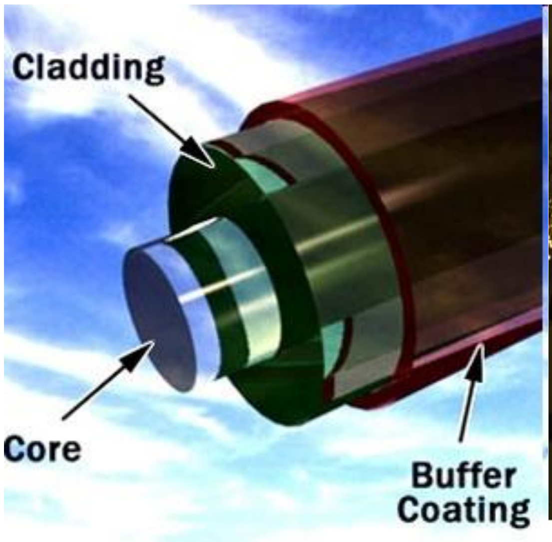
Topic 4

4 Optical loss

- 4.1 Introduction
- 4.2 Loss mechanisms in fibres
- 4.3 Optical fibre manufacture
- 4.4 Manufacturing technologies

<u>Introduction</u>



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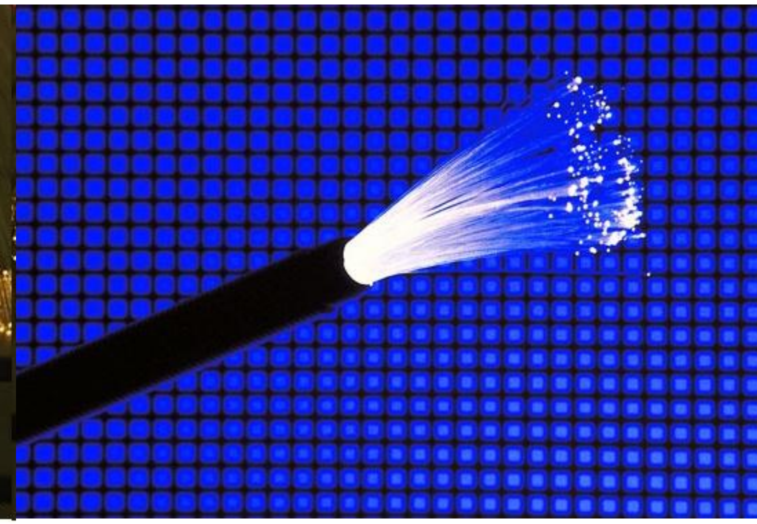


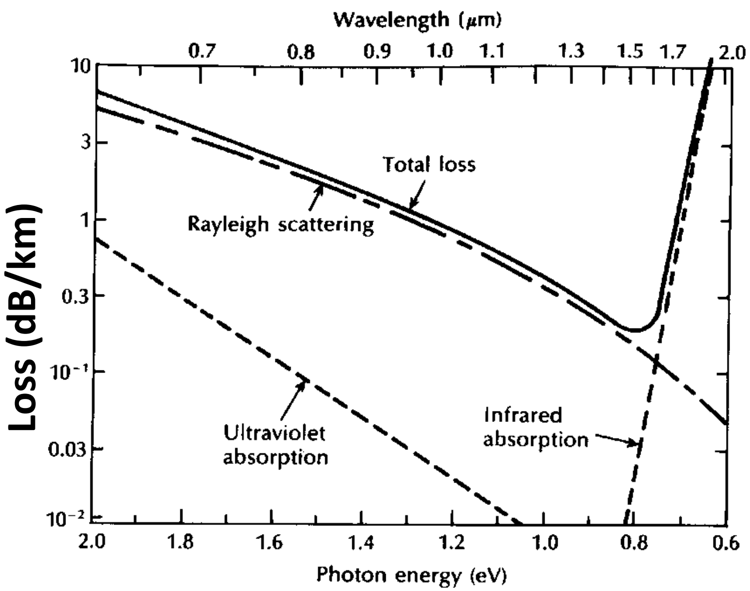
Even for a **best optical fibre**, there still exists optical loss in transmitted signal.

Optical loss in Optical Fibres

Sources of optical loss (attenuation)

- Intrinsic Absorption
- Rayleigh Scattering
- Extrinsic Absorption (impurities)
- Bending losses
- Fresnel reflection losses

Intrinsic absorption (1)



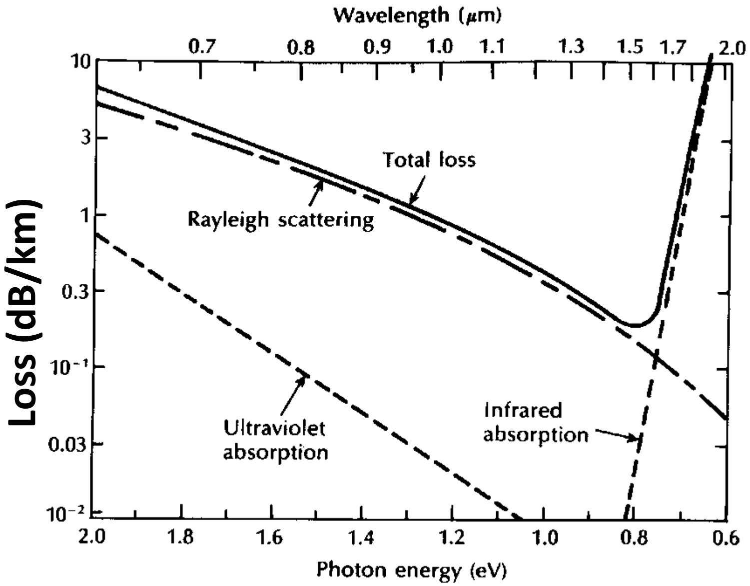
(1) Ultraviolet (UV) absorption

- UV light absorption: tails extend into the near infra-red (IR)
- λ↓, Absorption ↑, this is related to **transitions between electronic states**

(2) **IR absorption**

- Due to the excitation of **molecular vibrations** within the material – the tails of these absorption peaks extend into the near IR

Intrinsic absorption (2)- UV absorption



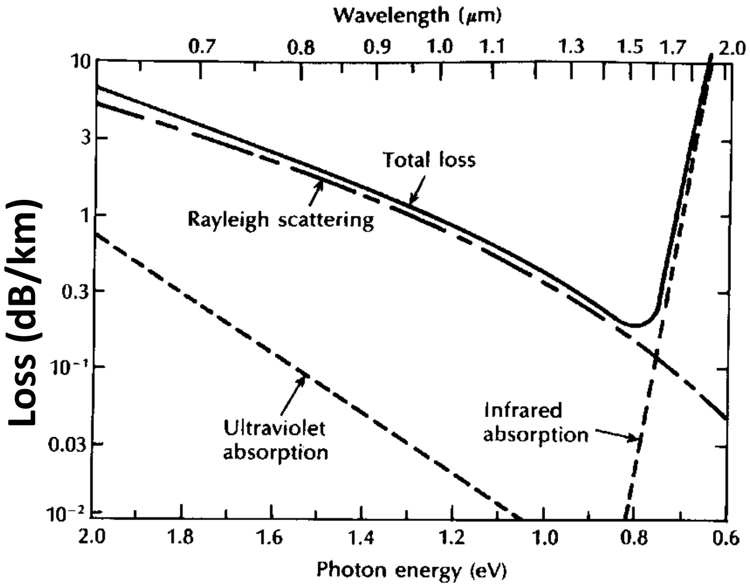
UV absorption:

a direct optical transition of electronic states within the material

Electronic states - solid

amorphous solid

Intrinsic absorption (3)- IR absorption



IR absorption:

Interaction between photon and molecular vibrations

For examples:

Strong absorption bands due to oscillation of structural units: Si-O (9.2 μm), P-O (7.2 μm), Ge-O (11.0 μm), etc

