Optical Communications

Optic Fiber Waveguides

Part5

Fiber Optic Communications

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Fourth Edition PRENTICE HALL

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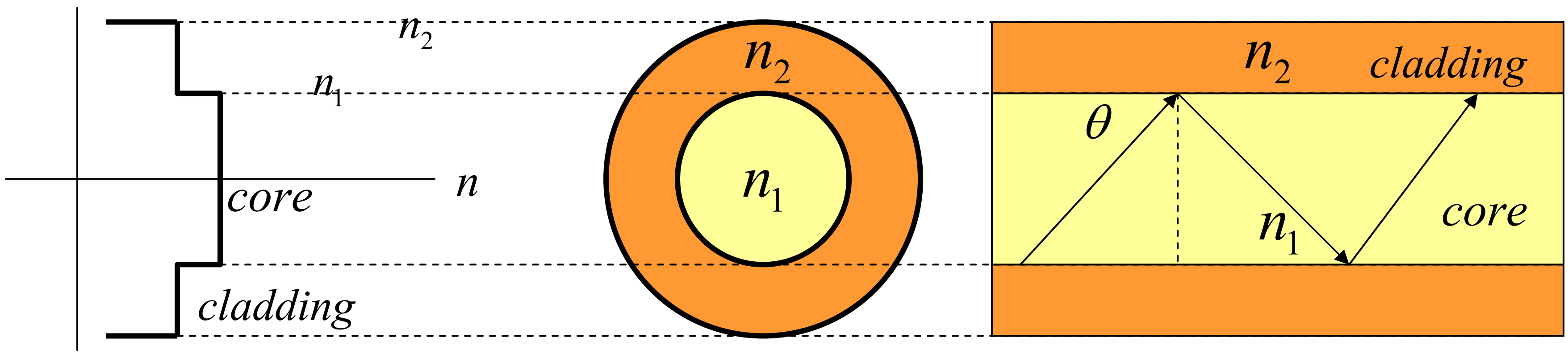
Step-Index (SI) Fiber

SI fiber consists of a central **core** whose refractive index is $\mathbf{n_1}$ surrounded by a **cladding** whose refractive index is $\mathbf{n_2}$



Step-Index Fiber

Cross-Sectional-Side

End-View

The critical angle of the SI fiber is $\sin\theta_c = \dfrac{n_2}{n_1}$ $\quad n_2 < n_1$

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Step-Index (SI) Fiber

The fractional refractive index change is

$$\Delta = \frac{n_1 - n_2}{n_1} \qquad \Delta > 0$$

Efficient transmission requires that the core and cladding be as free of loss as possible.

Some light travels in the cladding. If he cladding in nonabsorbent, then this light is not lost but travels along the fiber.

SI fibers have three common forms:

1- a glass core, cladded with a glass having a slightly lower refractive index (refractive index step is smallest)

2-A silica glass core, cladded with plastic (a little larger).

3- A plastic core, cladded with another plastic (Largest)

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Step-Index (SI) Fiber

The numerical aperture (NA) for SI fiber is:

$$NA = n_0 \sin\theta$$

The NA increases if the difference (n_1-n_2) increases (for all glass fiber core diameter=50 and cladding 125 both in micrometers. So NA is small for all glass fibers and largest for all plastic fibers.

The small NA making it difficult to efficiently couple light into the fiber.

The pulse spread is small for all glass fibers and largest for all plastic fibers. So large data rates and long paths using all glass fibers (30 MHzxkm).

The attenuation loss is lowest in the all glass fibers (few dB/km) and largest in all plastic fibers (several hundreds dB/km)

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Step-Index (SI) Fiber

Property	All glass	PCS	All plastic
NA	low	high	highest
Data Rate	high	moderate	lowest
Attenuation	lowest	high	highest
Pulse spread	smallest	large	largest
Core diameter (micrometer)	50/125	200	1 mm
Coupling loss	high	low	lowest
Paths	long	short	shortest

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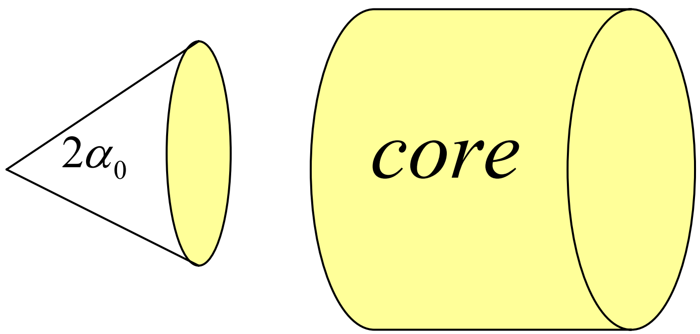
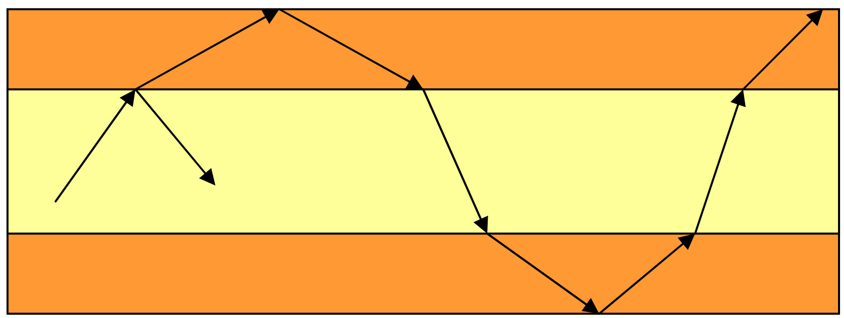
Step-Index (SI) Fiber

