{c(1-\Delta)}{4n\Delta B}.$$

[5]

$$L \leq \frac{3 \times 10^8 \times 0.99}{4 \times 1.5 \times 0.01 \times 50 \times 10^6}$$

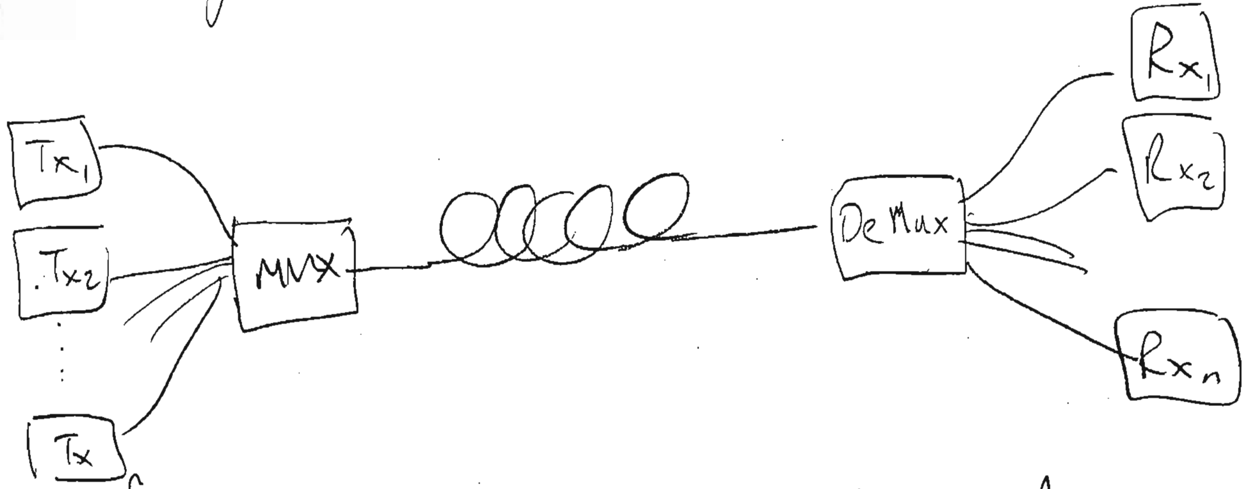
$$L \leq \frac{3 \times 10^8 \times 0.99}{3 \times 10^6}$$

$$L \leq 99 \text{ m}$$ [2]

so maximum link length ~ 100 m.

WDM.

Relies on capability of fibre to carry light of different wavelengths, without the interactions of the optical signal.



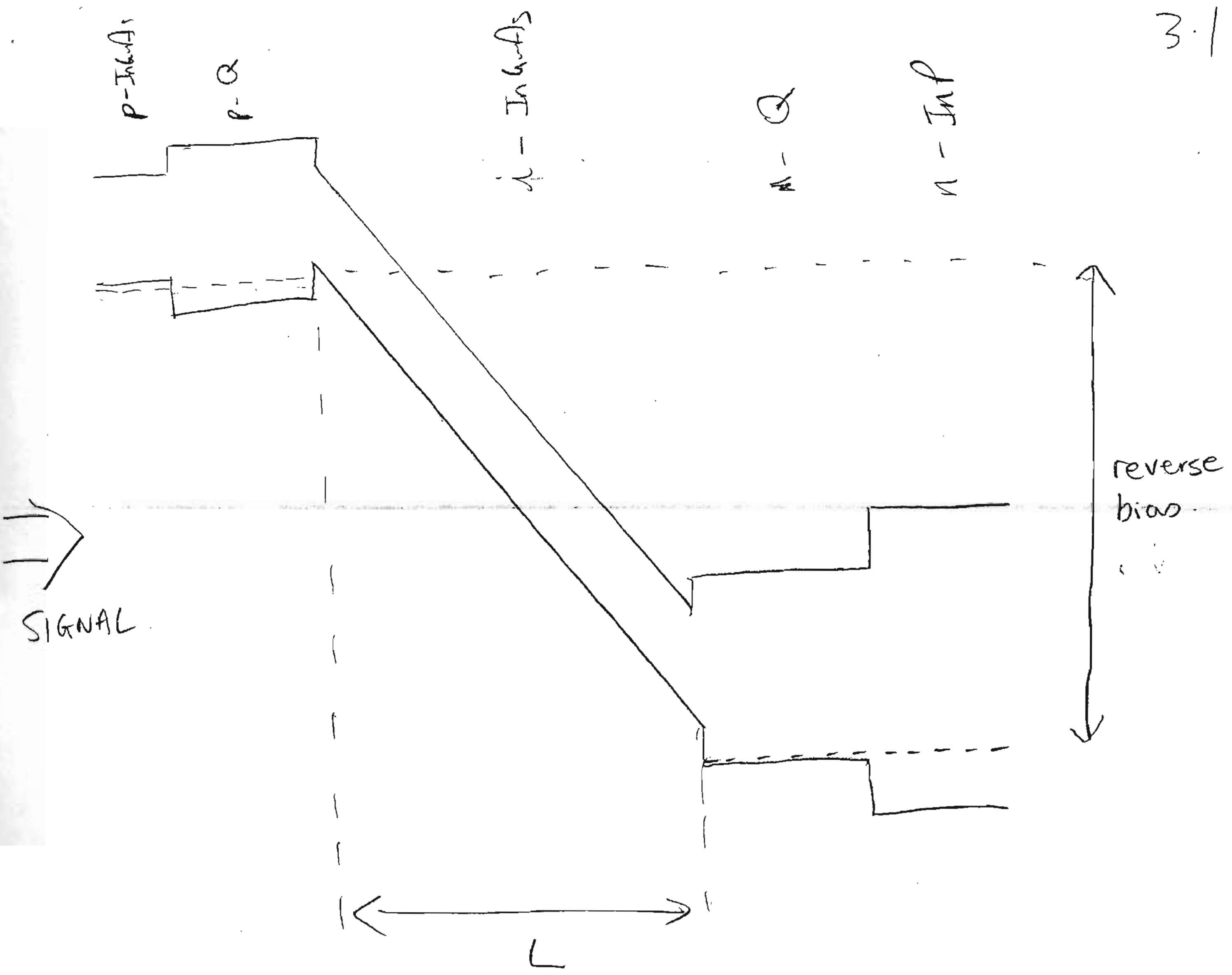
Requires components to combine optical signals in a fibre (MUX) and to filter multiple optical channels in one physical channel into one optical channel in each physical channel. [5]