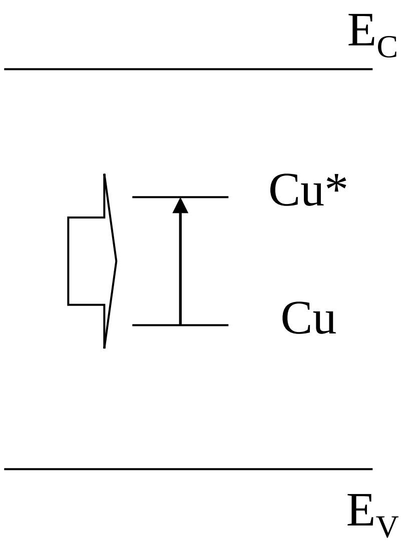
The tails of these absorption peaks extend into the near IR (1.5~1.7 μm)

- **The minimal absorption is at 1.55 μm**
- **An optical communication over long distance requires an optical source at 1.55 μm**

Extrinsic absorption- metallic impurity

Basically, it is due to impurities, and major extrinsic loss mechanisms:

(i) Metallic impurities: **absorptions at 0.4-1.1 μm**



Fe^{2+} (1100 nm), Fe^{3+}(400 nm); Cr^{3+} (625 nm), Cu^{2+}(850 nm); Ni^{2+}(650nm); Mn^{3+}(460nm)

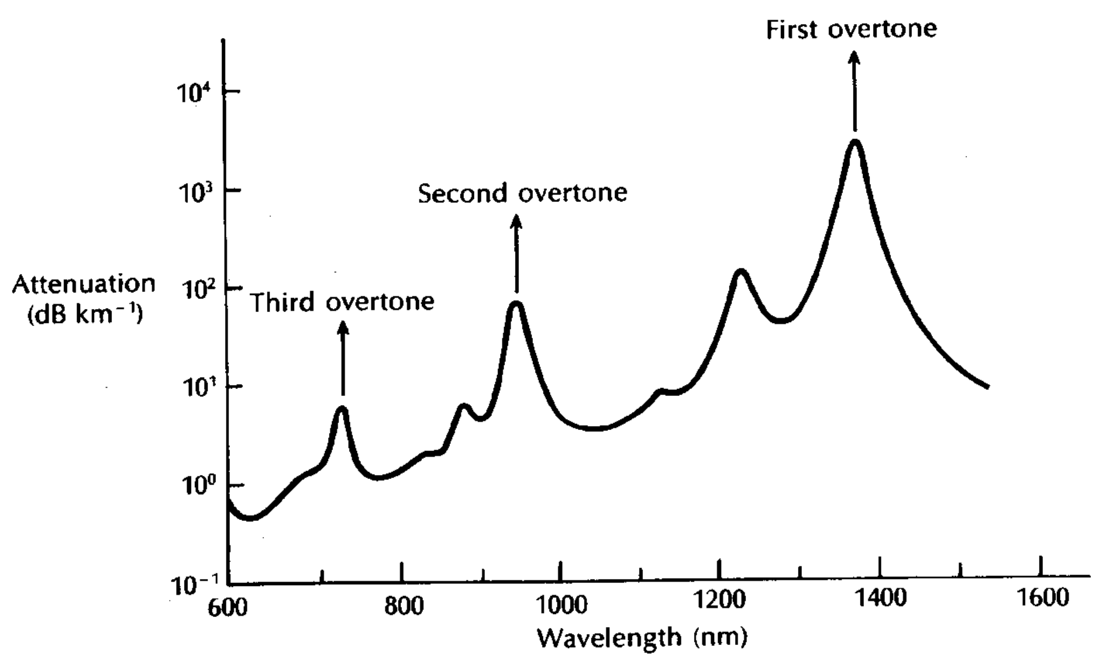
(From the metallic crucible used to melt glass)

Solution:
Must keep trace metals at below the **10^{-10} level**

Extrinsic absorption- Hydroxyl impurity (OH-water)

Another major extrinsic loss mechanism:

(ii) **Absorption due to OH- water**: absorption peaks **1.39**, 1.24, 0.95, 0.75 μm

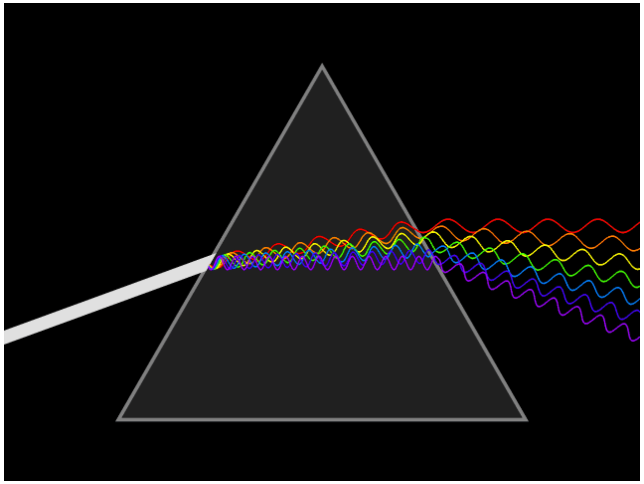


Solution:

Must keep moisture at a few **ppb (10^{-9})** level

This is why we developed technology for growth of laser diodes with **1.3 μm and 1.55 μm,** not 1.4 μm.

Why is the Sky Blue?



Rayleigh Scattering

light scattering by particles of size << wavelength of light

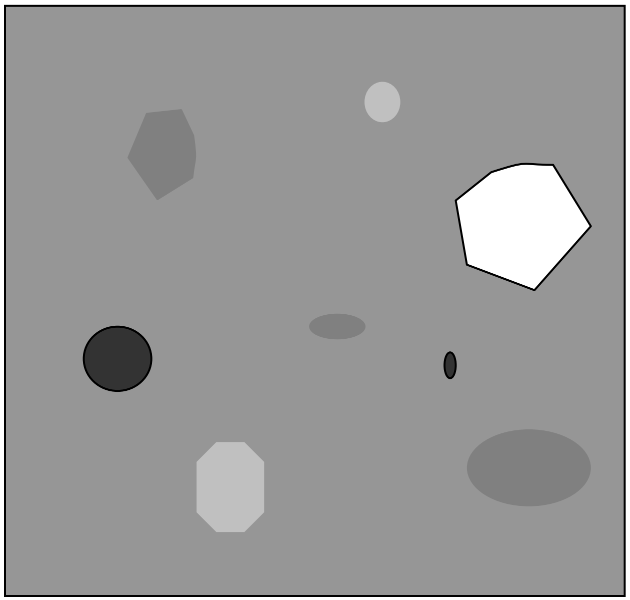
Scattering $\propto \lambda^{-4}$

Blue ~450nm
Green ~525nm
Red ~630-650nm

BLUE being scattered more than the other colours

Lord Rayleigh

Rayleigh Scattering in Fibre (1)



Glass is an amorphous solid

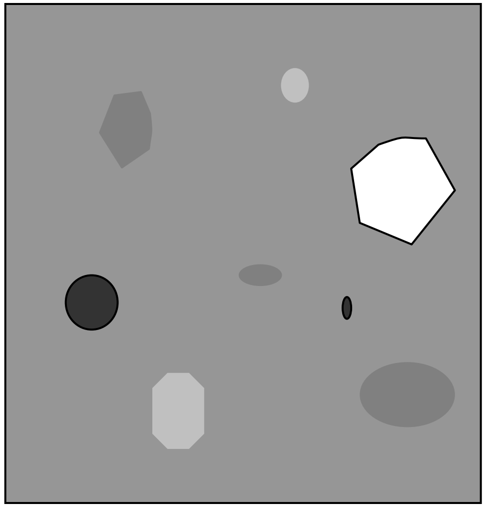
– **inhomogeneities**

– **fluctuations in refractive index** :
• Density and compositional variation during the cooling process
• Compositional variation can be reduced by improved fabrication
• Density variation: cannot be avoided

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

Rayleigh Scattering in Fibre (2)

- Microscopic variations around average material density **– on scale < λ**
- These regions with 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



At 1.55 μm, the loss due to Rayleigh Scattering 0.12~0.16 dB/km
At 1.00 μm, the loss due to Rayleigh Scattering 0.8 dB/km
At 0.63 μm, the loss due to Rayleigh Scattering 5.2 dB/km

This is another reason for choosing long wavelength optical sources.