Construction	n_1	n_2	NA	α_0 0	Critical angle	Δ
All-Glass	1.48	1.46	0.24	13.9		0.0135
PCS	1.46	1.4	0.41	24.2		0.041
All-Plastic	1.49	1.41	0.48	29		0.054





Only rays emitted within a cone having a full angle $2\alpha_0$ will be trapped by an IS fiber.

$$NA = n_0 \sin\theta = n_0\sqrt{n_1^2 - n_2^2}$$ or $$NA = n_1\sqrt{2\Delta}$$

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Step-Index (SI) Fiber

The light traveling in a cladding mode attenuates rapidly than light in a core mode because the outer boundary of the cladding is normally in contact with a lossy material.

Example: Suppose that the glass fiber in table above is surrounded by air. Compute the critical angles at glass-cladding and cladding-air boundaries.

Solution:

1- at glass-cladding boundary

$$\theta_c = \sin^{-1}(1.46/1.48) = 80.6^o$$

2- at cladding-air boundary

$$\theta_c = \sin^{-1}(1/1.46) = 43^o$$

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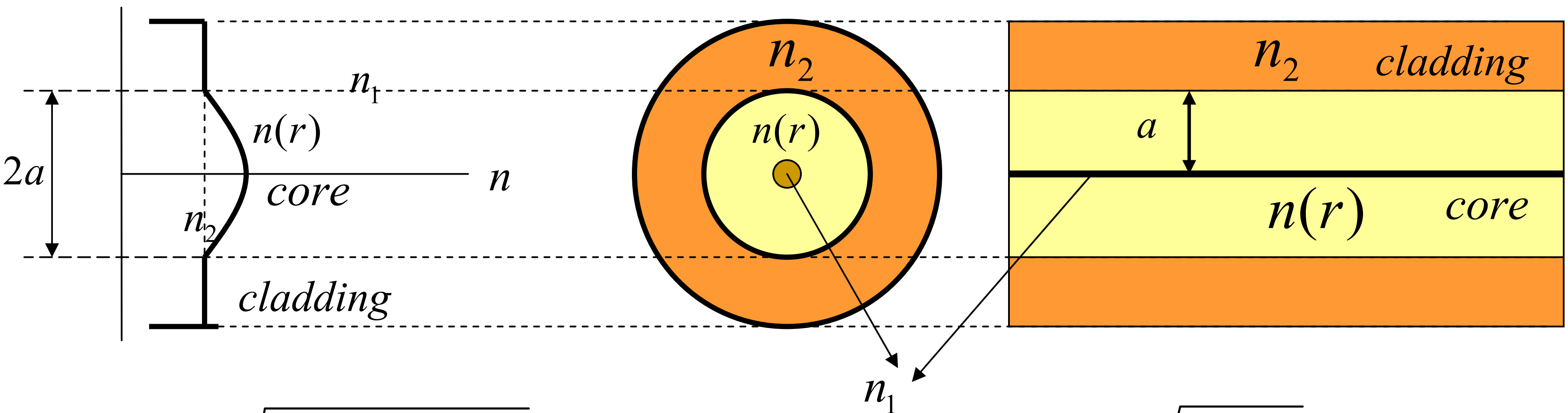
Graded-Index (GRIN) Fiber

GRIN fiber has a core material whose refractive index decreases continuously with distance from the fiber axis.



