OPTICAL FIBRE CHARACTERISTICS

Attenuation in fibres

- rayleigh scattering
- impurities
- bending loss
- reflections at cleaved facets

Fibre Manufacture

Amplitude Modulated Bit

- Attenuation Limits
- Dispersion Limits

Power Budget

Attenuation in Optical Fibres

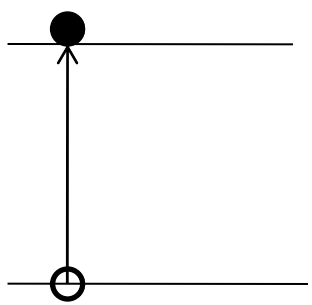
- Sources of attenuation
  - Intrinsic Absorption
  - Rayleigh Scattering
  - Extrinsic Absorption (impurities)
  - Bending losses
  - Fresnel reflection loss

Intrinsic Absorption (1)

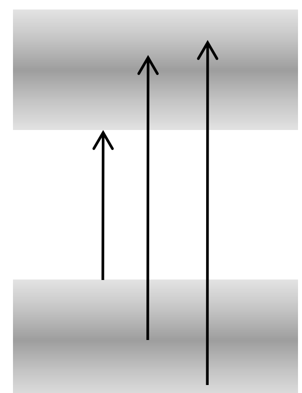
UV Absorption

Glass absorbs UV light – tail extends into the near IR

Termed UV absorption – this is a direct optical transition of electronic states within the material



Electronic states - solid



amorphous solid

Amorphous - any noncrystalline solid in which the atoms and molecules are not organized in a definite lattice pattern. Such solids include glass, plastic, and gel.

Intrinsic Absorption (2)

Infrared Absorption

Glass absorbs in the Infra-red –this is due to the excitation of molecular vibrations within the material – the tails of these absorption peaks extends into the near IR

Rayleigh Scattering

Scattering of light by particles of size << wavelength of light

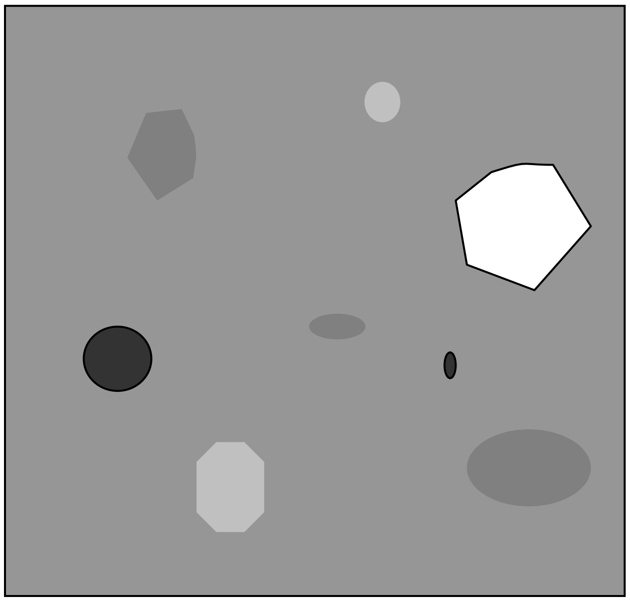
Scattering loss $\propto \lambda^{-4}$

Blue ~450nm
Green ~550nm
Red ~650nm

Blue scatters more than other colours

Lord Rayleigh

Rayleigh Scattering (2)



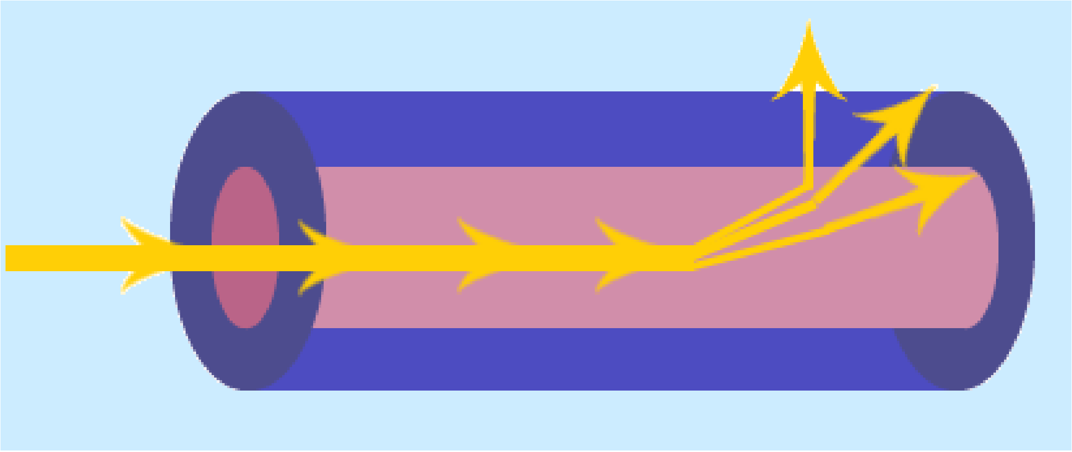
Glass is an amorphous solid

– not a homogeneous material
– local variations in refractive index

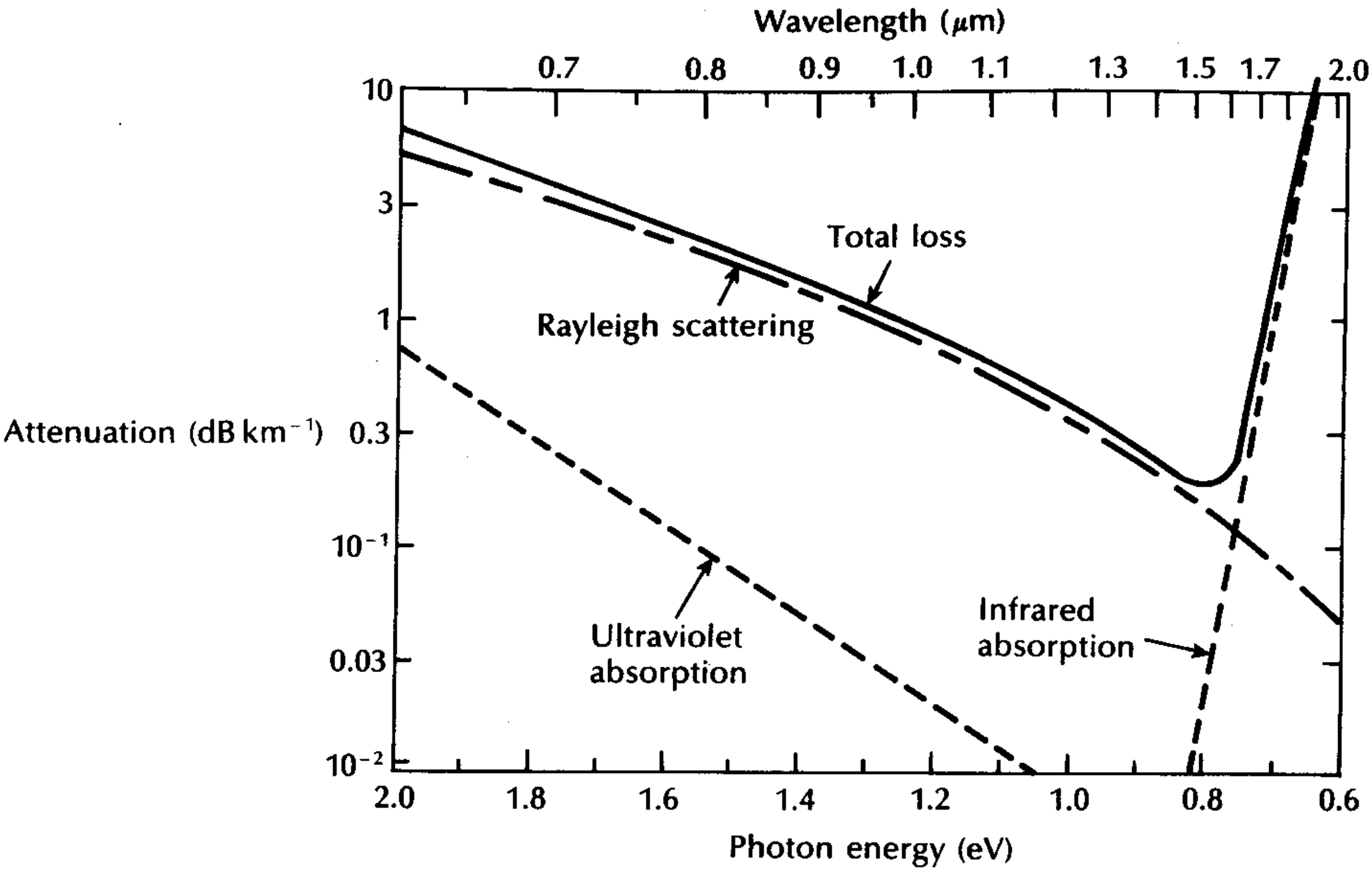
Scattering of light due to variations of refractive index on the scale << the wavelength of light

Rayleigh Scattering (3)

- Microscopic variations around average material density –on scale < λ
- These regions of fluctuating refractive index can scatter light out of core
- Elastic (wavelength before scattering = wavelength after)
- Linear (Scattering coefficient independent of optical power)
- Rayleigh Scattering Loss Coefficient varies as λ^{-4}
- More scattering as wavelength decreases