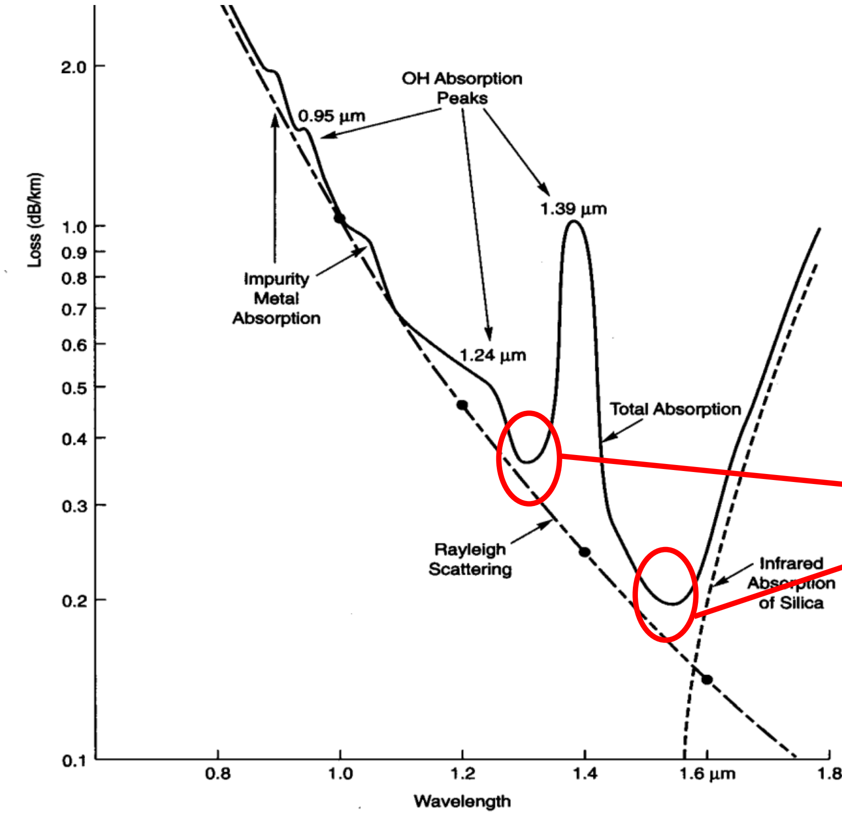
Other Scattering Loss

- Mie scattering:

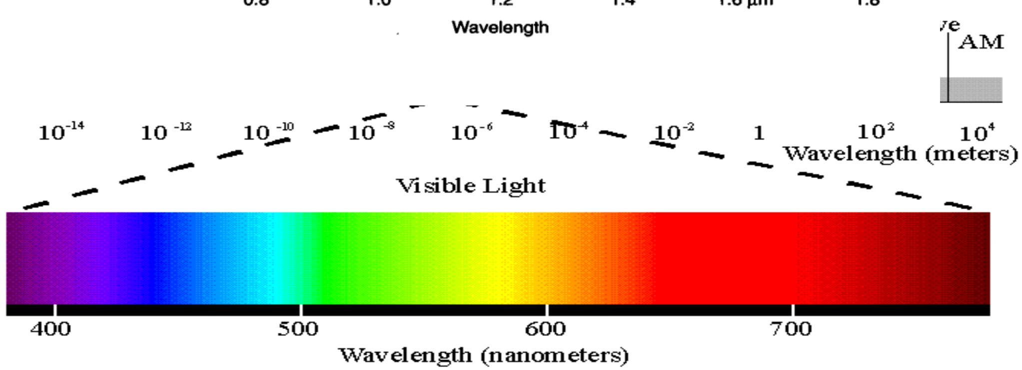
  Imperfect cylindrical structure, leading to (i) irregularities in the core-cladding interface; (ii) core-cladding refractive index difference along the fiber length; (iii) diameter fluctuations, (iv) strains; (v) bubbles

- Non-linear scattering losses

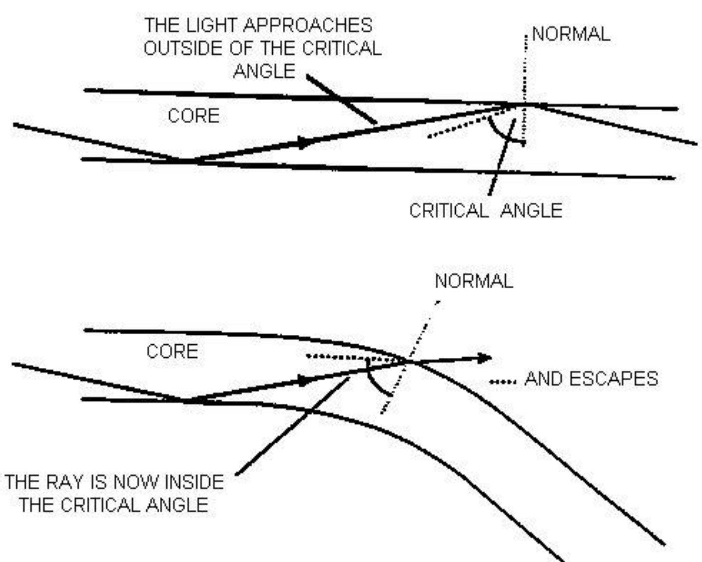
Attenuation Versus Wavelength

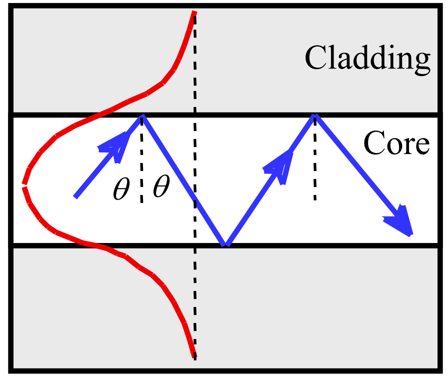


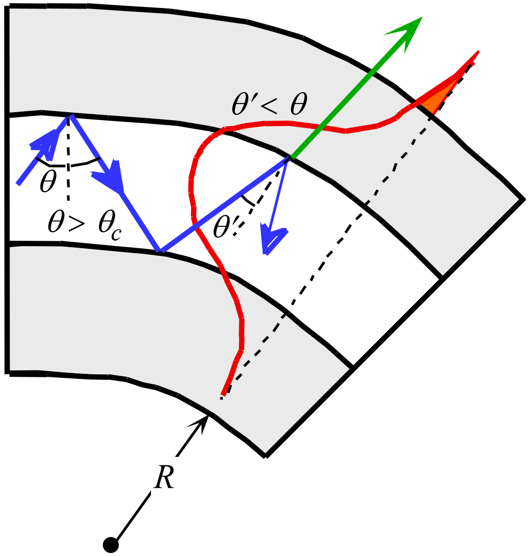
Two windows for optical communication



Bending Losses (1)