$$n(r) = n_1\sqrt{1 - 2(r/a)^{\alpha}\Delta} \quad , r \le a$$

$$n(r) = n_1\sqrt{1 - 2\Delta} = n_2 \quad , r > a$$

a Core radius α Parameter describing the refractive index profile variation

Δ Parameter determining the scale of profile change

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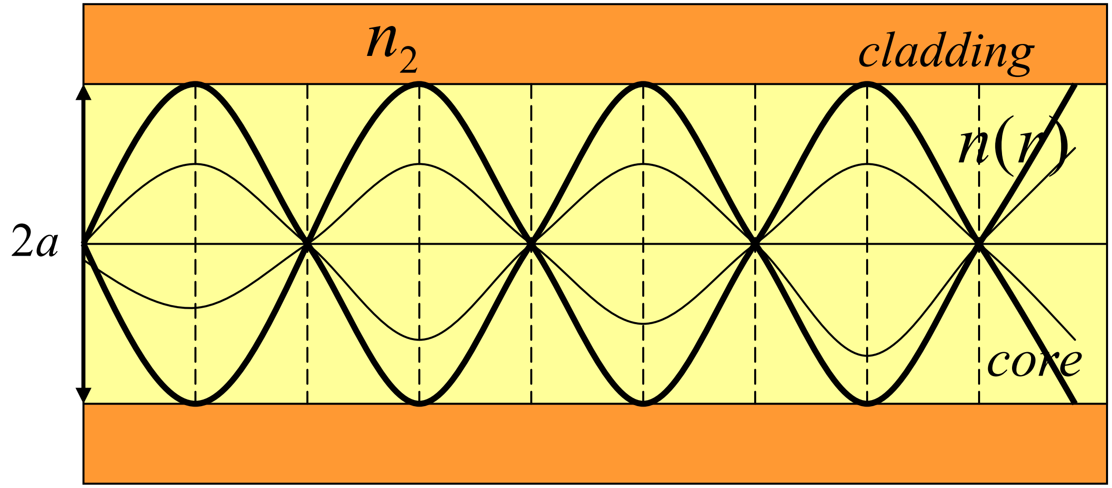
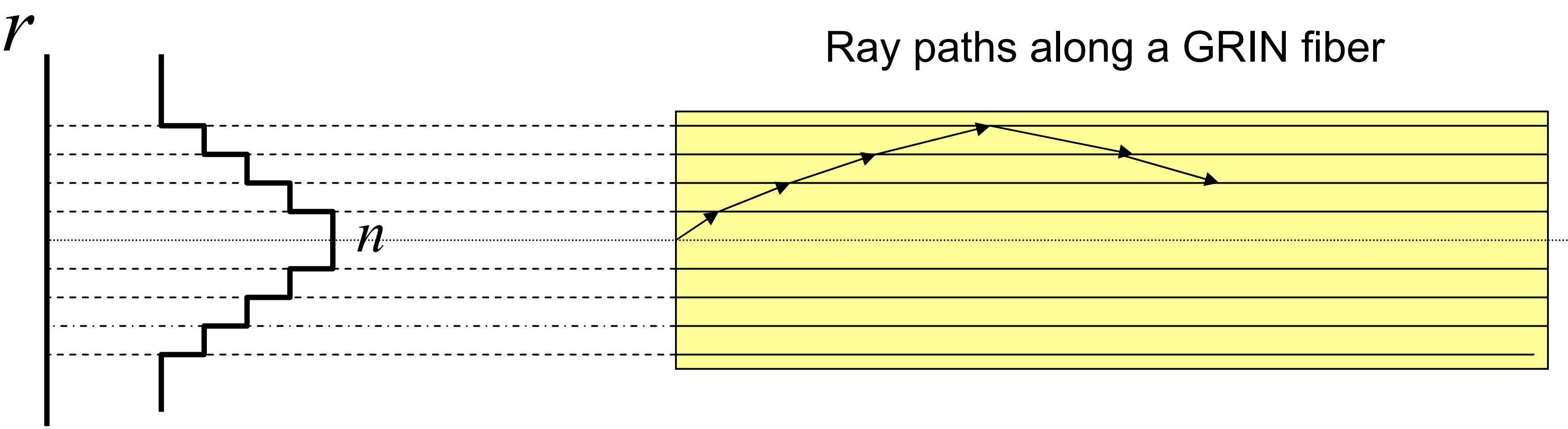
$$\Delta = \frac{(n_1^2 - n_2^2)}{2n_1^2}$$

The changing in refractive index causes the rays to be continually redirected toward the fiber axes.

Graded-Index (GRIN) Fiber



Ray paths along a GRIN fiber



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Graded-Index (GRIN) Fiber

The pitch of a GRIN fiber can found by:

$$P = \pi a \sqrt{2/\Delta}$$

Example: compute the pitch of a GRIN fiber that has a diameter of 62.5 μm

and a fractional refractive index change of 0.01

Solution:

$$P = \left(\frac{0.0625)mm)}{2}\right)\pi\sqrt{2/0.01(mm)} = 1.39mm$$

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Attenuation

All receivers require that their input power be above some minimum level, so transmission losses limit the total length of the path. Losses occur in several points:

-Splices

-Connectors

-Channel input coupler

-Fiber itself

We will study the losses in most practical fiber communications in the range (0.5-1.6) μm

Glass fibers generally have lower absorption than plastic fibers, so they used for long-distance communications.

To obtain different refractive indices, other materials are added to the mixtures.

The losses in Glass fibers can be classified as

-Absorption

-Scattering

-Geometric effects

Absorption:

1- Intrinsic: a natural property of the glass itself. It is very strong in the short-wavelength ultraviolet portion of the electromagnetic spectrum. It is characterized by peak loss in the ultraviolet and diminishing loss as the visible region is approached.

In infrared, the peaks are between 7 and 12 (micrometers) which far from the region of interest.

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Attenuation

2- Impurities: from a practical point of view, the most important impurity to minimize is the hydroxyl ion (OH). The oxygen and hydrogen atoms are vibrating owing to thermal motion. The peak absorption lies at 2.73 (micrometers) which lies outside interest.