Crosstalk ..

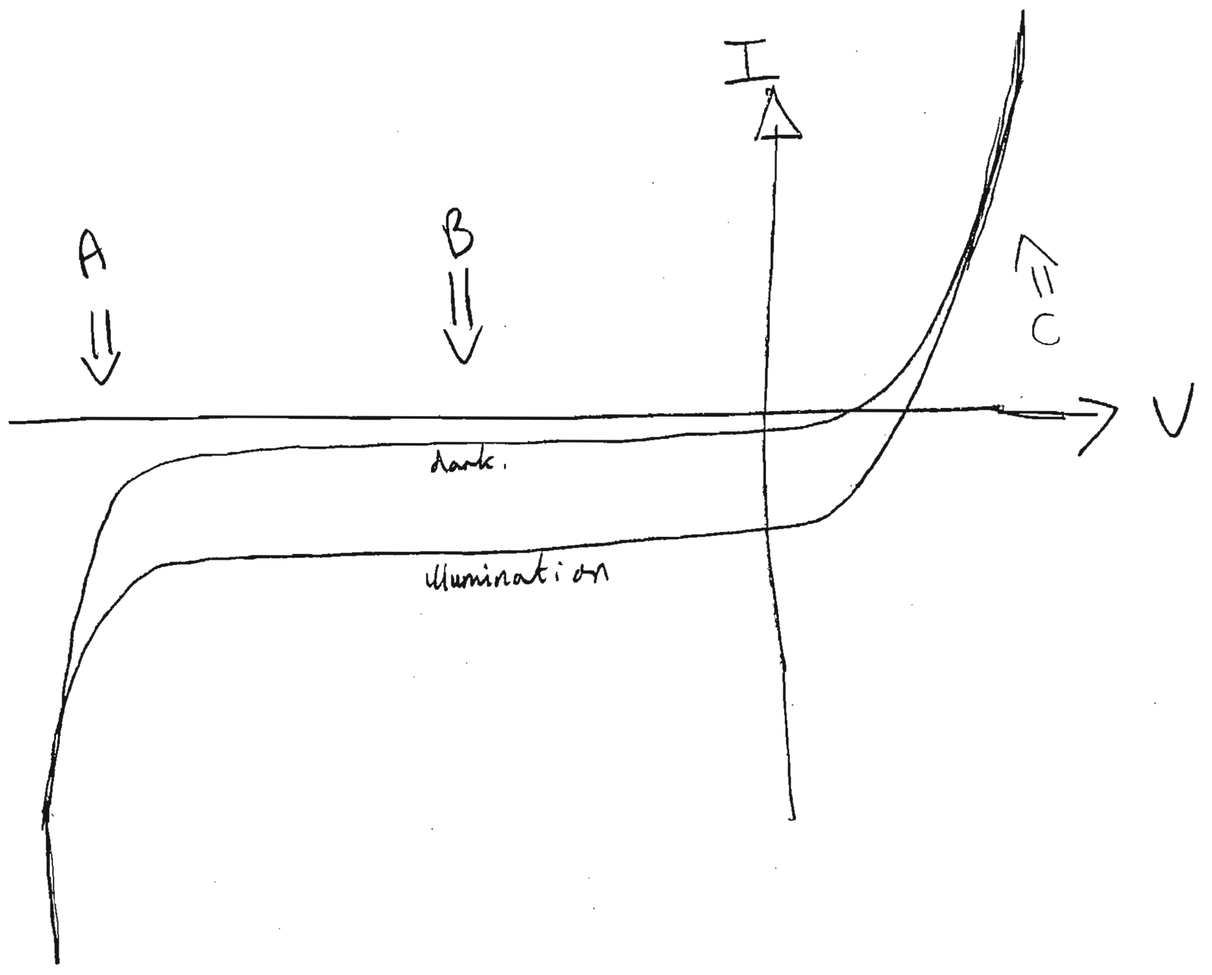
1. ⇒ De-Mux not 100% efficient at removing other channels. (Out-of-band - X-talk).