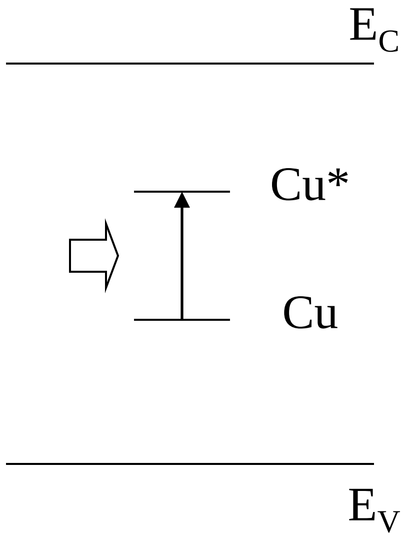
Intrinsic Processes



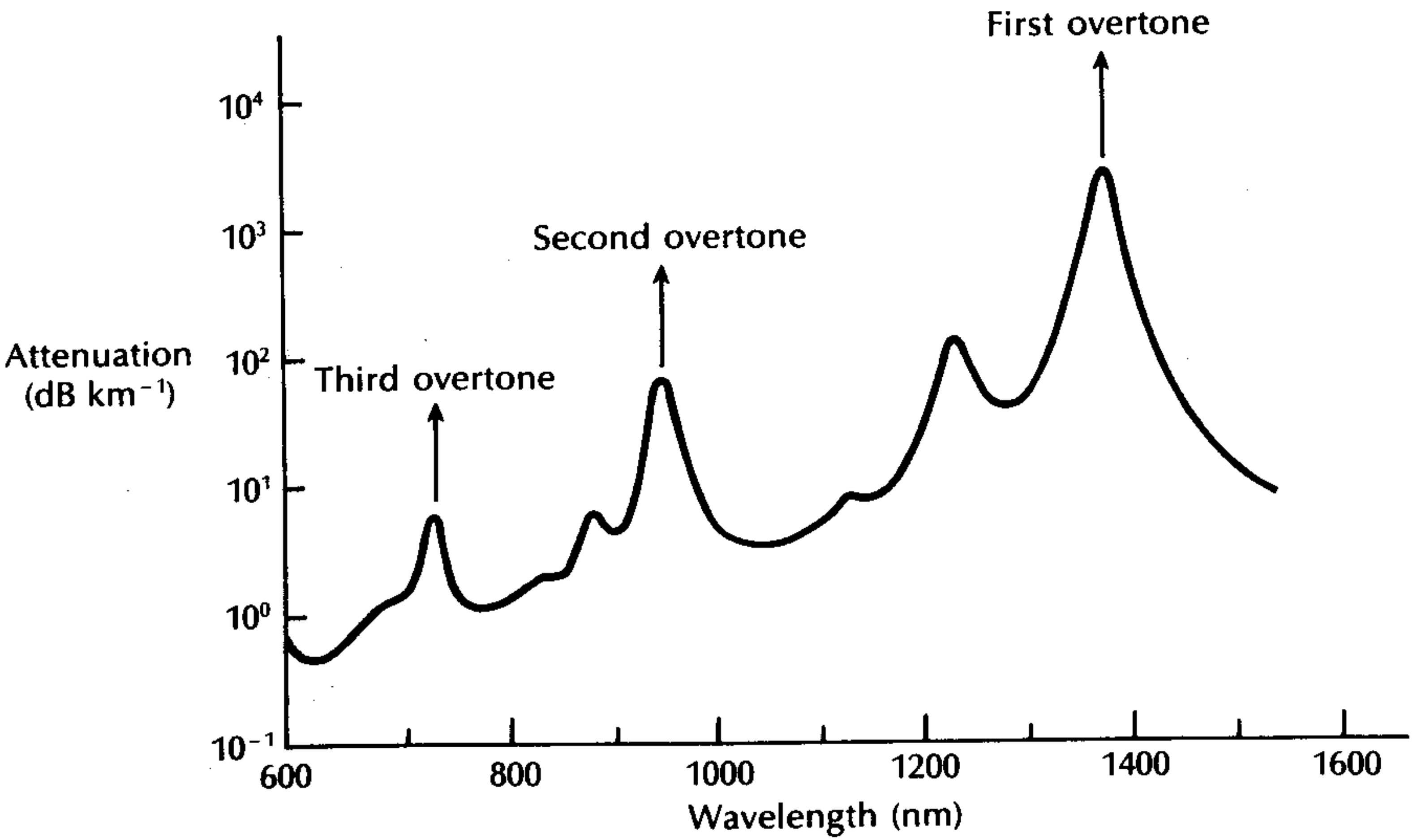
Absorption ~ power

Absorption by impurities

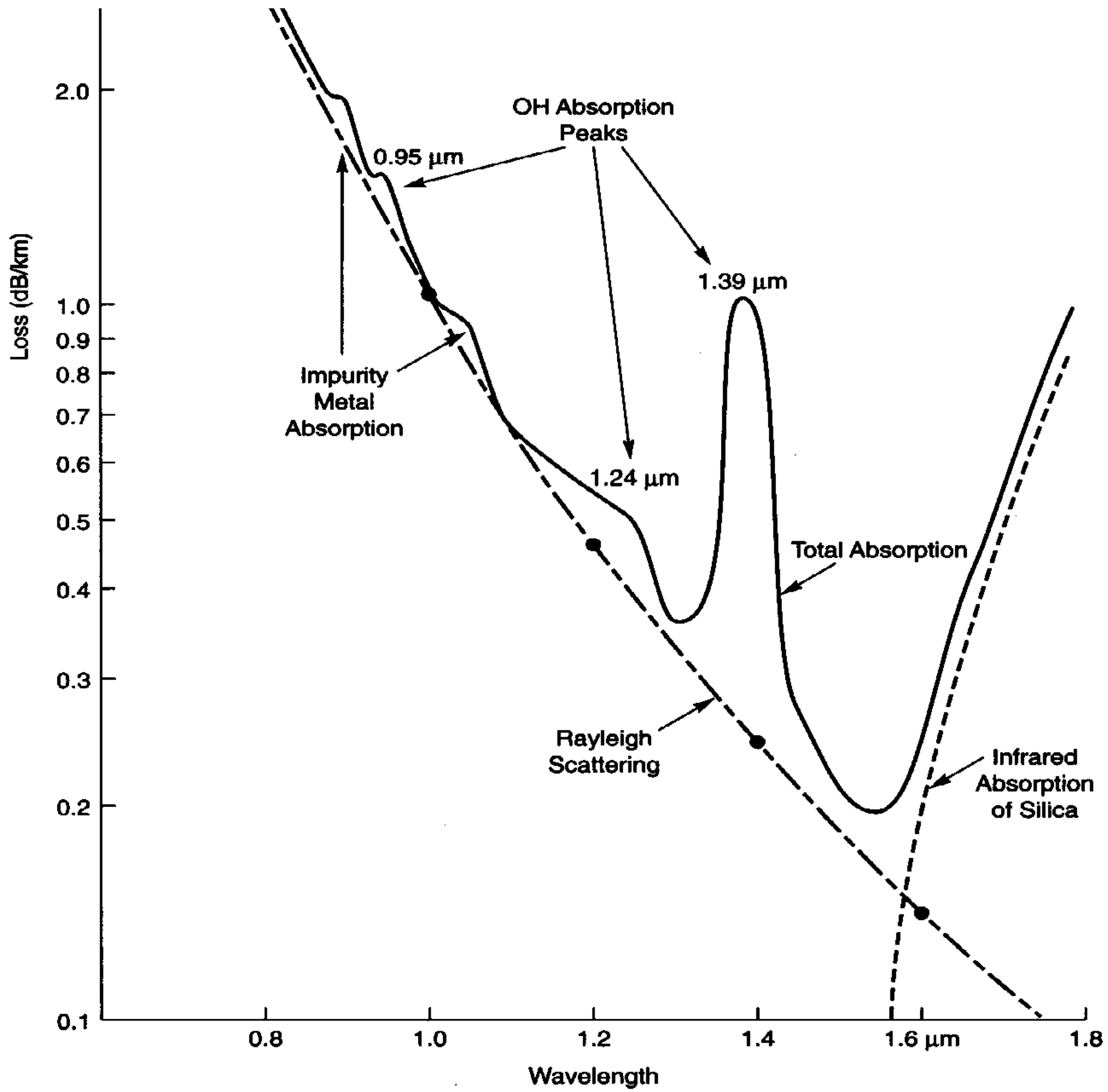
- Light energy can be absorbed by impurities in the glass.
- The captured energy is converted to thermal vibrations (heat).
- Strong absorption resonances occur for:
  - water contamination (OH bond). Must keep water at few parts p billion (10^{-9}).
  - metallic impurities (from metallic crucibles used to melt glass). Must keep trace metals at below 10^{-10} level.
- Also get absorption at INFRARED wavelengths due to vibration resonances for Si-O and Ge-O bonds



Hydroxyl Impurities (OH- Water)

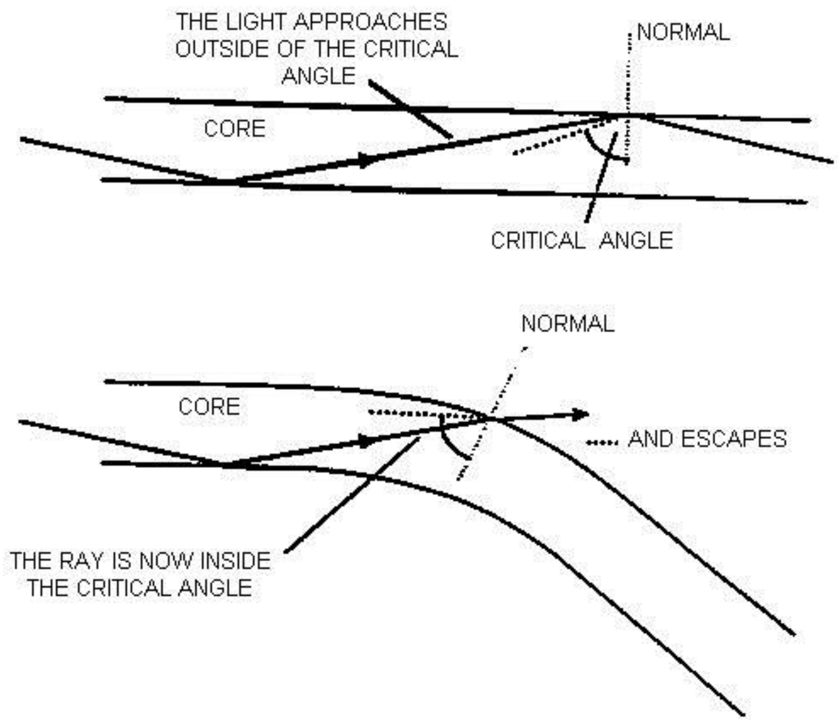


Attenuation Versus Wavelength



Bending Losses

- Macrobending
  - bending causes previously channelled light to hit core-cladding interface at **less** than the critical angle (hence transmission loss)