3- Atomic defects: also contribute to fiber absorption.

Rayleigh scattering (L):

A beam of light passing through a structure with a small scattering objects embedded in a homogenous material, will have some of its energy scattered by these objects. In this case, a medium has scattering objects smaller than a wavelength.

$$L = 1.7(0.85/\lambda)^4$$

L is in dB/km and wavelength is in micrometers.

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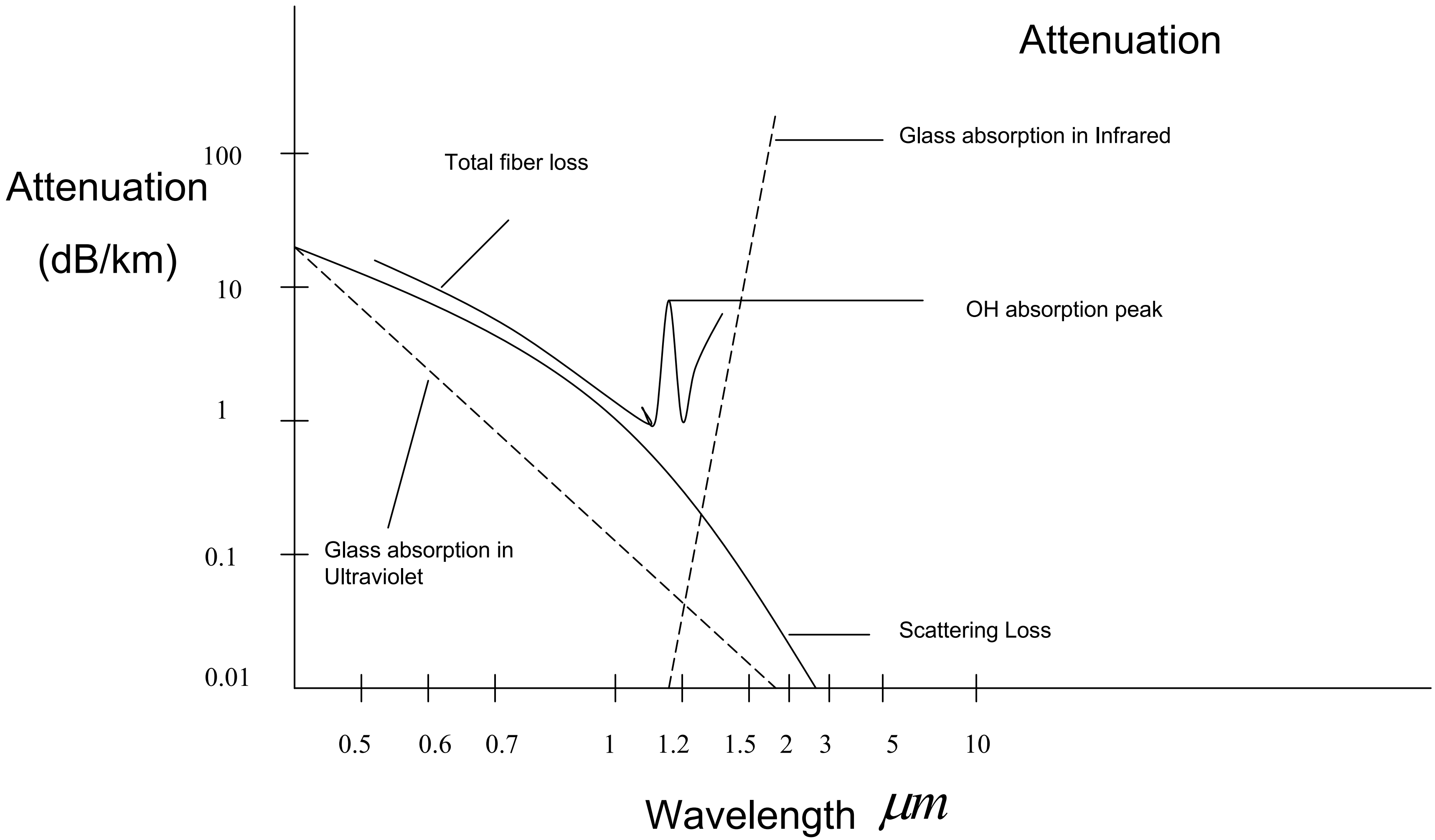
Attenuation



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Attenuation

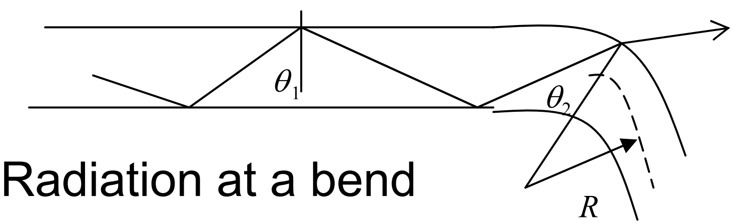
Inhomogeneities: introduced into the glass during manufacture also cause scattering loss.