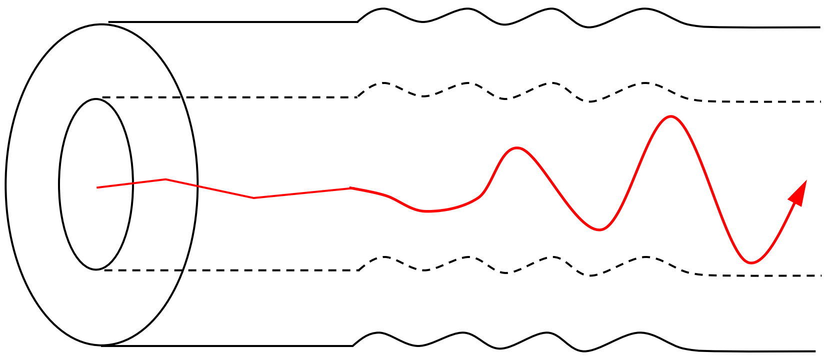




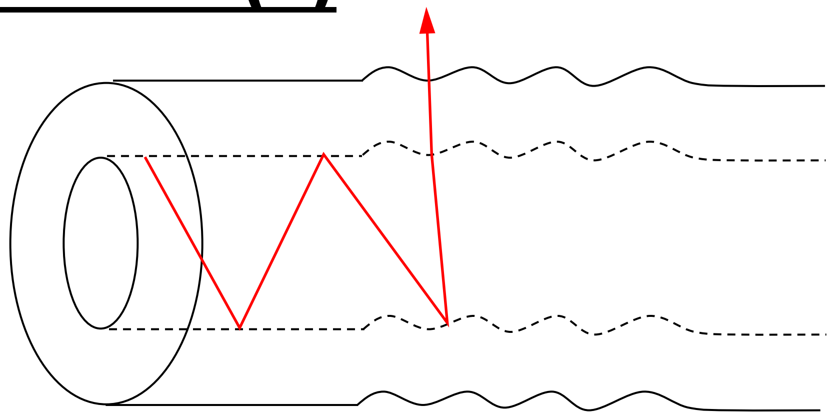
- **Macrobending:** curvature is much larger than diameter of optical fibre
  - bending causes previously channelled light to hit core-cladding interface at **less** than the critical angle (hence transmission loss)

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

Bending Losses (2)



Low order mode



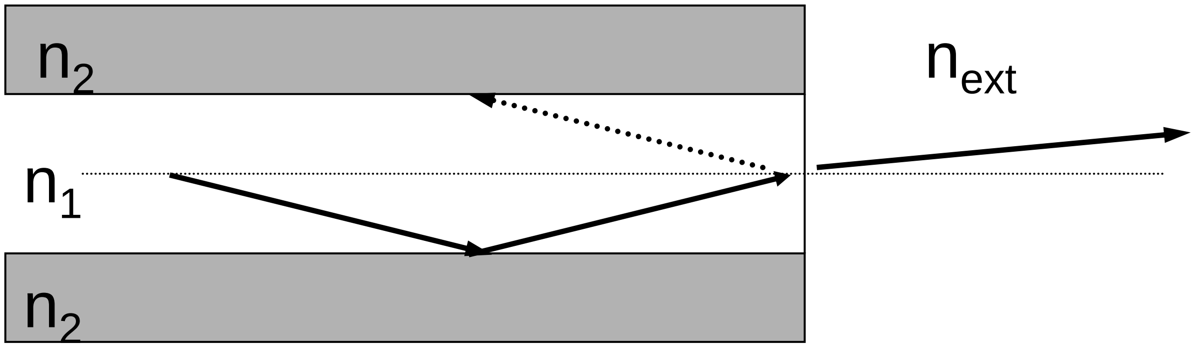
High order mode

- **Microbending:** curvature is on a micrometer scale, less than diameter of optical fibre
  - bending caused by a difference in thermal co-efficient between core and cladding; in practical applications, external non-uniform stress

Solution:

An extra protective layer covering optical fibre

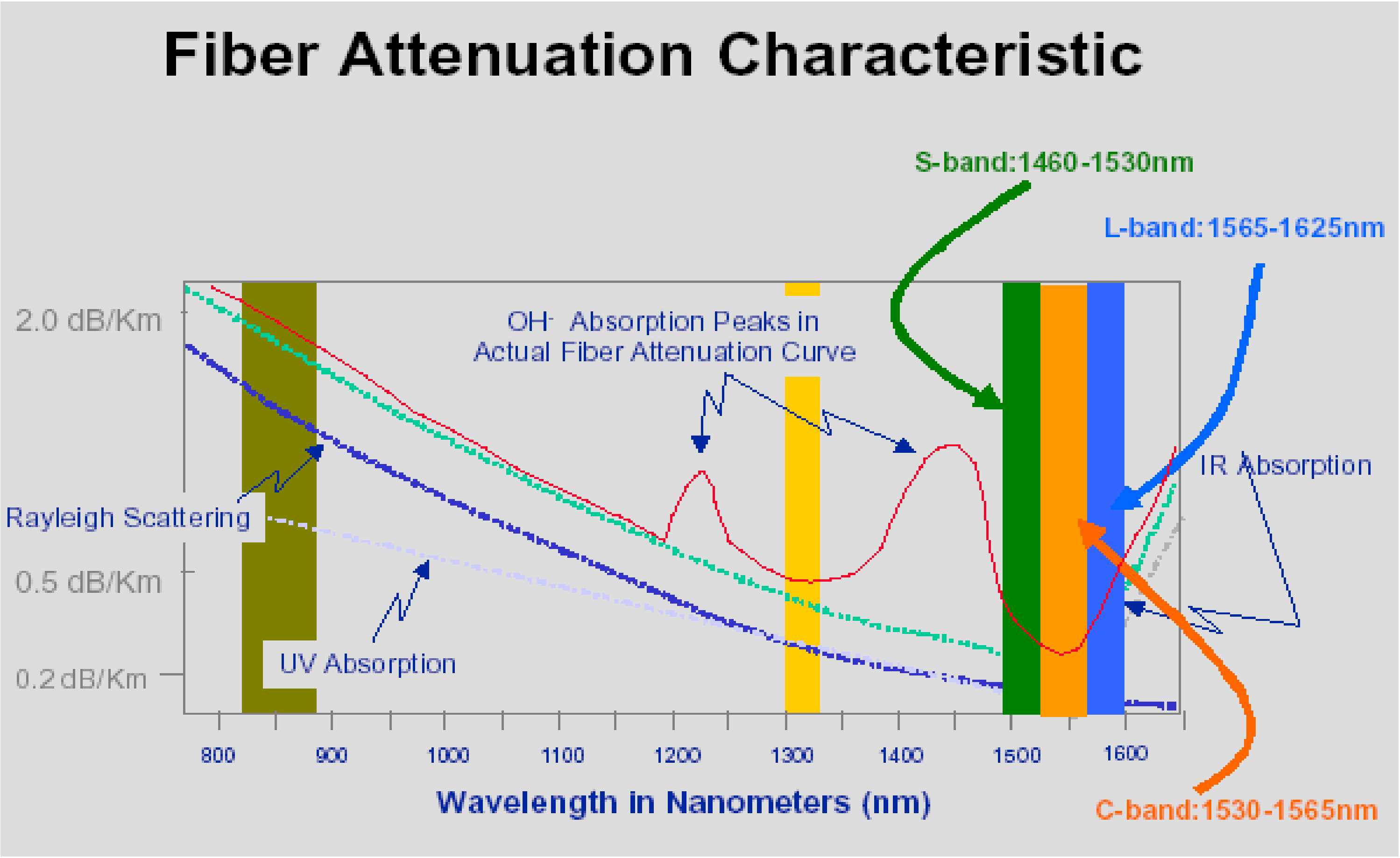
Reflection At Cleaved Fibre



Reflected Power

$$I_R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2$$

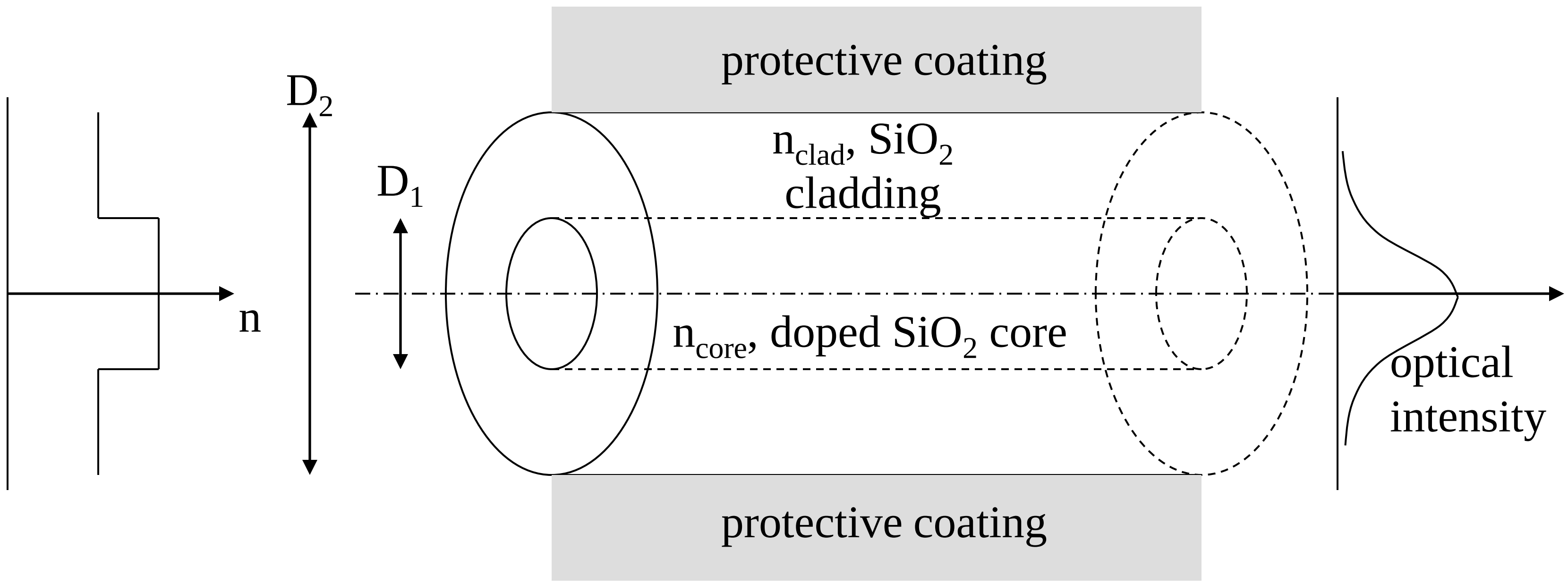
- Although most of the light transmits through the distal end of the fibre, **a small fraction is reflected**
- The amount reflected varies with the incident angle, but for low order modes, θ~0^o and I_R is a minimum (few percent)
- When going from one fibre to another – **use gel which matches the refractive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



- SM optical fibre: two spectral regions with low loss, λ= 1.3 and 1.55 μm, namely, **1.3 and 1.55 μm** optical windows
- 1.55 μm: **C-band** (1525nm-1562nm) and **L-band** (1565nm-1610nm)
- Loss at 1.55 μm: **0.2 dB/km**

Preparation of optical fibres

Optical Fibre

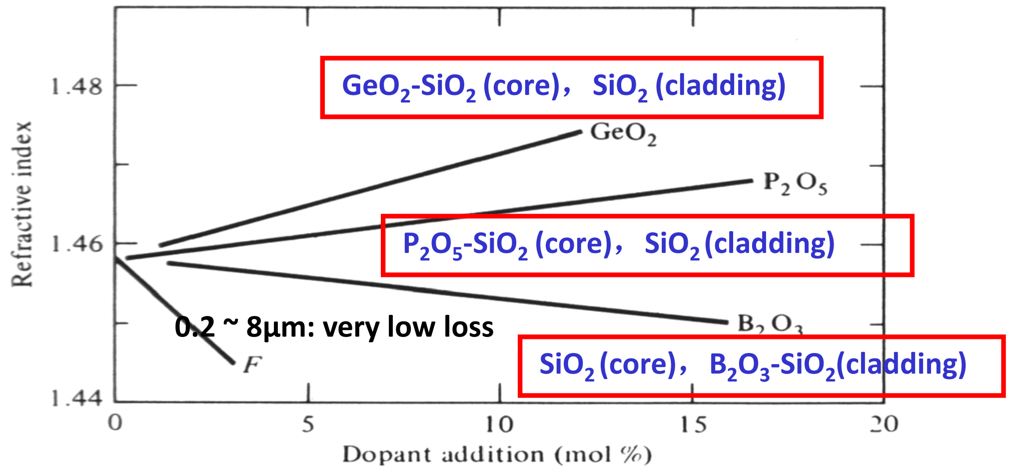


SiO2- high purity: n_{ref} ~ 1.45

<u>Dopants</u>:

B, F: decrease n_{ref} ,

P, Ge, Ti: increase n_{ref}



Fabrication of Optic Fibre

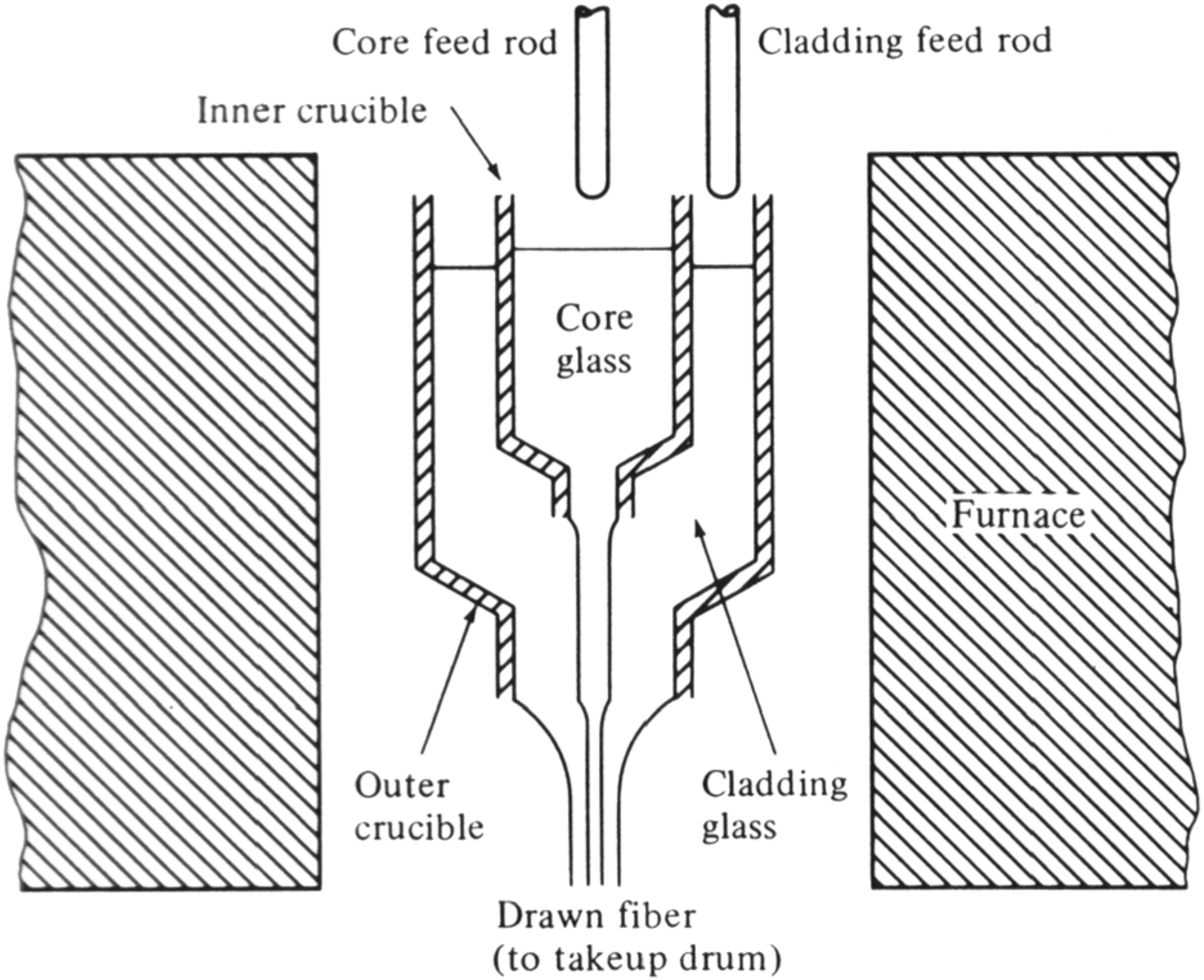
Two basic approaches:

- **Melting technique (crucible method): direct**
- **Chemical vapour deposition (two-stage process):**

(i) Pure glass is produced and converted into a form (rod or preform)

(ii) Drawing or pulling technique is employed to obtain the end product

Melting technique



- Continuous process
- low cost
- high loss: 5 dB/km

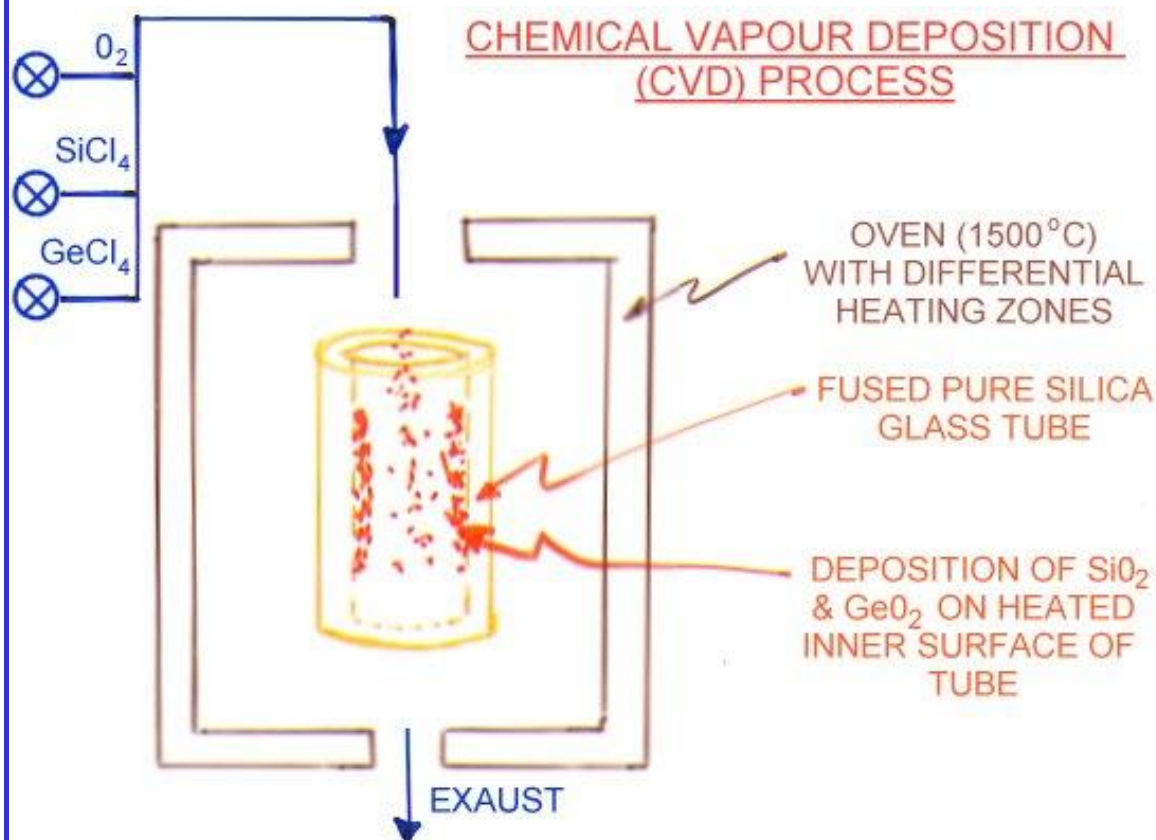
Chemical Vapour Deposition Processes

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

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

(3) Heating via plasma or flame

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



$$SiCl_4(GeCl_4) + O_2 \longrightarrow SiO_2(GeO_2) + 2Cl_2$$

Outside Vapour-Phase Oxidation – "Soot"

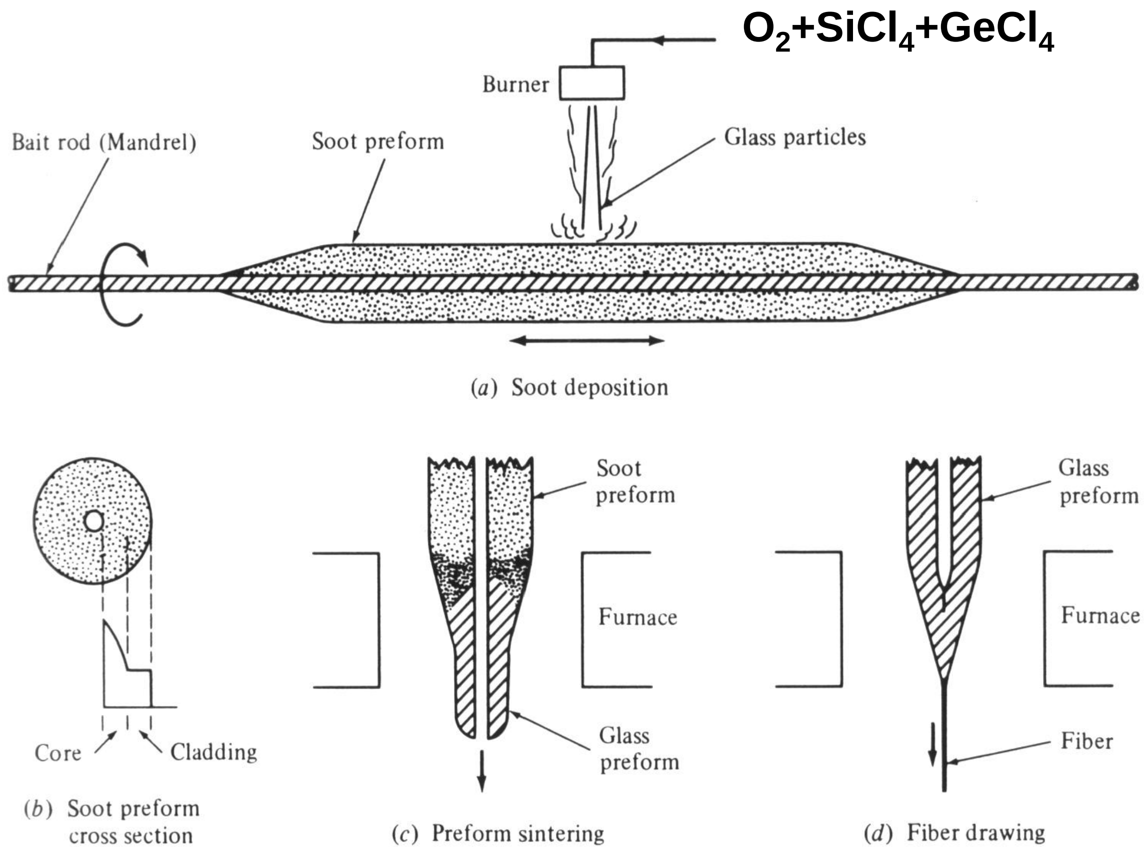
• SiO_2 + GeO_2 soot deposited on mandrel (forms core), then pure SiO_2 soot deposited next (forms cladding)

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

Remove glass mandrel (drill it out and polish)