How much bending?
R = 50 mm (no loss)
R = 6 mm (1 dB loss)
R = 1.5 mm (4 dB loss)

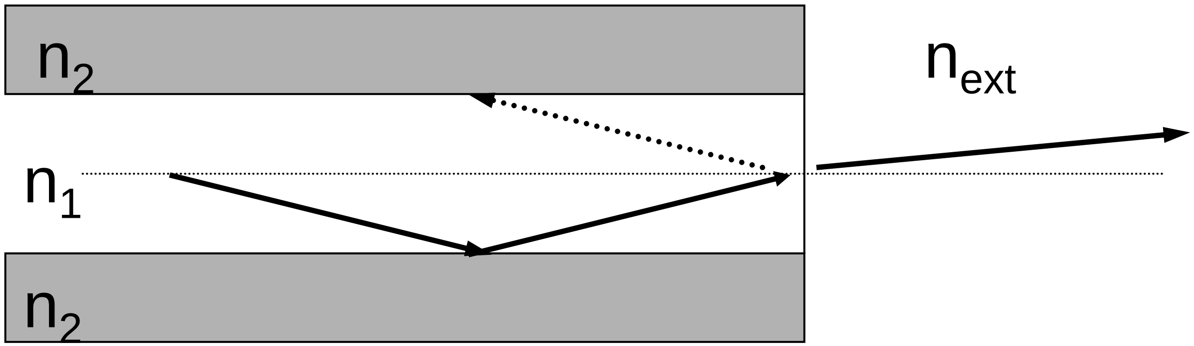
R is bending radius

Not a big problem for Comms

Joining (splicing) fibres together

- Optical fibres may be connected to each other by connectors or by *splicing*, that is, joining two fibres together to form a continuous optical waveguide. The generally accepted splicing method is arc fusion splicing, which melts the fiber ends together. For quicker fastening jobs, a "mechanical splice" is used.
- Fusion splicing is done with a specialized instrument - the two cable ends are fastened inside a splice enclosure that will protect the splices, and the fibre ends are stripped of their protective polymer coating (as well as the more sturdy outer jacket, if present). The ends are *cleaved* (cut) with a precision cleaver to make them perpendicular, and are placed into special holders in the splicer. A splice loss under 0.1 dB is typical.
- Optical fibres are connected to equipment by connectors.

Reflection At Cleaved Fibre – Fresnel Loss

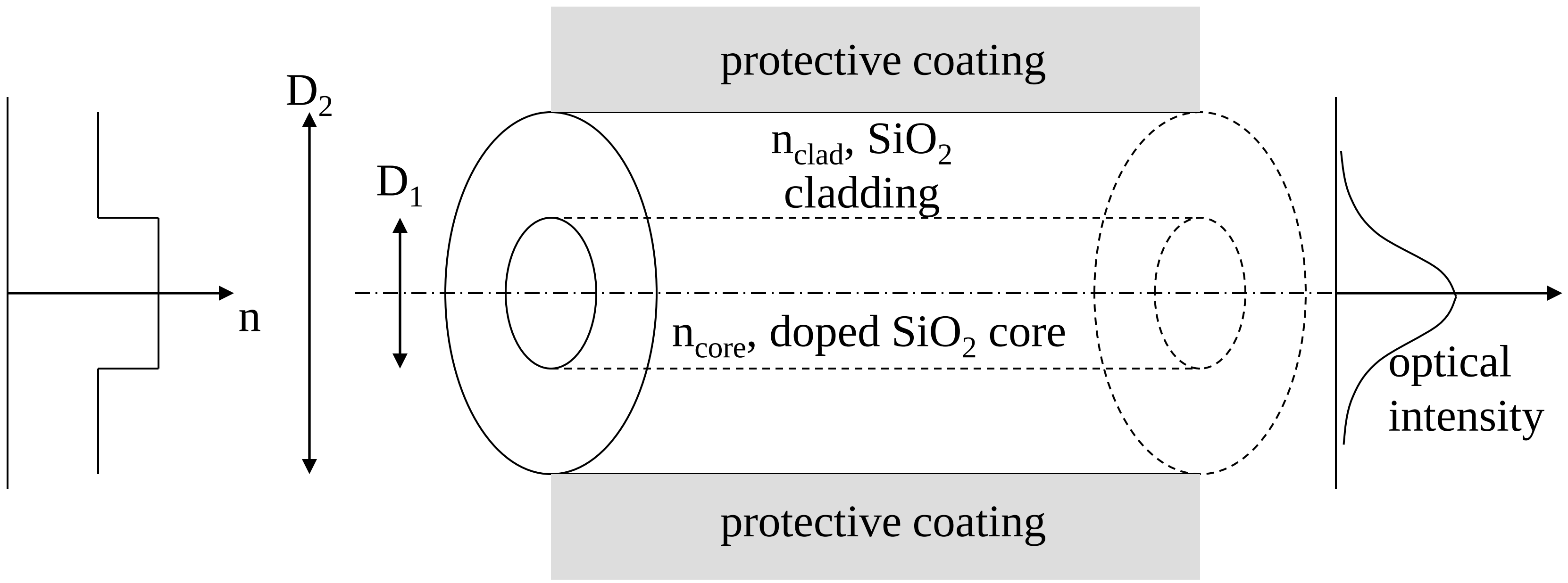


Reflected Power

$$I_R = \left(\frac{n_1 - n_{ext}}{n_1 + n_{ext}} \right)^2$$

- Although most of the light is transmitted through the end of the fibre, a small fraction is reflected
- The amount reflected varies with incident angle, but for low order modes, $\theta \sim 0^o$ and I_R is a minimum (few percent)
- When going from one fibre to another – use gel which matches refractive index of fibre to eliminate reflections

Fibre Optic Cable manufacture



$SiO2$- high purity: low loss, n_{ref} ~ 1.45

Dopants: Boron, Fluorine: decrease n_{ref} ,

Phos, Ge, Ti: increase n_{ref}

D_1 ~ 10-100's μm

1.First make a preform

(large boule or sausage)

2.Heat it and draw the fibre

“Blackpool” Rock

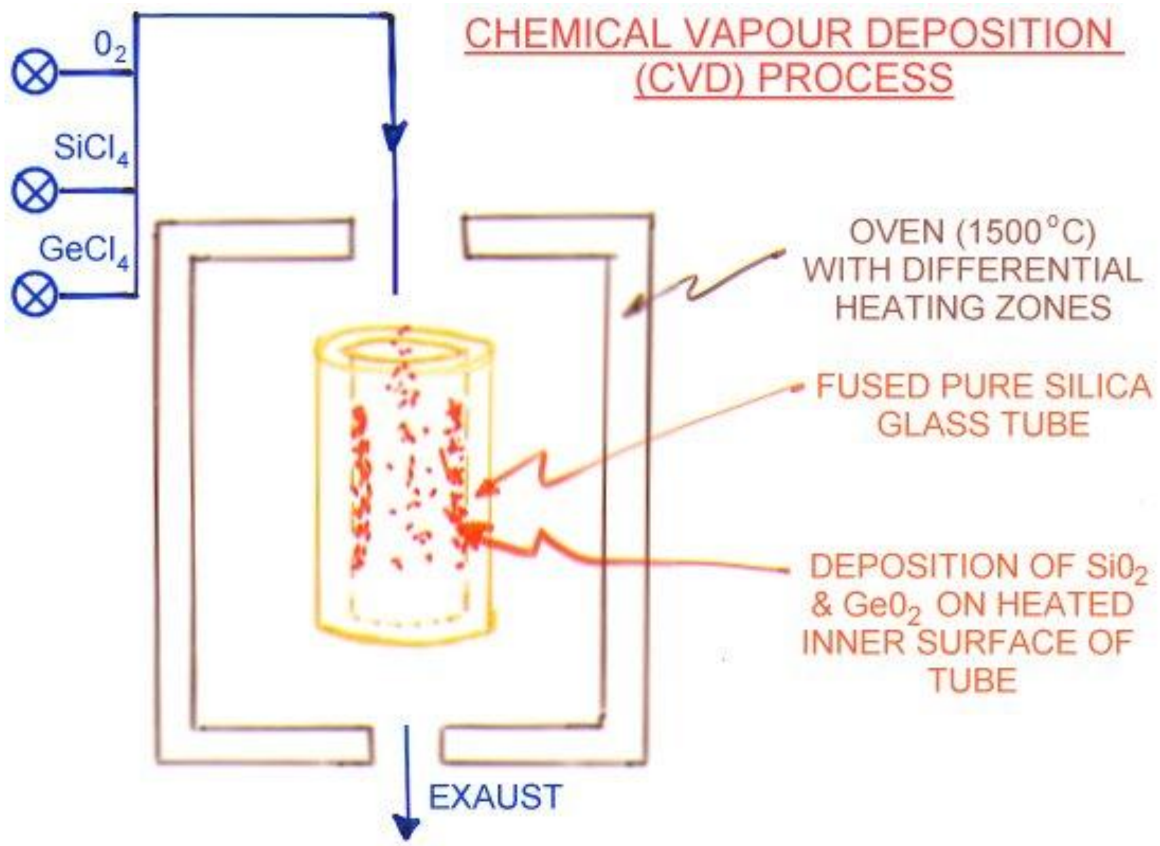
Chemical Vapour Deposition Processes

(1) $SiCl_4$, O_2 & $GeCl_4$ vapour fed inside heated silica glass tube.