-Imperfect mixing causes inhomogeneties within the core

-Imperfect processing can produce a rough-core-cladding interface.

Geometric effects:

Macroscopic bending: refers to large-scale bending (spool, around the corner). Fiber with diameter 125 (micrometer) can be bent with radius 25 mm without loss. **Microscopic Bending:** reduces the fiber tensile strength. The stress owing to bending may cause the early failure of a fiber. For commercial 125 micrometers fibers, the minimum bend radius of 25 mm that assures negligible loss also ensures negligible strength loss.



Radiation at a bend

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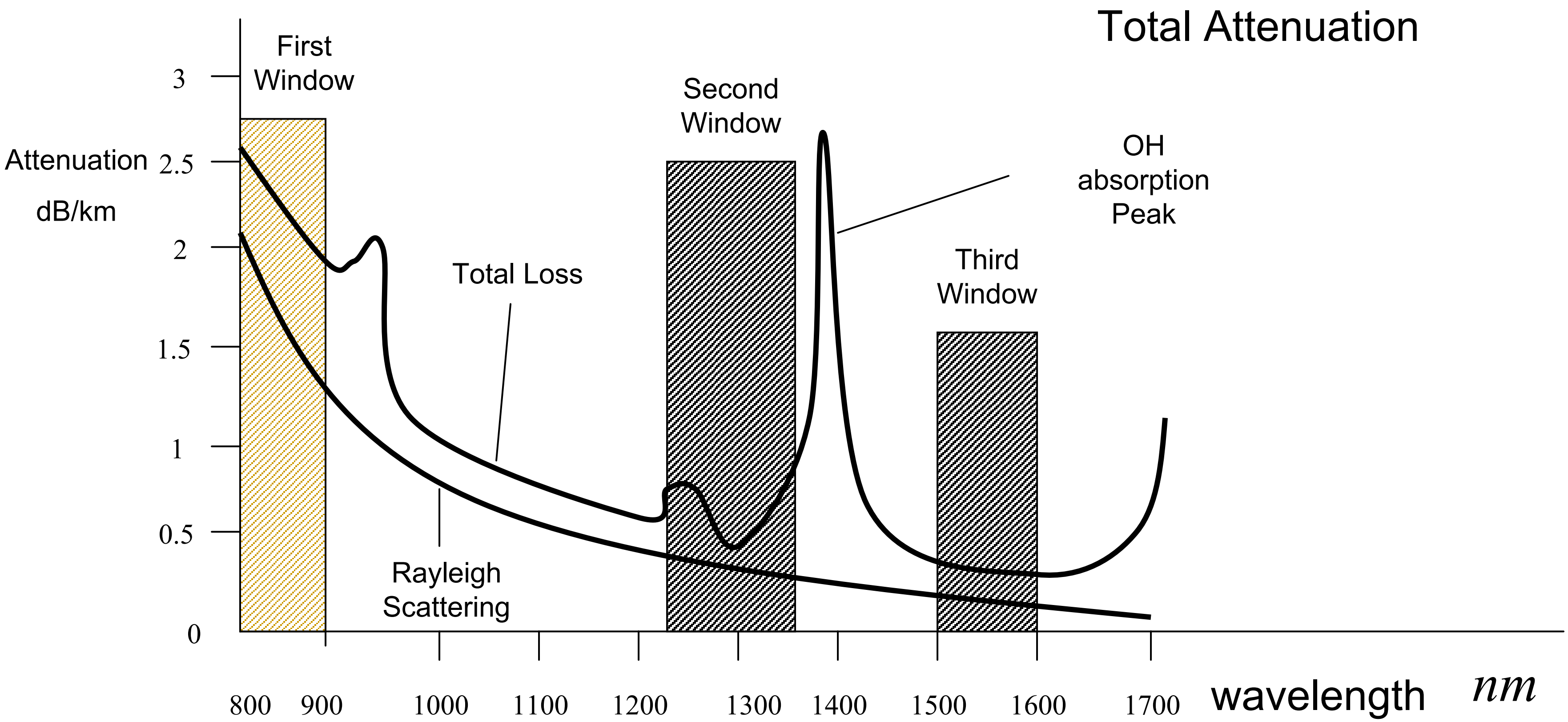

The minimum loss for silica fibers is about 0.15 dB/km at 1.55 micrometers.

The first transmission window is the practical region for glass fibers and for long distances. Between second and third region we have the OH absorption peak below 1400 nm.