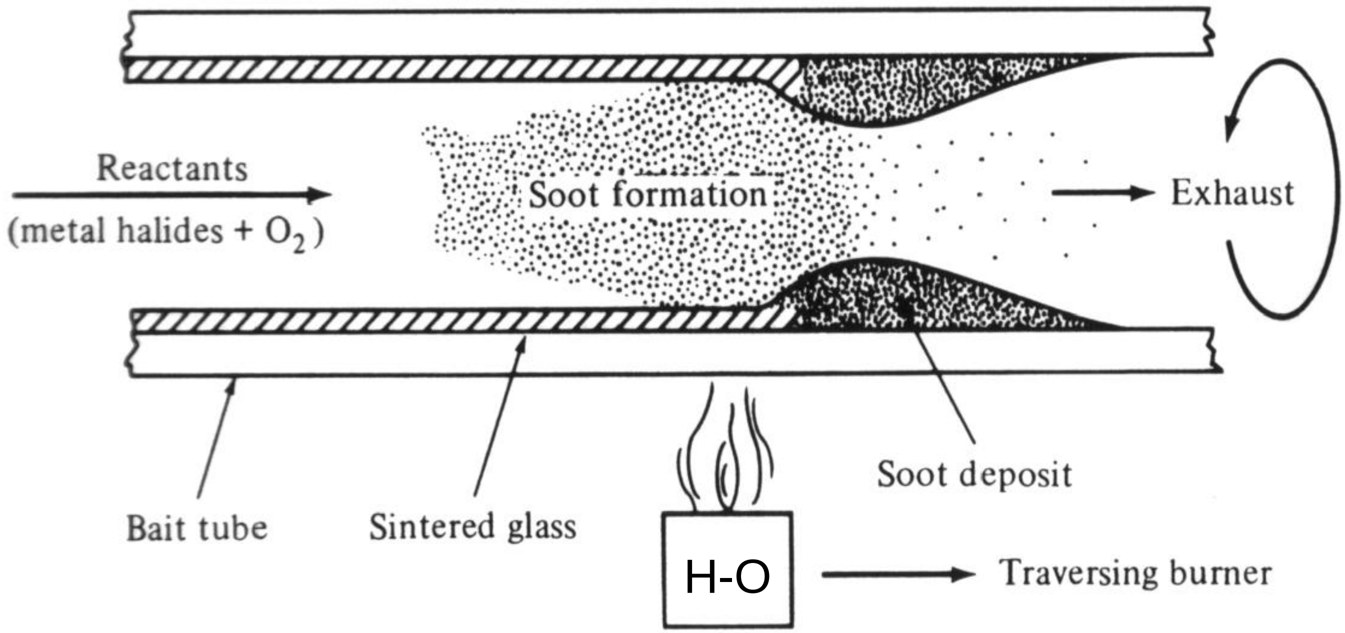
• Heat soot boule so that it sinters into dense glass mass (called a **preform**).

• Pulling process



$$SiCl_4(GeCl_4) + O_2 \longrightarrow SiO_2(GeO_2) + 2Cl_2$$

Internal Chemical Vapour Deposition

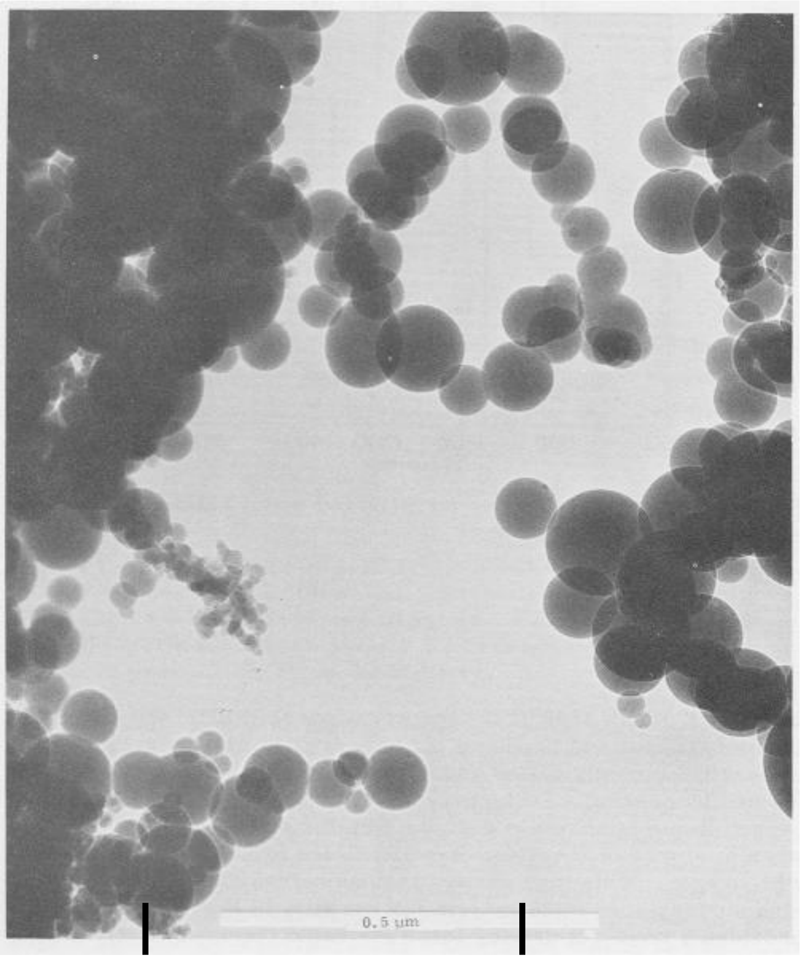


$$\boxed{SiCl_4(GeCl_4) + O_2 \longrightarrow SiO_2(GeO_2) + 2Cl_2}$$

Core: CVD; cladding: hollow tube of pure silica

Tube: 1mm in length; 15 mm in diameter; 1mm in wall thickness
inside: surface etched and washed

Photos of Soot Method



scale bar is 0.5 micron wide

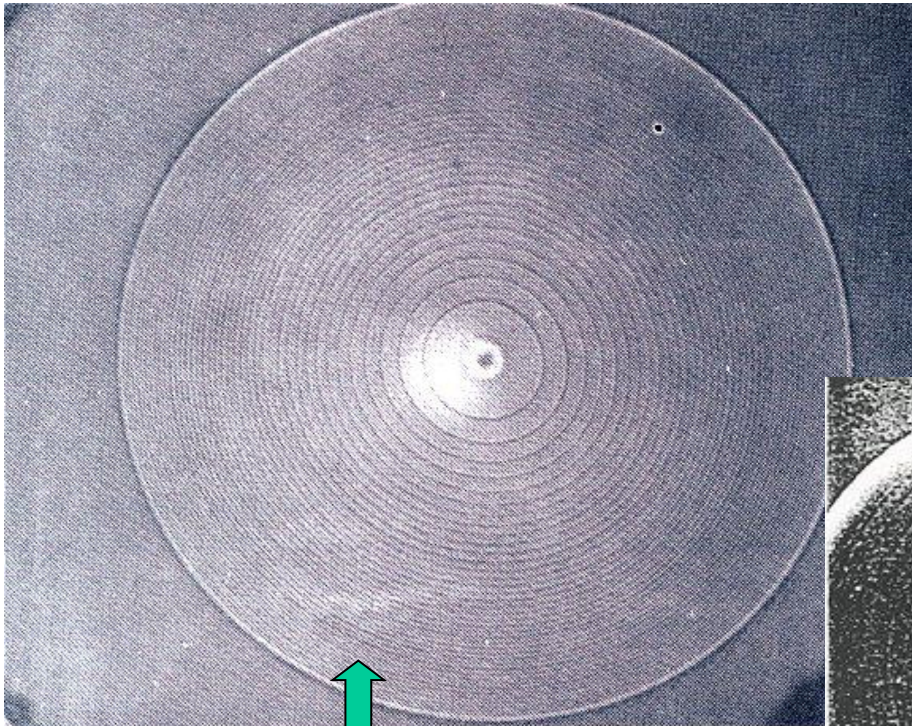
Soot Boule

Photos of Soot Method

Heating soot boule to form preform.