(2) Low temp. (1500ºC) chemical reaction results in glassy layer deposited on inner surface of rotating tube.

(3) Heating via plasma or flame

(4) Glass tube heated to 1800ºC which then collapses to form preform.



Cl_4 = tetra chloride, tube about 40cm long

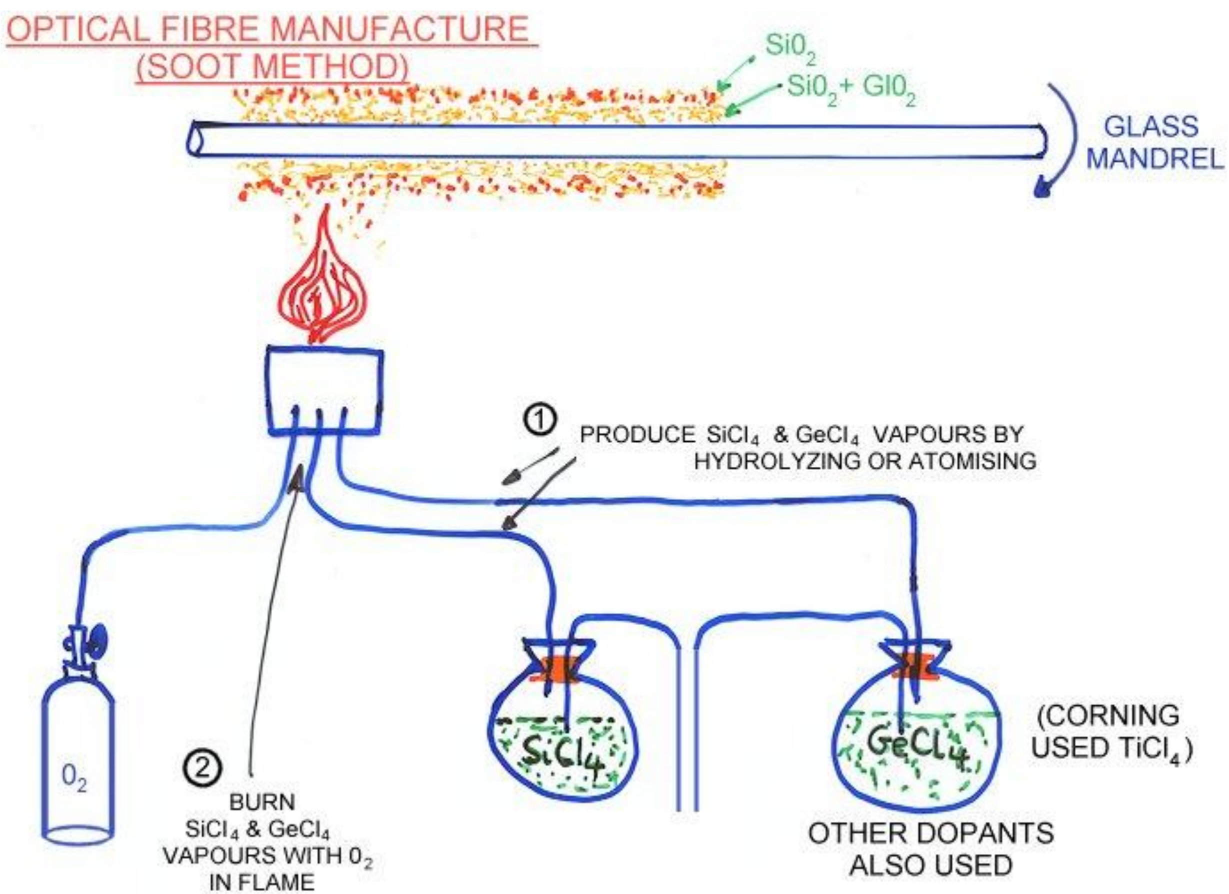
Outside Vapour-Phase Oxidation – "Soot"

(1) SiO_2 + GeO_2 soot deposited on mandrel (forms core), then pure SiO_2 soot deposited next (forms cladding)

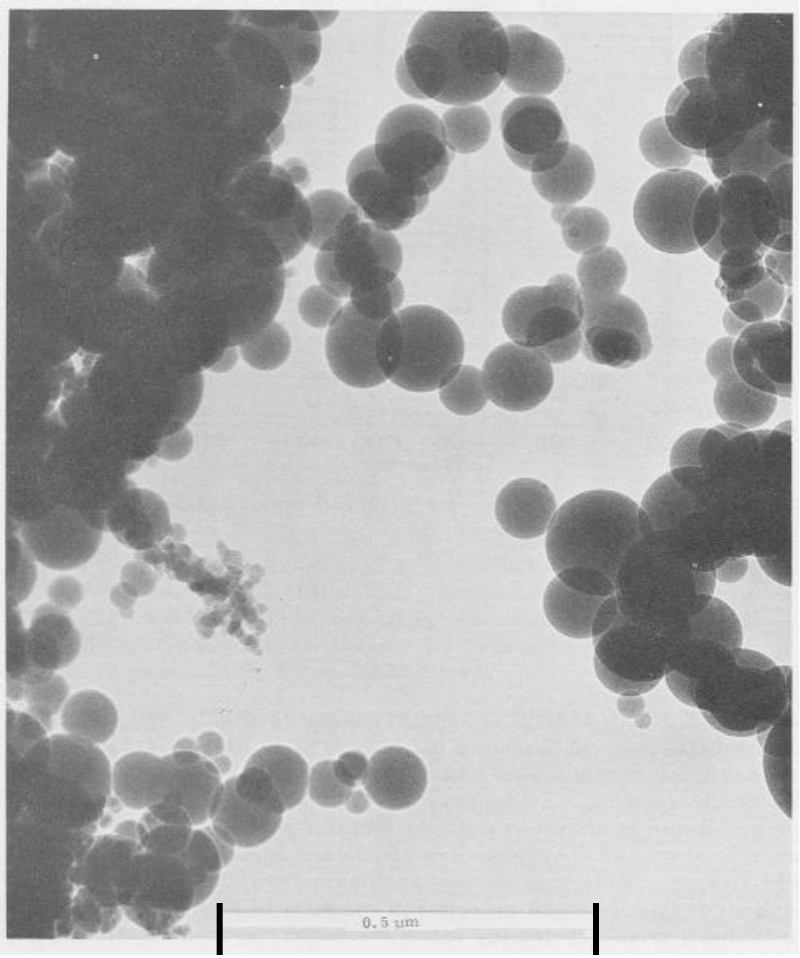
(2) This process forms a **SOOT BOULE** (white powder type substance)

(3) Remove glass mandrel (drill it out and polish)

(4) Heat soot boule so that it sinters into dense glass mass (called a **preform**).



Photos of Soot Method



scale bar is 0.5 micron wide

Doping molecules shown

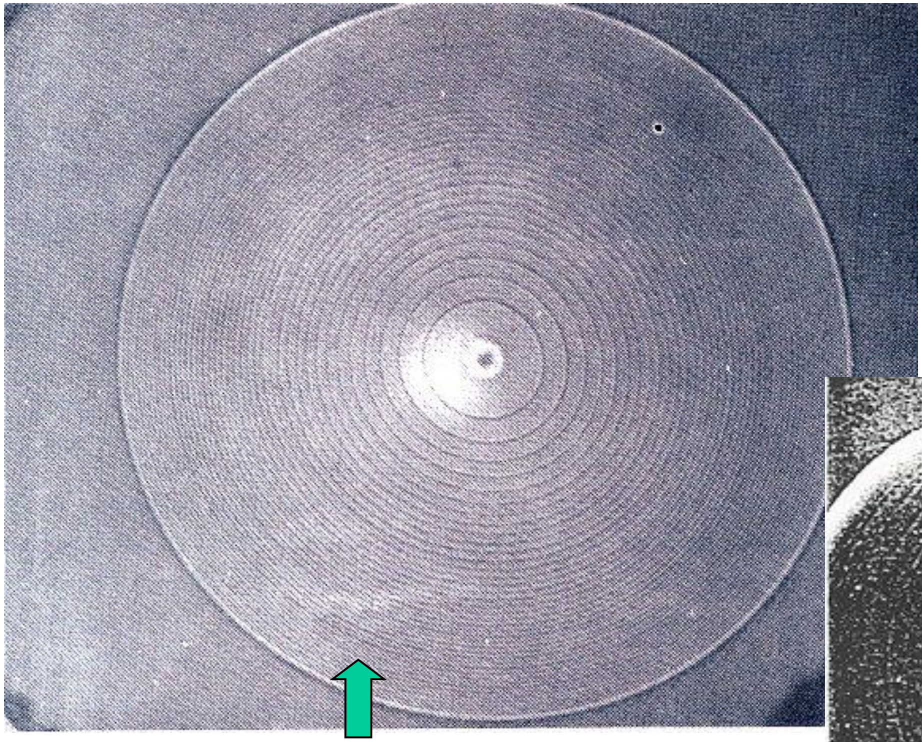
Soot Boule

Photos of Soot Method

Heating soot boule to form preform.