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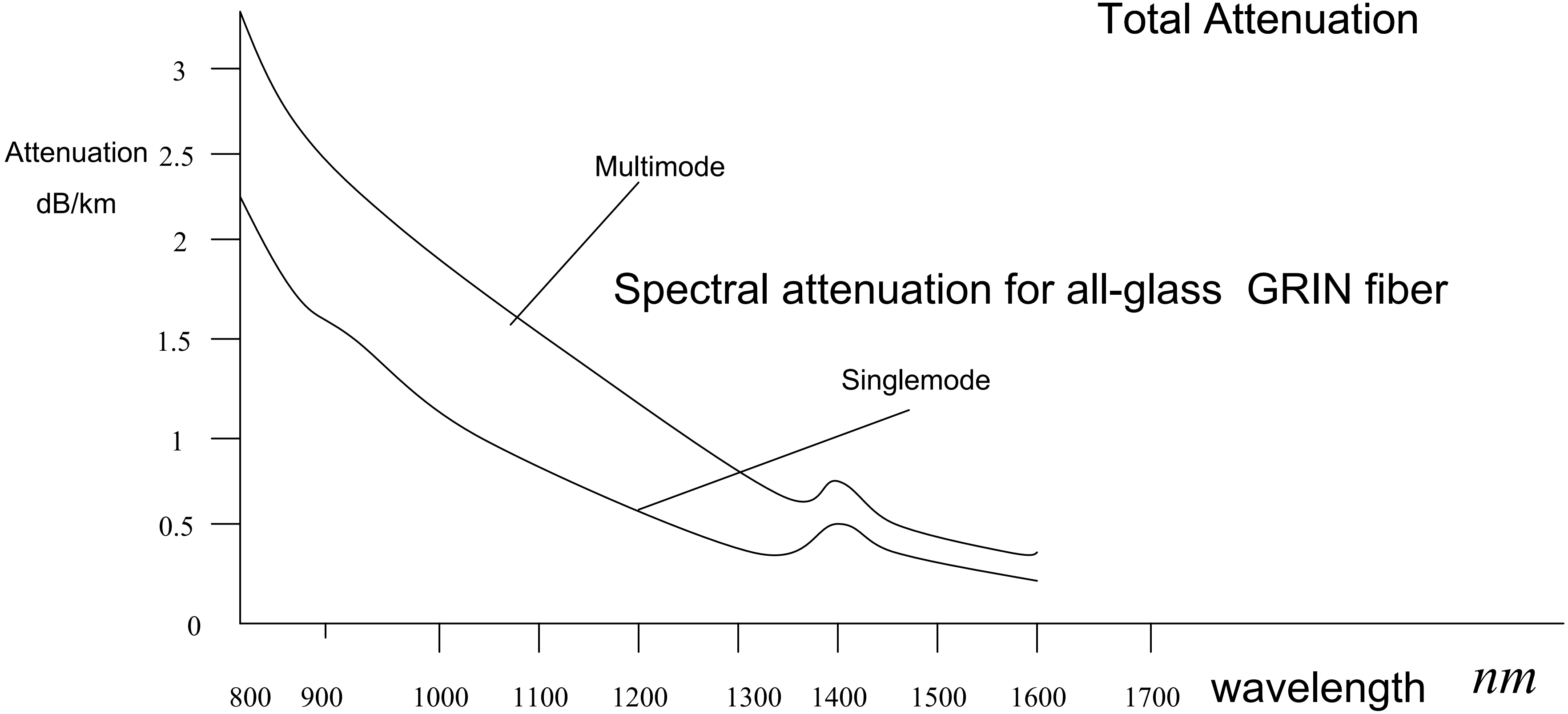
Total Attenuation



Glass fibers are pure silica and doped silica. A multimode fiber has a diameter 85 micrometer and spot size is 5 micrometer when operated at wavelength of 1300 nm. The larger attenuation for multimode fiber is due to increased loss associated with the propagation of higher order modes.

