1.5 ABSORPTION LOSSES

Absorption in optical fibers is explained by three factors: Imperfections in the atomic structure of the fiber material.

- The intrinsic or basic fiber-material properties.
- The extrinsic (presence of impurities) fiber-material properties
- Imperfections in the atomic structure induce absorption by the presence of missing molecules or oxygen defects. Absorption is also induced by the diffusion of hydrogen molecules into the glass fiber.

Intrinsic Absorption.- Intrinsic absorption is caused by basic fiber material properties. If an optical fiber were absolutely pure, with no imperfections or impurities, then all absorption would be intrinsic. Intrinsic absorption sets the minimal level of absorption

Extrinsic Absorption.- Extrinsic absorption is caused by impurities introduced into the fiber material. Trace metal impurities, such as iron, nickel, and chromium, OH ions are introduced into the fiber during fabrication. Extrinsic absorption is caused by the electronic transition of these metal ions from one energy level to another

Scattering losses

Basically, scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured. During manufacturing, regions of higher and lower molecular density areas, relative to the average density of the fiber, are created. Light traveling through the fiber interacts with the density areas as shown in Light is then partially scattered in all direction.

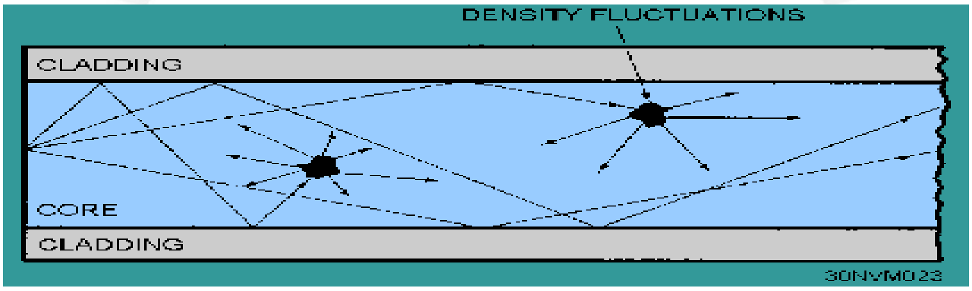

Figure 1.5.1 Scattering process

[Source: "Optical Fibre Communications" by J.M.Senior, Page: 73]

In commercial fibers operating between 700-nm and 1600-nm wavelength, the main source of loss is called Rayleigh scattering. As the wavelength increases, the loss caused by Rayleigh scattering decreases. If the size of the defect is greater than one-tenth of the wavelength of light, the scattering mechanism is called Mie scattering.

Linear scattering losses

1. Rayleigh scattering

It occurs because the molecules of silicon dioxide have some freedom when adjacent to one another. Thus, setup at irregular positions and distances with respect to one another when the glass is rapidly cooled during the final stage of the fabrication process. Those structural variations are seen by light as variations in the refractive index, thus causing the light to reflect – that is, to scatter – in different directions

- **Rayleigh scattering** is a scattering of light by particles much smaller than the wavelength of the light, which may be individual atoms or molecules.
- Rayleigh scattering is a process in which light is scattered by a small spherical volume of variant refractive index, such as a particle, bubble, droplet, or even a density fluctuation.

As light travels in the core, it interacts with the silica molecules in the core. Rayleigh scattering is the result of these elastic collisions between the light wave and the silica molecules in the fiber. Rayleigh scattering accounts for about 96 percent of attenuation in optical fiber

Causes of Rayleigh Scattering:

It results from non-ideal physical properties of the manufactured fiber. It results from inhomogeneities in the core and cladding.

Because of these inhomogeneities problems occur like –

a) Fluctuation in refractive index
b) density and compositional variations.

Minimizing of Rayleigh Scattering:

- Rayleigh scattering is caused due to compositional variations which can be reduced by improved fabrication.

Equation of Rayleigh Scattering:

Light scattering can be divided into three domains based on a dimensionless size parameter, α which is defined as

$$\mathbf{A} = \pi D_p / \lambda$$

where πD_p is the circumference(The boundary line of a circle) of a particle and λ is the wavelength of incident radiation. Based on the value of α, these domains are:

$\alpha \ll 1$: Rayleigh scattering (small particle compared to wavelength of light) $\alpha \approx 1$: Mie scattering (particle about the same size as wavelength of light)

Mie scattering

Non perfect cylindrical structure of the fiber and imperfections like irregularities in the core-cladding interface, diameter fluctuations, strains and bubbles may create linear scattering which is termed as Mie scattering

Mie scattering is a scattering of light by particles approximately equal to the wavelength of the light, which may be individual atoms or molecules.

Causes of Mie Scattering:

- Occurred due to inhomogeneities in the composition of silica. (i.e. inhomogeneities in the density of SiO_2)
- Irregularities in the core-cladding interface, Difference in core cladding refractive index, Diameter fluctuations
- Due to presence of strains and bubbles.

The scattering caused by such in homogeneities is mainly in the forward direction depending upon the fiber material, design and manufacture.

Minimizing of Mie scattering

Mie scattering is mainly caused by in homogeneities which can be minimized by

- Removing imperfection due to glass manufacturing process
- Carefully controlled extrusion(To push or thrust out) and coating of the fiber

Both Mie and Rayleigh scattering are considered elastic scattering (elastic scattering is also called Linear scattering) processes, in which the energy (and thus wavelength and frequency) of the light is not substantially changed.

Nonlinear scattering losses

Specially at high optical power levels scattering causes disproportionate attenuation, due to non linear behavior. Because of this non linear scattering the optical power from one mode is transferred in either the forward or backward direction to the same, or other modes, at different frequencies. The two dominant types of non linear scattering are :

a) Stimulated Brillouin Scattering and
b) Stimulated Raman Scattering.

a) Stimulated Brillouin Scattering:

This is defined as the modulation of light through thermal molecular vibration within the fiber. The scattered light contains upper and lower side bands along with incident light frequency. An incident photon produces a scattered photon as well as a photon of acoustic frequency. The frequency shift is maximum in the backward direction and it is reduced to zero in the forward direction. The threshold optical power for Brillion scattering is proportional to $d^2\lambda^2\alpha_B$

b) Stimulated Raman Scattering:

Here, the scattered light consists of a scattered photon and a high frequency optical photon. Further, this occurs both in the forward and backward direction in the optical fiber. The threshold optical power for Raman scattering is about three orders of magnitude higher than the Brillouin threshold for the given fiber, The threshold optical power for Raman scattering is proportional to $d^2\lambda^2\alpha_R$