2. ⇒ If EDFA used in system can get X-gain modulation or cross-talk.

[3]


p-InGaAs
p-Q
n-InGaAs
n-Q
n-InP
reverse bias
SIGNAL
L

IV


I
V
A
B
C
dark.
illumination

A $\rightarrow$ Reverse Breakdown due to either Avalanche (high purity crystal) or Zener (defective material) breakdown.

B $\Rightarrow$ Dark & Photo-current in operating regime: Dark current due to defects / unpassivated surfaces.

C $\Rightarrow$ Forward bias $\rightarrow$ light emission.

$\boxed{8}$

For High internal Quantum Efficiency, need $\alpha L \gg 1$ $(\eta_{int} = 1 - e^{-\alpha L})$. so need to maximise L.

For speed 2 factors.

1.) RC time constant $\Rightarrow C = \frac{\varepsilon \varepsilon_0 A}{L}$ Want L Big.

2.) Carrier transit time $\Rightarrow t_{transit} = \frac{L}{V_{sat}}$ ($\leftarrow$ saturation vel.)

Want L small.

$\boxed{6}$

Responsivity

(or edge entry / waveguide config)

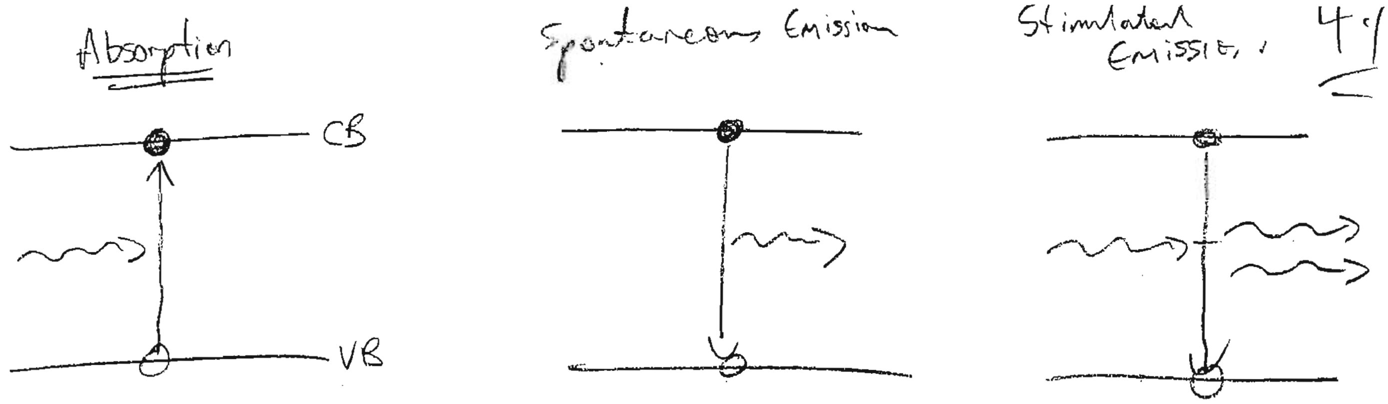
1.) Use substrate entry: p - InGaAs cap will absorb light but not contribute to signal photocurrent.

2.) Use Anti-Reflection coatings → loose ~ 30%

$$\left[R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 \quad n_1 = 1 \quad n_2 \sim 3.5 \right]$$

3). Redesign to utilize avalanche multiplication →
APD

$\boxed{6}$



Absorption → A photon with sufficient energy can excite an electron from the valence band to the conduction band. the absence of an electron in the v-b is termed a 'hole'.