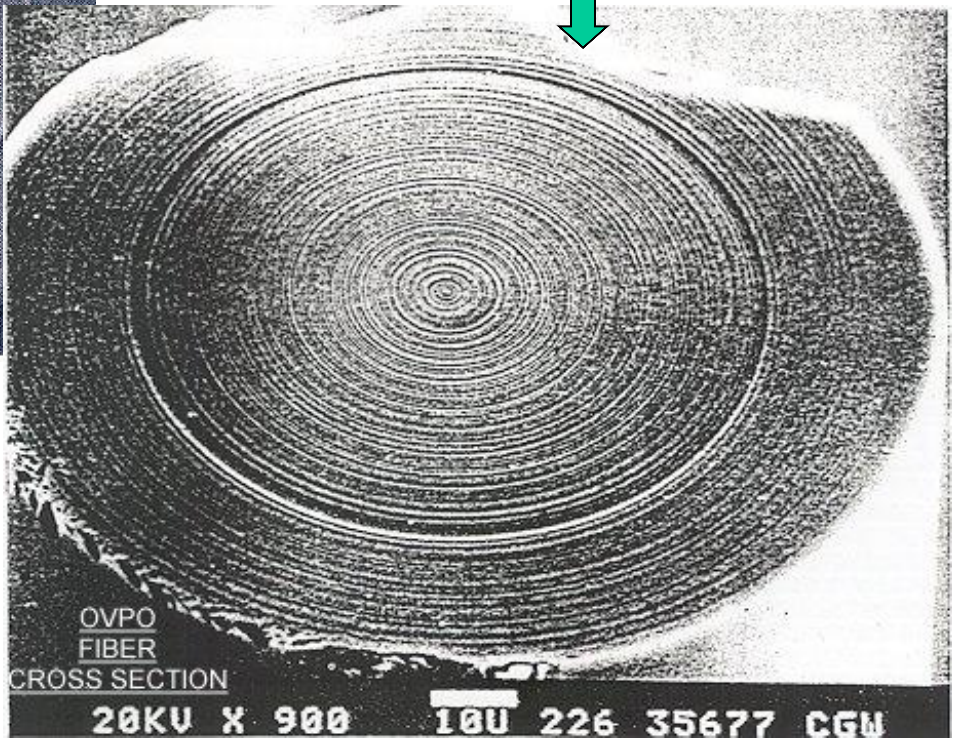
Typically preforms are about 1 metre long and 20 cm in diameter, and produces about 25 km of optical fibre.

Preforms and Fibres



Cross-section through a glass preform. The various deposited layers are clearly shown.

Scanning electron microscopy image of the cross-section through a glass fibre. The fibre is most probably a graded index MM fibre with an 80 micron core.



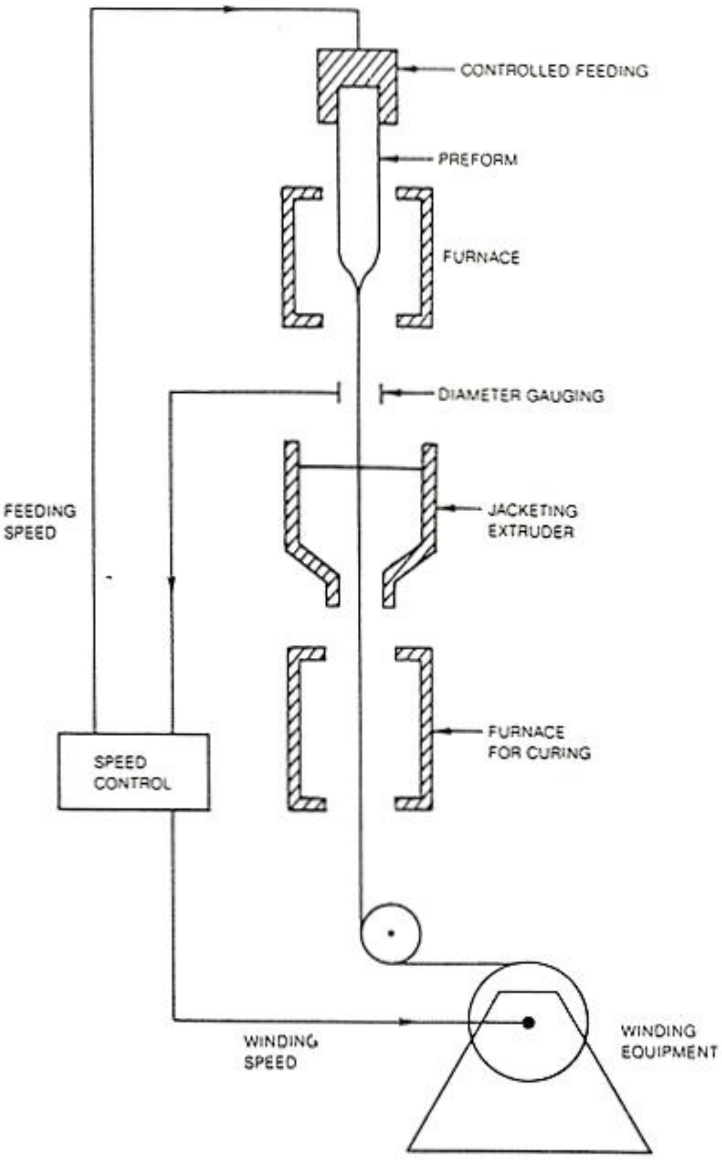
Drawing Fibres

Fibre is drawn in a pulling tower.

End of preform heated to 2100ºC, then tension applied to draw fibre.

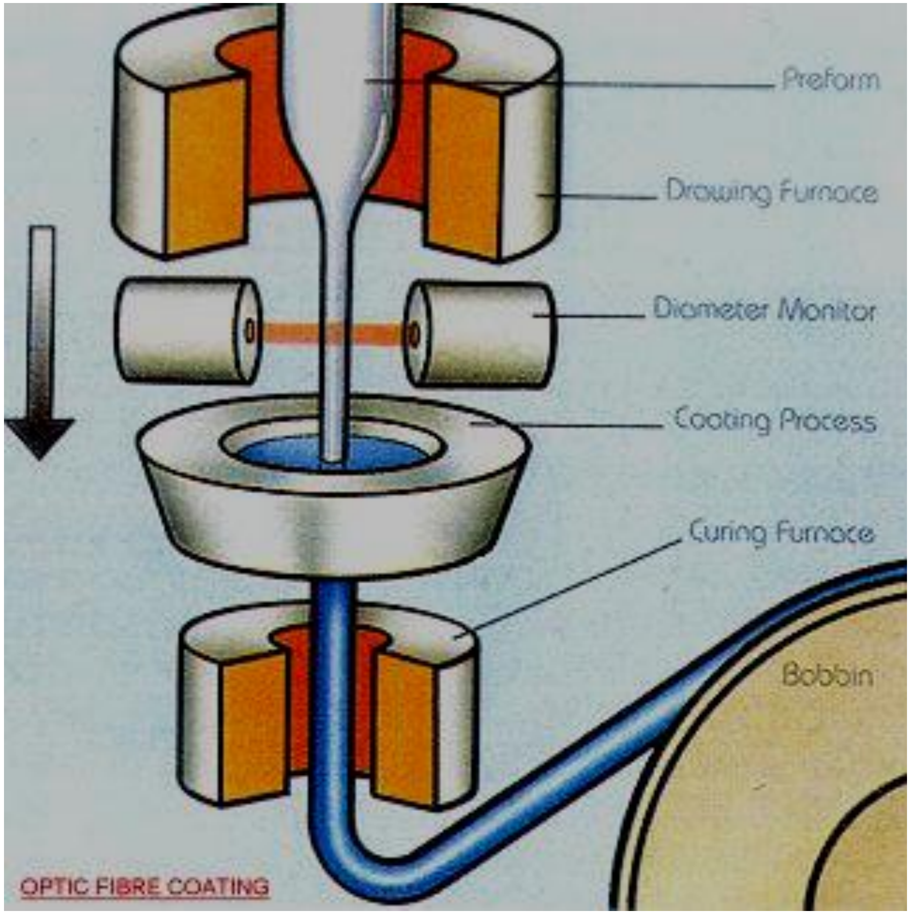
Done in dry clean atmosphere to avoid contamination

Preform inner core and outer cladding material flow together towards the pulling point



APPARATUS FOR PULLING OPTICAL FIBERS

Drawing Fibre



Laser gauges monitor fibre thickness

Monitor provides feedback for auto-adjustment of pulling rate, temperature control etc.

Plastic jacket applied via extruder, then immediately cured.

Summary

- **Single Mode Fibre – Loss**
- Loss is a fn of wavelength in single-mode fibres
- Intrinsic loss
  - UV absorption (tail of absorption in UV)
  - IR absorption (tail of resonances in IR)
  - Rayleigh Scattering (µm scale refractive index variations)
- Extrinsic loss
  - metal impurities
  - water impurities (hydroxyl)

- **Single Mode Fibre – Manufacture**
- Step 1 – Preform

A large scale version of the fibre is manufactured by some form of chemical vapour deposition of glasses of different composition (hence refractive index)– e.g. on the inside of a glass tube which is then collapsed onto itself.