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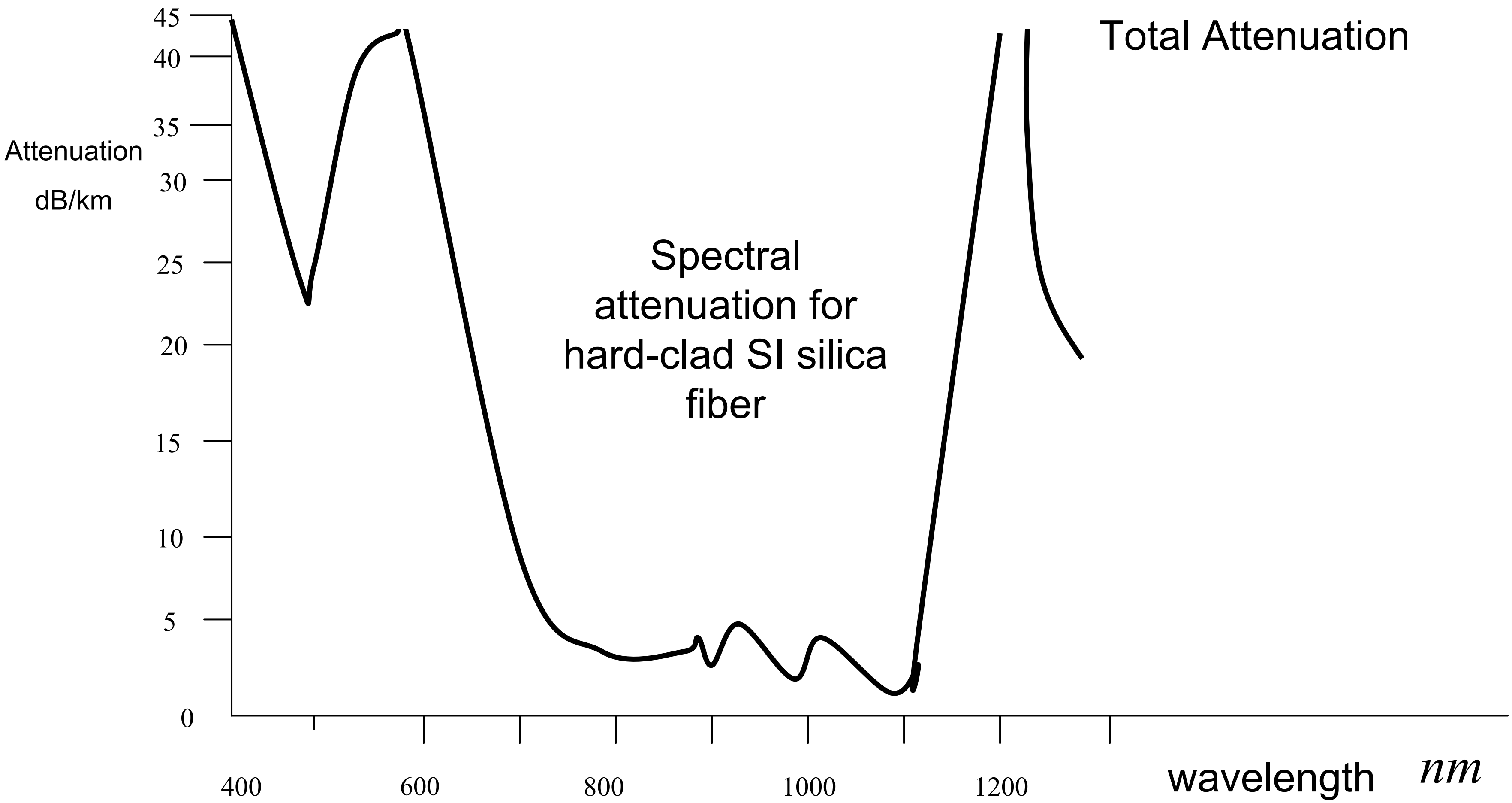

The PCS fiber has a pure silica core, and a thin hard polymer coating serves as cladding (hard-clad silica). PCSs have more attenuation than glass fiber (around 800 nm)

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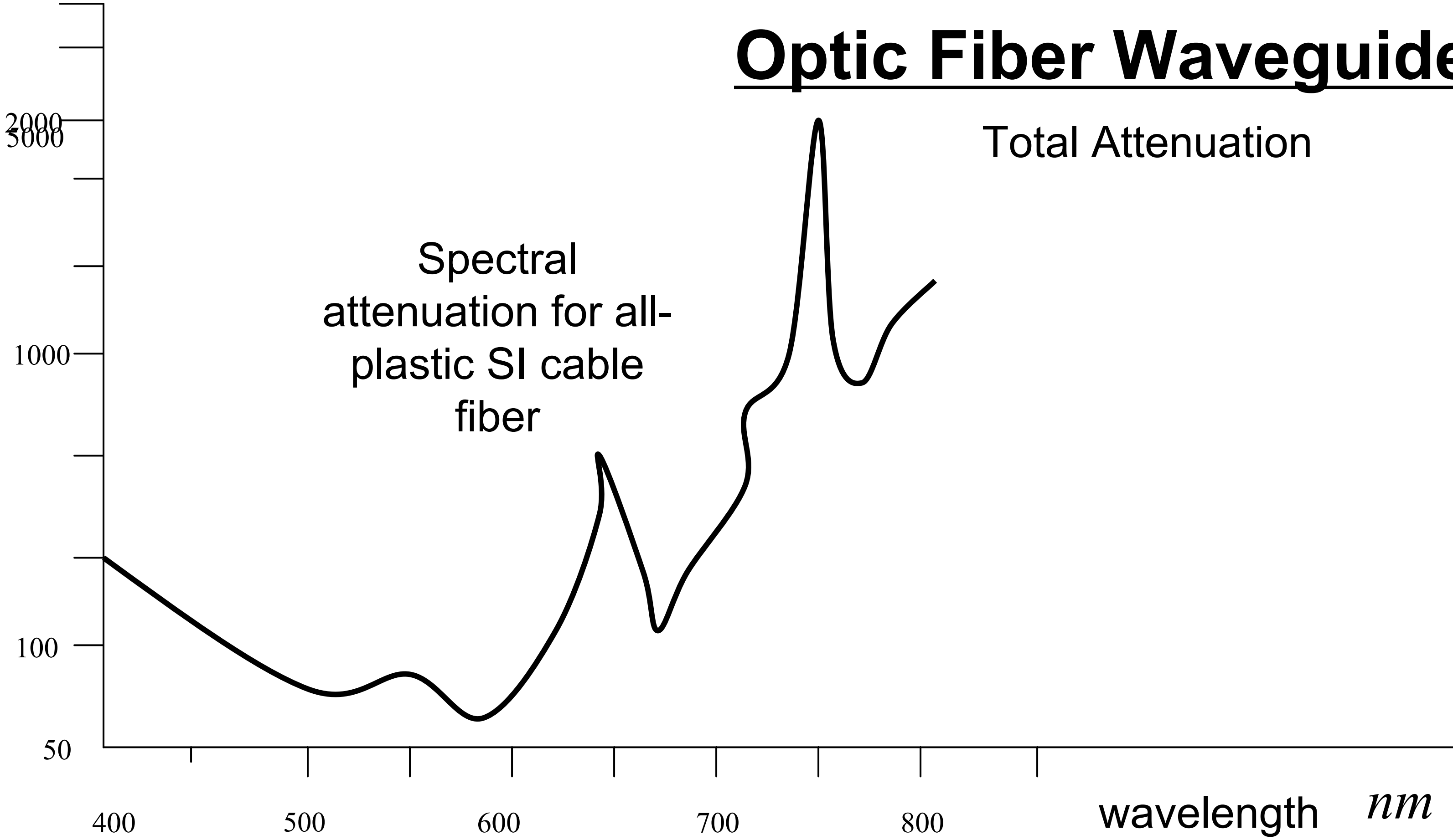