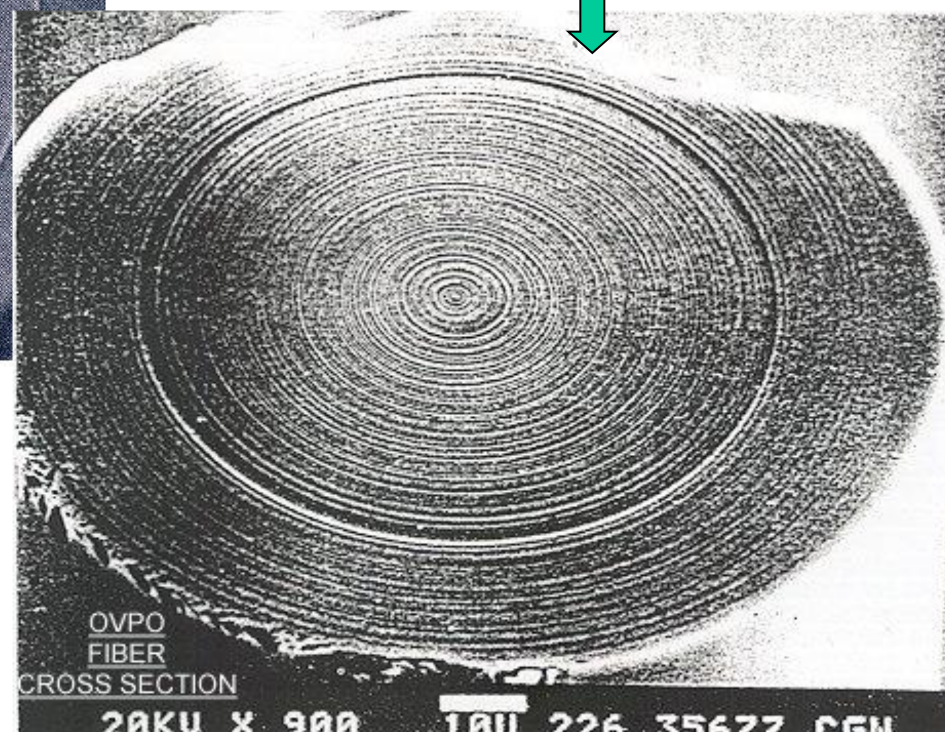
Typically preforms are about 1 metre long and 20 cm in diameter, and produces about 25 km of optical fibre.

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 2100^{o}C, 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

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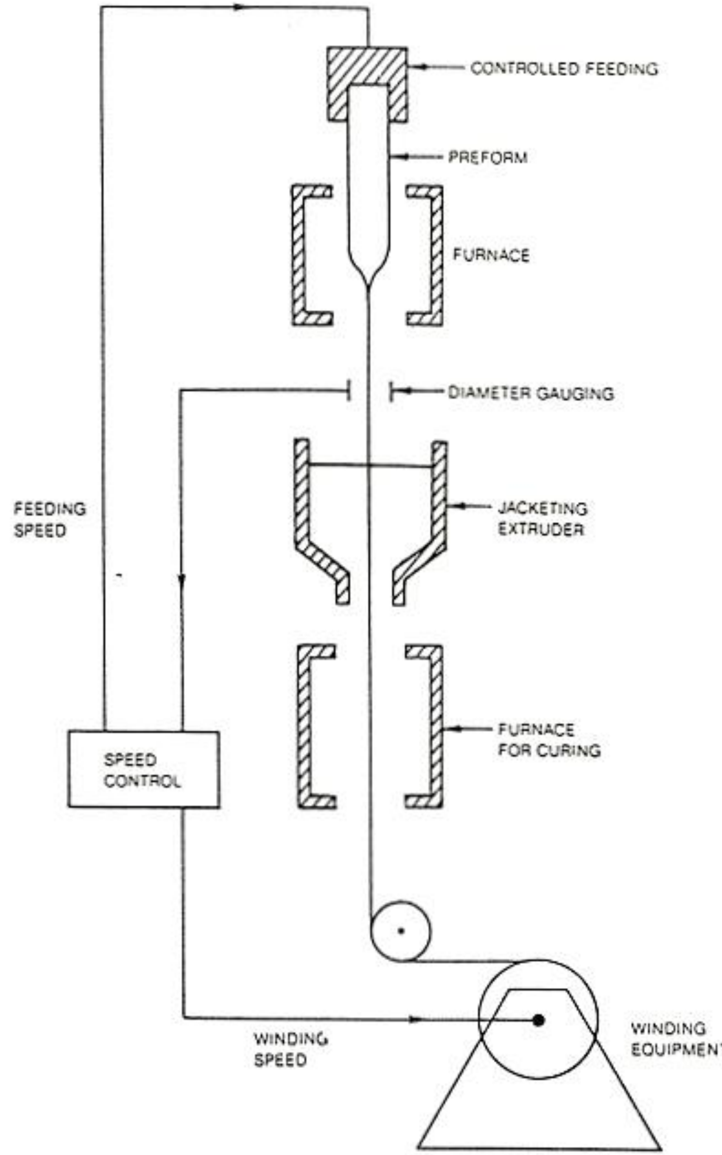
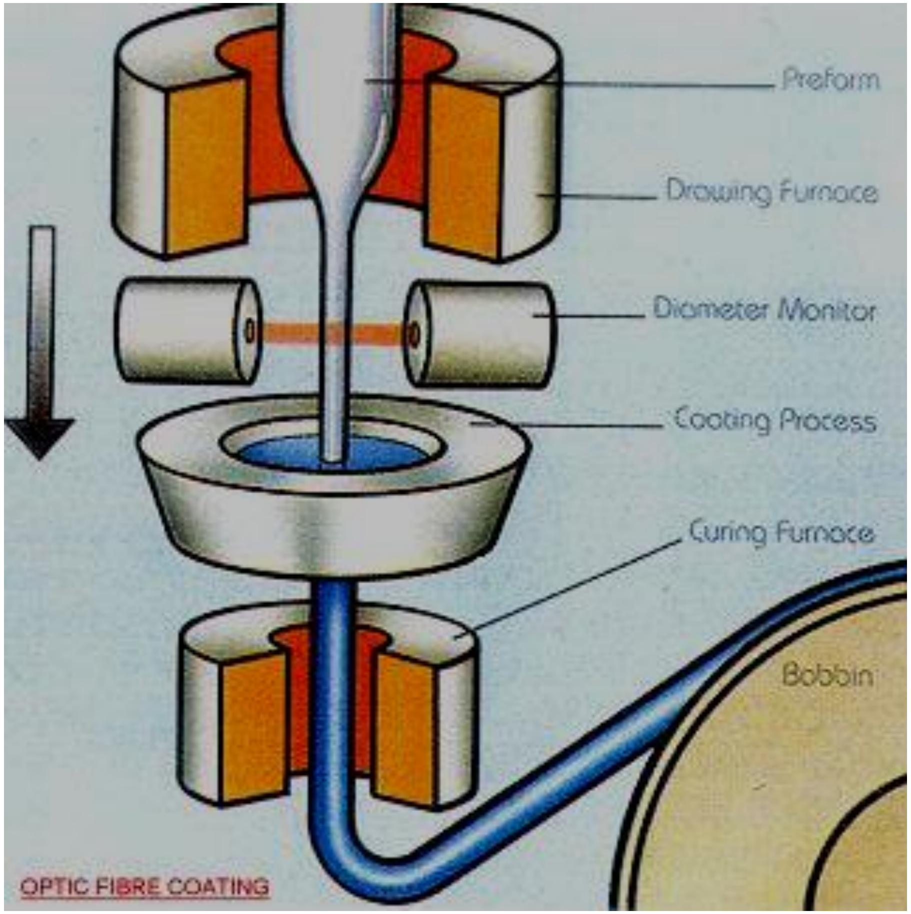


APPARATUS FOR PULLING OPTICAL FIBERS

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.

T4 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

T4 Tutorial Questions

T3.1 Describe what is meant by material and waveguide dispersion in a single mode fibre. Sketch a Dispersion (D) vs. wavelength graph for a typical silica fibre. Describe possible sources of Loss in a silica fibre. Sketch the Loss vs wavelength graph for a typical silica fibre. How do these two graphs affect the choice of a transmitter in a fibre optic system?

T3.2 Describe how a single mode fibre optic cable is manufactured.