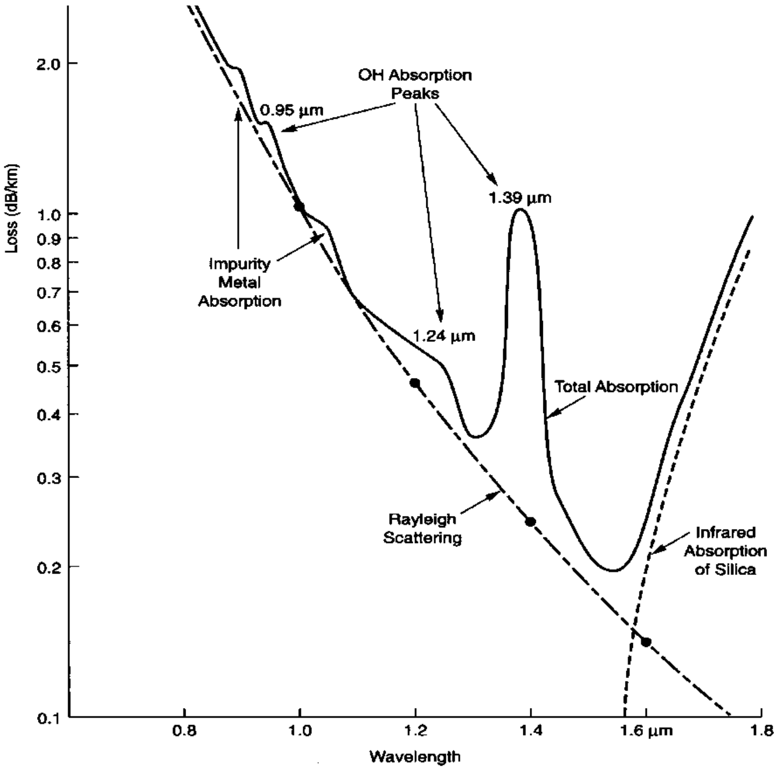
- Step 2 – Drawing

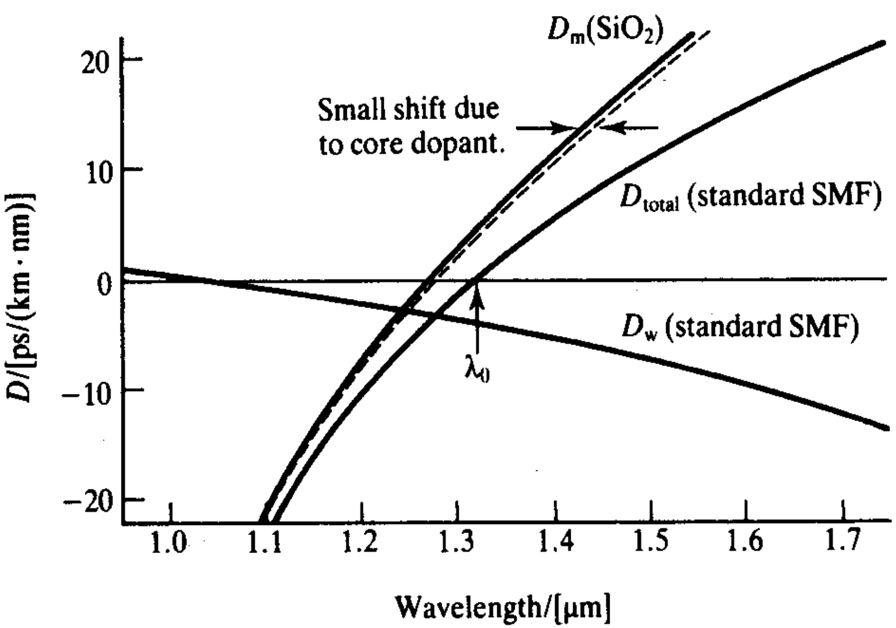
  Simply (!) stretch out to obtain correct dimensions

Need to ensure dimensions constant and minimise impurities

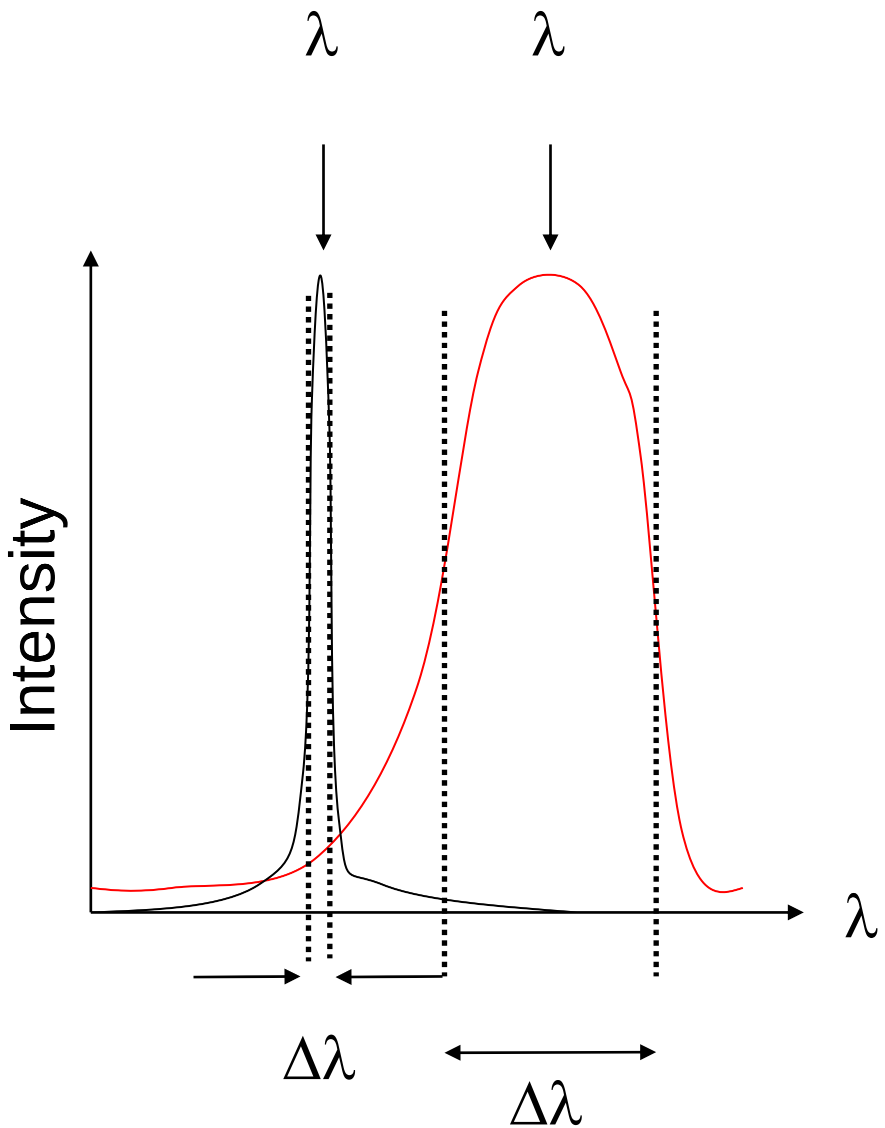
Review of Fibre Properties

NA – acceptance angle
Dispersion (modal, material, waveguide), Attenuation, and bit-rate determine suitable wavelengths for optical transmission systems