The plastic fiber has polymethy1 methacrylate core and flouropolymer cladding. The attenuation is high and it used for short paths. It compatible with LED and LD for wavelengths around 650-670 nm.

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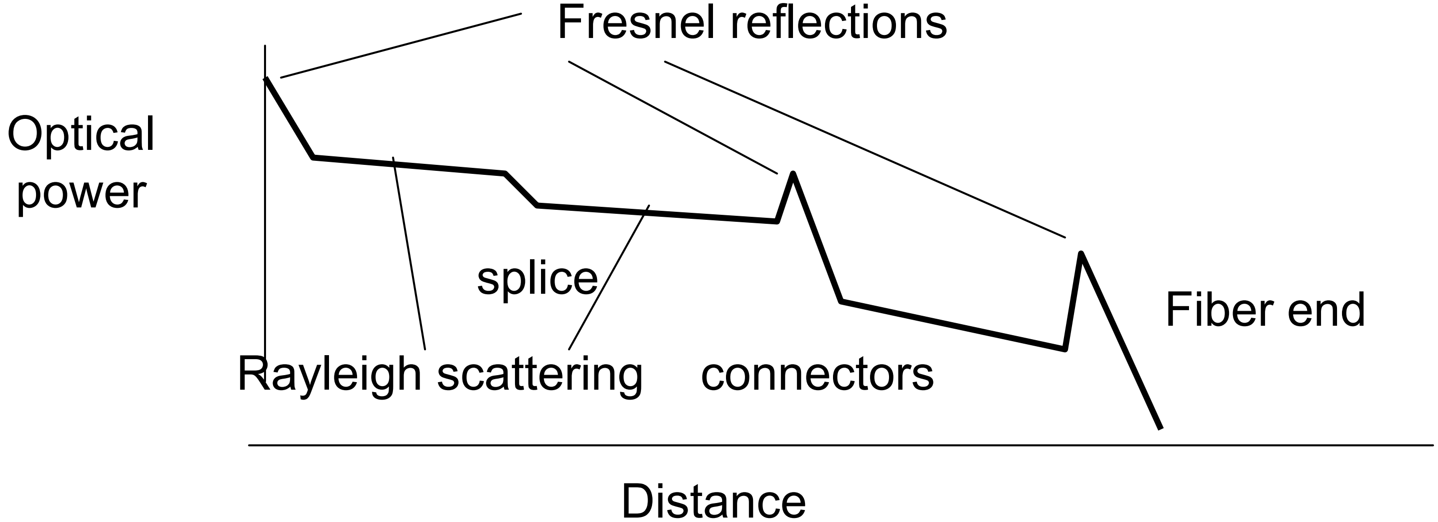
Total Attenuation

The attenuation is measured using *straight forward method* using optical power meter at two points. Then the loss is defined by dB/km.

We can use another method called *optical time-domain reflectometer* (OTDR). This method requires that only one end of the fiber be available for measurement. It transmits an optical pulse down the fiber and measures the reflections which occurs owing to discontinuities (splices, connectors, and fiber breaks.



Example:

Total Attenuation

A fiber system operates at a wavelength of 1300 nm where the fiber loss is 0.5 dB/km. the LED light source emits 1.59 mW and couples with 16-dB loss into the fiber. Connectors and splices in the system contribute a total loss of 6 dB. The receiver sensitivity is given as -30dBm. A 4-dB margin specified to account for system degradations. What is the maximum length of fiber that can be used?

Solution:

Sample power Calculations		
LED output power		10log(1.59)=2dBm
Receiver sensitivity		-30 dBm
Loss budget		32 dBm
Coupling loss	16 dB	
Connector & splices	6 dB	
Power margin	4 dB	
Total loss	26 dB	-26 dB
Available fiber loss		6 dB

The maximum allowable length is 6/0.5=12 km.