Spontaneous Emission → An electron and hole, being of opposite charge are attracted to each other. The electron looses it's energy to a photon and relaxes to the valence band. Emitted photon has random phase & direction.

Stimulated Emission → This is the emission of a photon by the relaxation of an electron from the conduction band to the valence band — but the process is stimulated by an incident photon. The emitted photon is of the same energy, phase & direction to the stimulating photon.

for LD

Applying small current get spontaneous emission due to injected holes & electrons. As carrier density is increased Absorption is bleached (reduced electrons in VB, [illegible] VB) and stimulated emission becomes more probable. When stimulated emission is more likely than absorption an incident signal experiences gain. $\frac{4 \cdot 2}{[6]}$

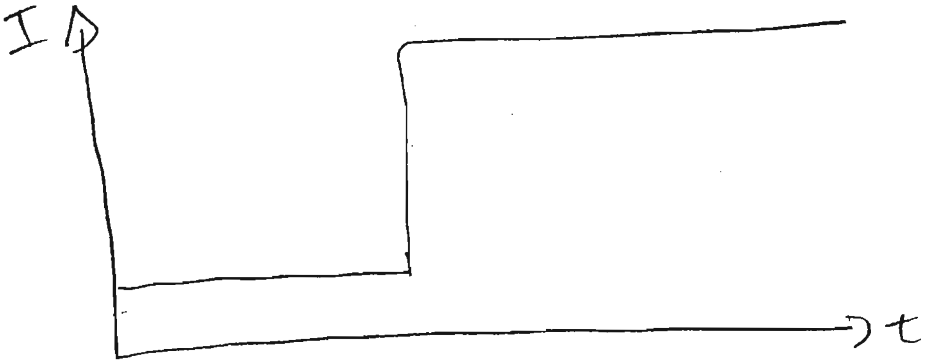
ii) Longitudinal $\Longrightarrow$ Reduce spectral width & reduce chromatic dispersion. Achieved by reducing length of FP laser or better to introduce a wavelength selective filter within the laser structure.

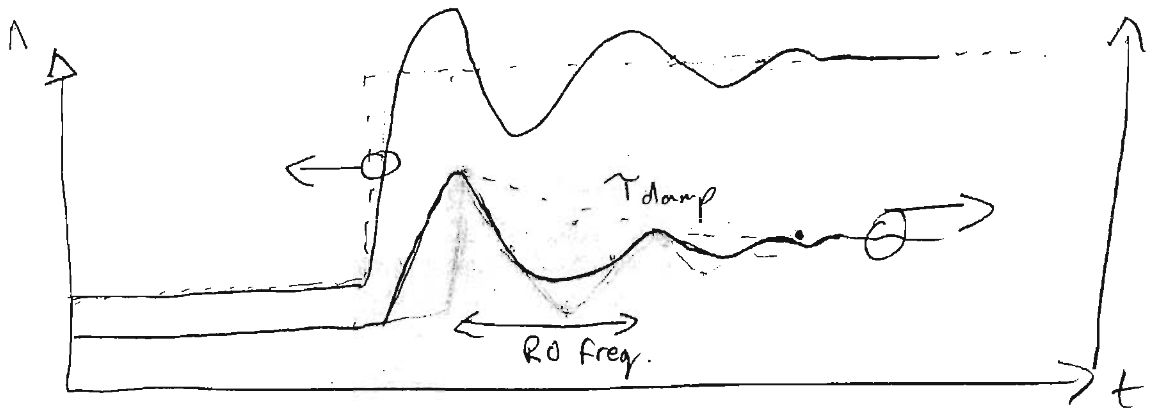
Transverse $\Longrightarrow$ Need to fibre-couple laser. Additional lateral modes do not couple efficiently to fibre. Remove by making laser width sufficiently small that higher order optical modes experience a high loss and have a high threshold compared to the fundamental. [4]

(c). Carriers & photons coupled.

$$\frac{dn_{el}}{dt} = \frac{J}{qd} - \frac{n}{\tau_{sp}} - g\,n_{photon}$$

$$\frac{d\,n_{photon}}{dt} = g\,n_{photon} - \frac{n_{photon}}{\tau_{photon}} + \frac{\beta n}{\tau_{sp}}$$





4-3

[4]

STRATEGIES FOR INC. ω_0.

$\frac{dg}{dn}$ → increase → δ-p-doping to remove carrier transport effects.
→ Use QWs, strained QWs, QDs to reduce DOS.

N_{photon} → increase → High current → High power
→ problems with heat, facet damage.

τ_{photon} → decrease → short cavity → J_{thrsh} increases
→ thermal problems

[6]