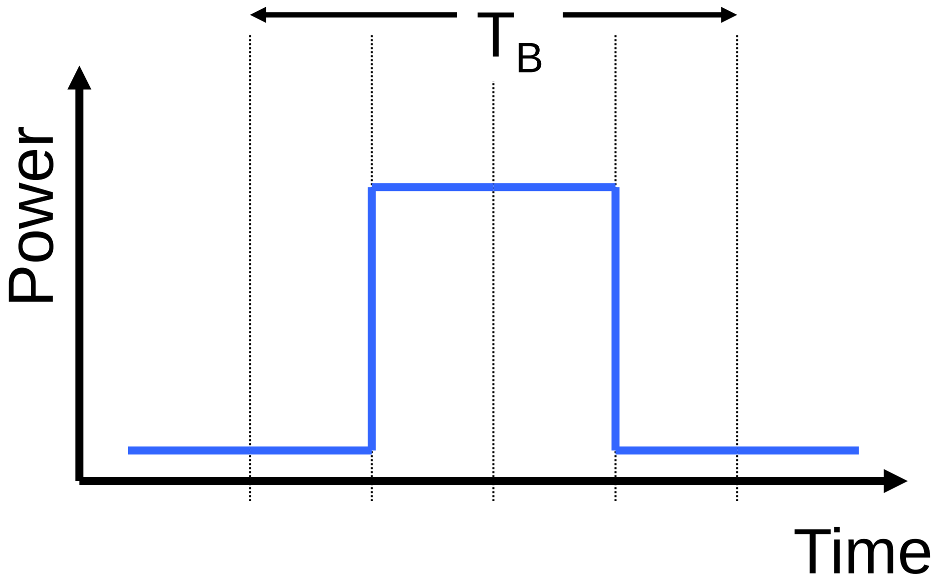
Transmitter - Wavelength and Linewidth



Peak – operating wavelength

Linewidth given by Full Width at Half Maximum

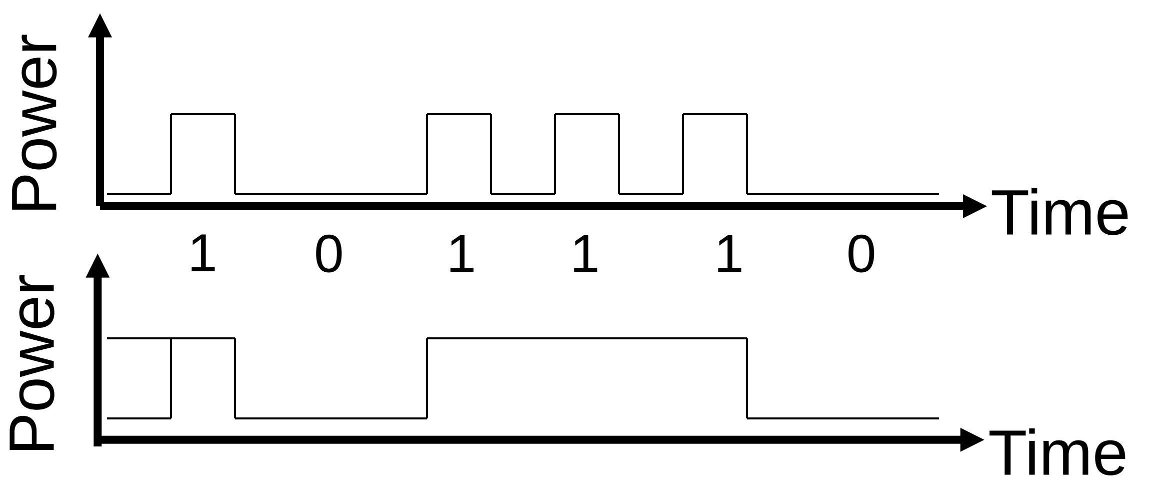
Amplitude Modulated Optical Pulse



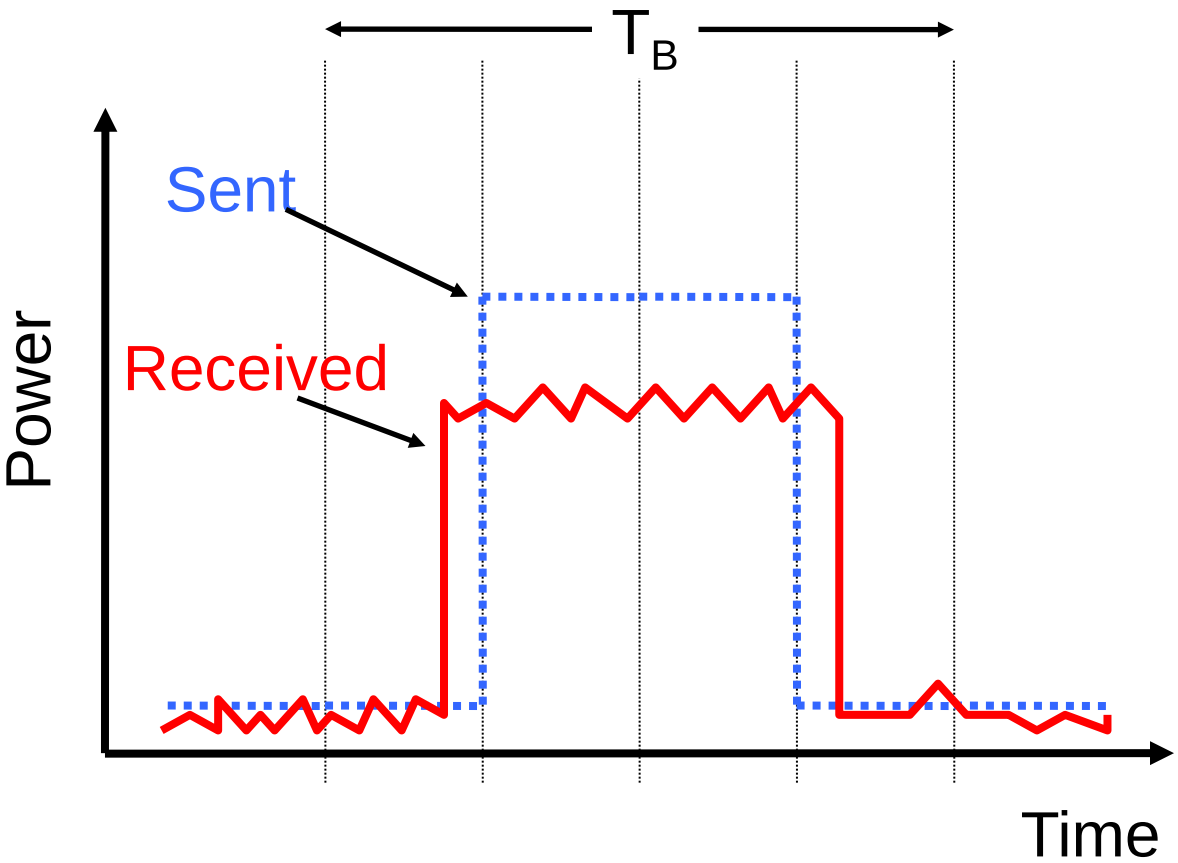
T_B= Bit Slot

=1/B where B = bit rate

n.b. AM modulation may be return to zero or non-return to zero (nrz)



Signal at Receiver



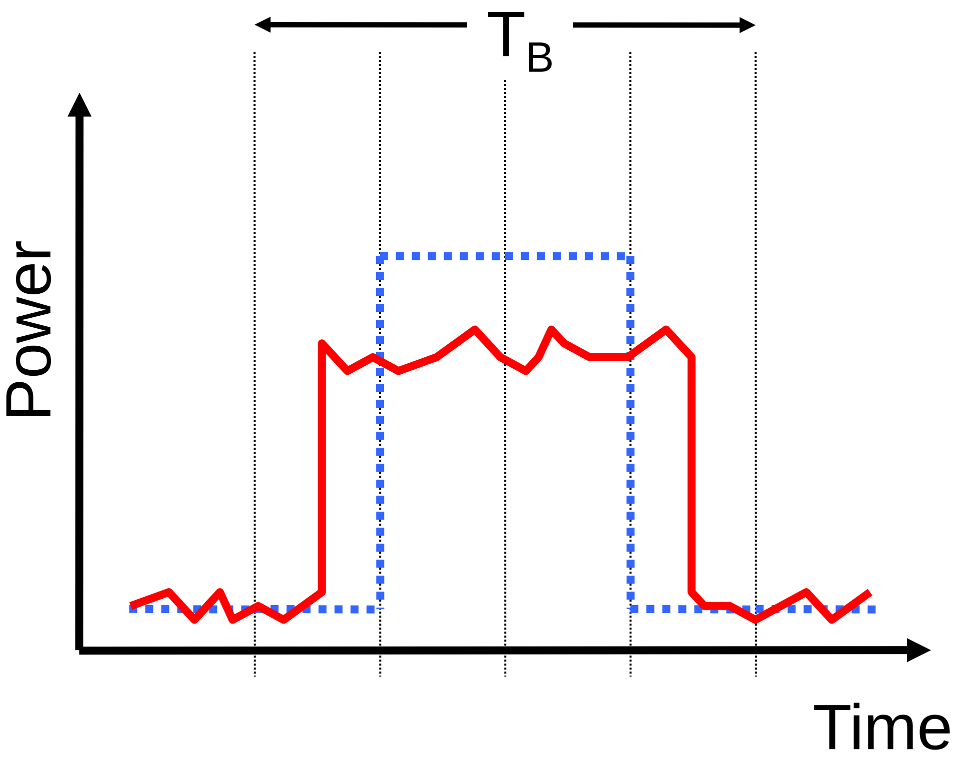
Assume "top hat" pulse is launched down fibre

At receiver have;

Attenuated pulse & Real detector of finite sensitivity

Broadened pulse due to dispersion

Broadened Pulse – Dispersion limit and BL product



Commonly used criterion is that broadening $\Delta t \leq T_B/4$

$$\Delta t = L\Delta\lambda\ D(\lambda)$$

$$L\Delta\lambda\ D(\lambda) \leq T_B/4$$

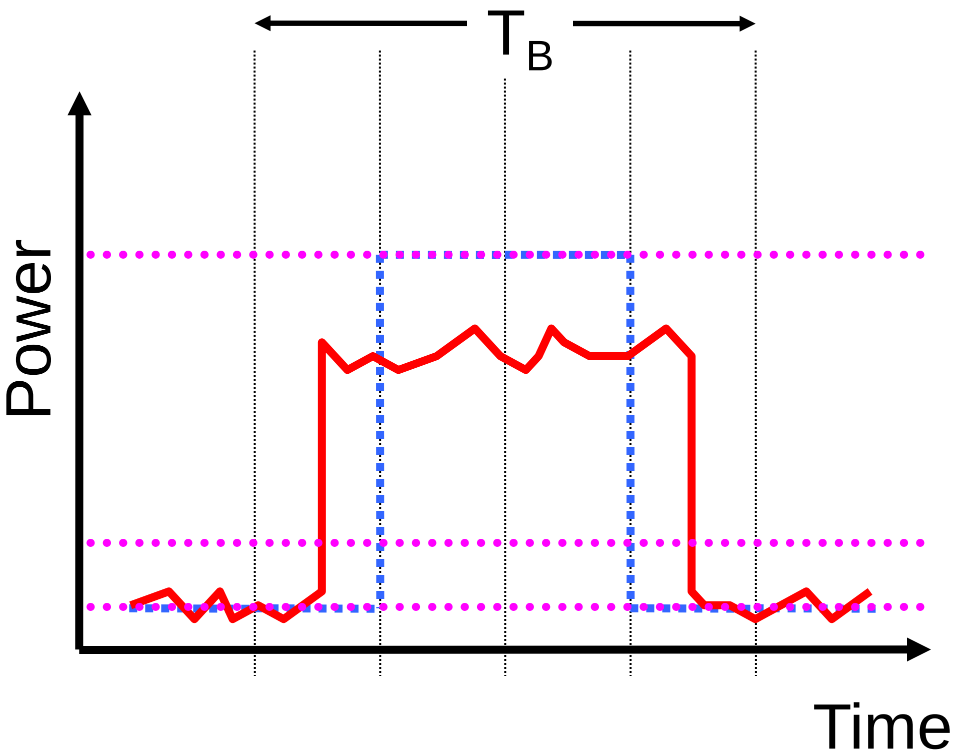
$$BL\Delta\lambda\ D(\lambda) \leq 1/4$$

$BL=1/[4\ \Delta\lambda\ D(\lambda)]$

Note: $\Delta\lambda\ D(\lambda)$ often quoted as dispersion in ns/km

BL=bitrate x length

Loss-Limited Lightwave systems



P_{tr} = Time averaged power launched into fibre

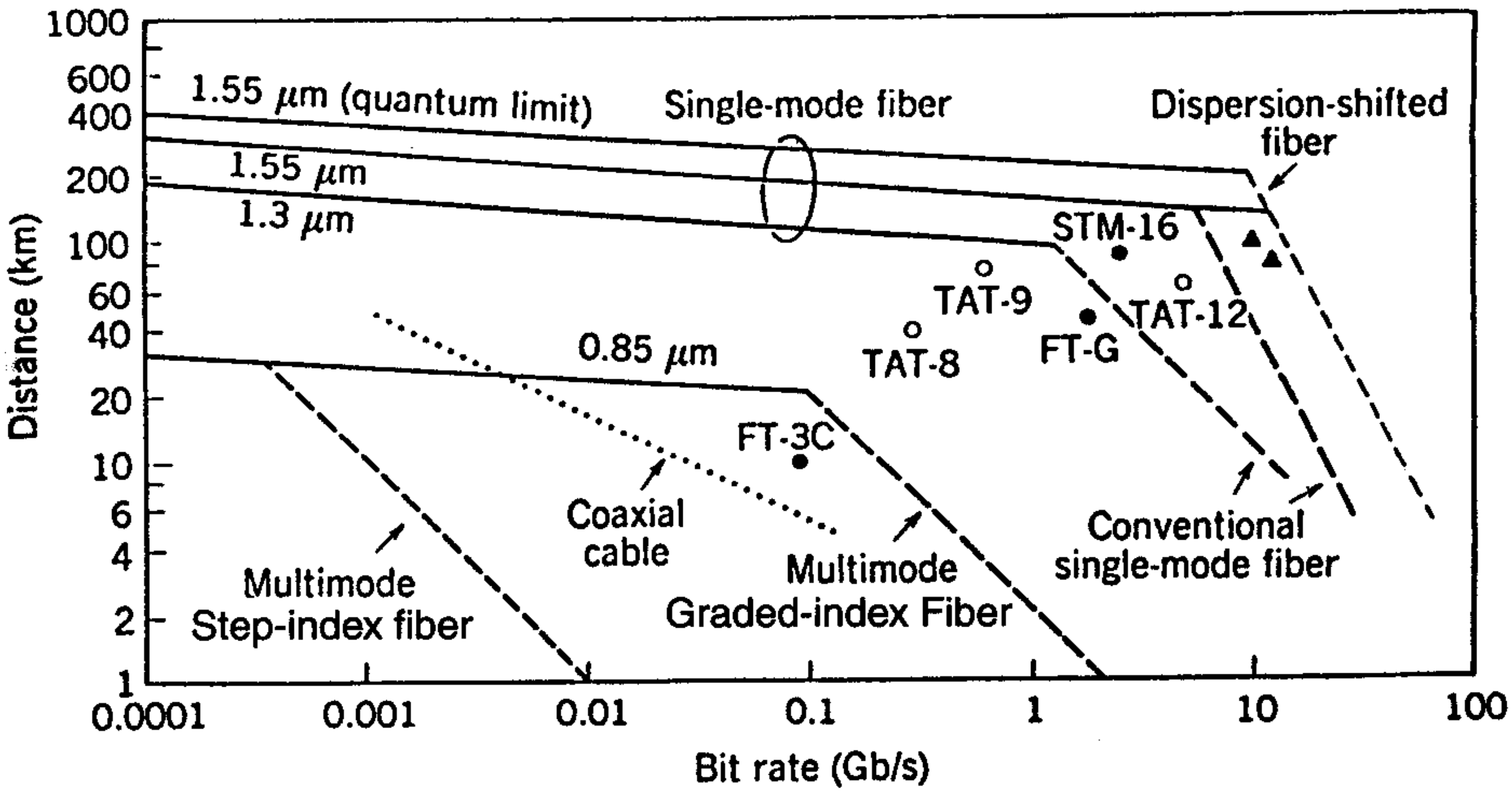
P_{rec} = minimum time averaged power required by receiver

$P_{rec} \propto B$ (as B increases – for constant P_{tr} get less and less instantaneous power per bit)

Fibre length $L = [10/\alpha_{tot}].\log_{10}(P_{tr}/P_{rec})$ km

α_{tot} = Total Loss dB.km^{-1} L decreases logarithmically as B increases

Typical Systems – Attenuation and Dispersion Limits



Solid – Loss limited
Dashed – dispersion limited

Fibre Properties – Effect on Transmitter and Receiver

Operating Wavelength – Minimum for attenuation or dispersion?

Dispersion limited transmission;

Linewidth of Transmitter – Minimise Dispersion

Loss Limited Transmission:-

Power of Transmitter – Turn power up and up! (maximum limit exists)

Receiver sensitivity – Function of Bit-rate,

Loss (dBm)

Loss (dB) = $10 \log_{10} (P_{in}/P_{out})$

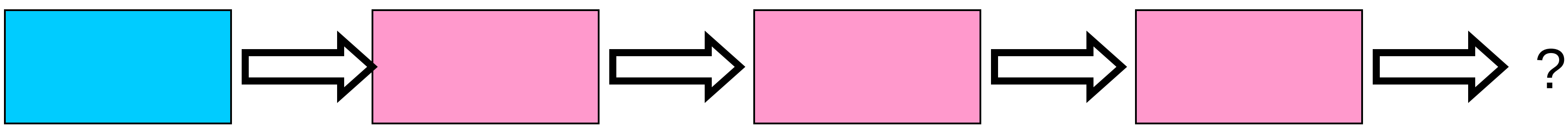
dBm = $10 \log_{10} (P_{opt}/1mW)$

Laser
-1dBm

Fibre Attenuation
14.5 dB

20 x Connectors
@0.3dB each
=6dB

5x Splices
@0.1dB each
=0.5dB



Easy – Total loss = 21dB

$(P_{in}/P_{out}) = 10^{21/10} = 126$

$P_{out} = 0.795\text{mW}/126 = 0.63\mu\text{W}$

Easier way $\Rightarrow$ -1dBm-21dB = -22dBm = 0.63μW

Important when we have many sources of gain and loss!
Remember attenuation is –ve, amplification is +ve

Losses In A System

Fibre ~ few tenths of dB/km

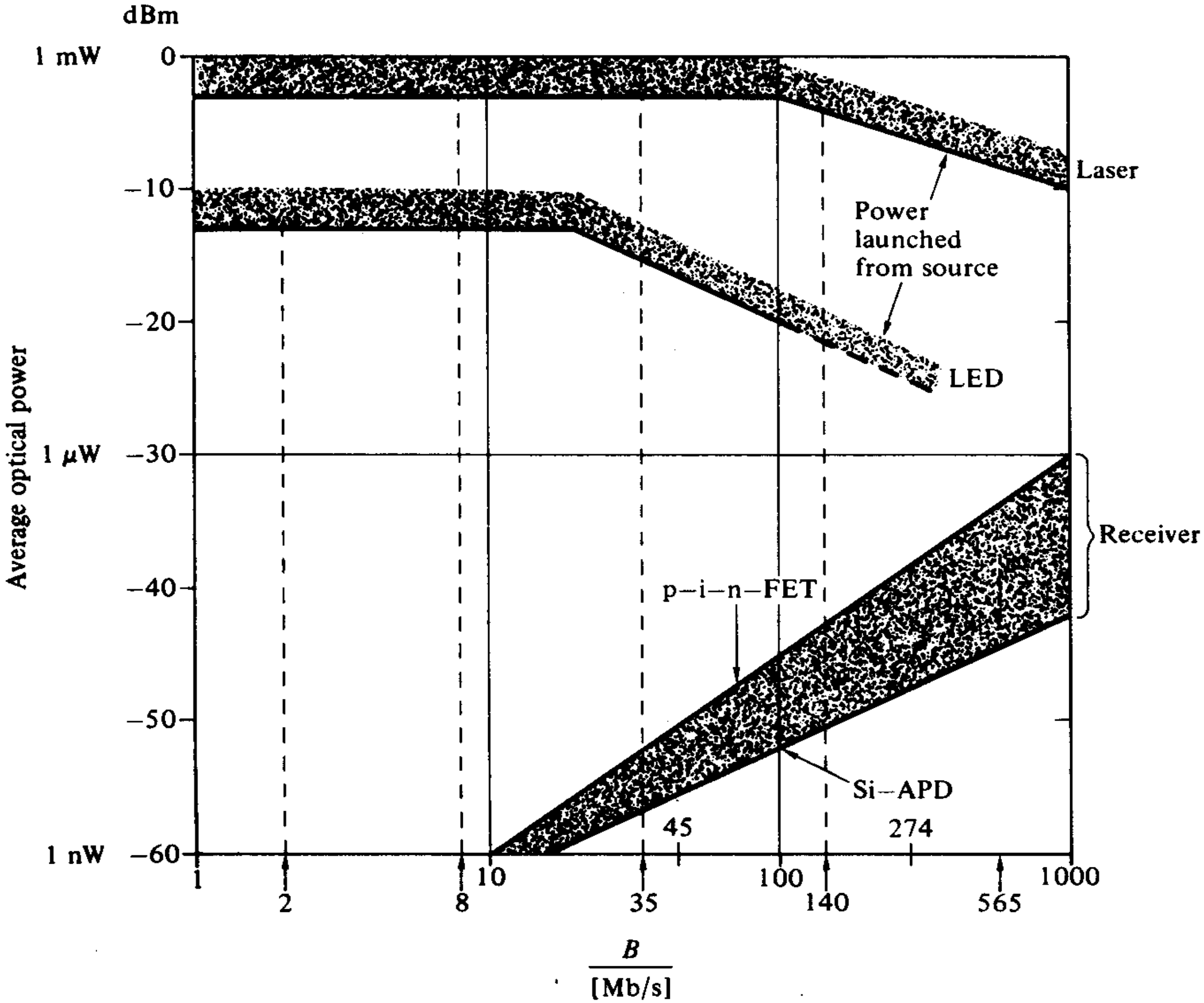
Splice ~ 0.1 dB each

Connector ~ 0.3 dB each

If we just budget for fibre loss in designing our system we will be in big trouble if we have to repair the fibre or add and additional components..

A smart Engineer will leave some slack or “margin”

Power Budget



Tx power - total loss+ amplification = margin + Rx sensitivity

Power Budget Example

1GHz system

-10 dBm Transmitter Power
-30 dBm Receiver Sensitivity
10 dB gain EDFA
Need Margin of 20 dB for connectors/splices/unexpected losses etc
What is total loss I can tolerate?
Loss of fibre is 0.2 dB/km – how far can I transmit?

Tx power - total loss+ amplification = margin + Rx sensitivity

Student exercise – work through example

Summary

- **Amplitude Modulated Bits**
- Loss and Dispersion Characteristics are key in determining how far and at what data rate we can transmit data
- Dispersion – broadens bit within it's bit-slot – if too severe get inter-symbol interference and errors
- Loss – if not enough photons in a pulse cannot differentiate between "0" and "1" at receiver
- Latter gives rise to a "power budget"
- Power budget – determined by power required at receiver (fn Data rate), launch power, margin, other factors e.g. Dispersion penalty, Extinction ratio penalty, etc