Simulation of Material losses in SMD Fiber

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Abstract— The Simulation and analysis of the SMF is carried out with the total loss of the germania-doped silica-core fibers can be separated into the inherent ultraviolet absorption loss, the scattering loss and the inherent infrared absorption loss. It is also seen that the ultraviolet absorption loss and the scattering loss are dominated at the short wavelengths below 1.2 µm and the infrared absorption loss is dominated at longer wavelengths above 1.5 µm. The dopants have a great effect on the transmission loss of high-silica glass optical fibers at long wavelengths. When an optimum dopant is selected for making a doped-silica optical fibers and OH content is greatly reduced, a phenomenally broad window where the loss is below 1 dB/Km can be achieved. An ultimate lower loss SMF has been fabricated by reducing the excess loss due to imperfections of waveguide as much as possible. The loss mechanism in the optical fiber discussed has been also analyzed. Transmission losses have been reduced almost down to the intrinsic material loss and the minimum loss is 0.20 dB/Km at 1.55 µm. The dispersion characteristics also analyzed at long wavelength the dispersion is minimized, thus it is confirmed that the single mode fibers are most applicable for long distance and large capacity transmission.

Keywords*- FiberOptics, Material Losss, UV absorption, Scatering Loss, Infrared absorption loss.*

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I. MATERIAL LOSSES

1.1 Fiber propagation loss definition

The total fiber loss can be divided into material losses and fiber induced losses. Material losses include Rayleigh scattering, ultraviolet (UV), infrared (IR) absorption, and hydroxyl (OH) absorption losses. Material losses are the limiting losses in fibers. Fiber loss is defined as the ratio of the optical output power Pout from a fiber of length L to the optical input power Pin. The symbol α is commonly used to express loss in decibels per kilometer[1]:

$$\alpha = \frac{10}{L}\log\left(\frac{P_{in}}{P_{out}}\right) \qquad \ldots\ldots\ldots\ldots (1)$$

1.2 Rayleigh scattering model

Because of the granular appearance of atoms or molecules of the glass fiber, light transmitted through the fiber suffers scattering loss. This is known as Rayleigh scattering loss. Rayleigh scattering in glass is the same phenomenon that scatters light from the sun in the atmosphere, thereby giving rise to a blue sky. Rayleigh scattering losses in a fiber are typically determined through experimental measurement. The loss is expressed in decibels per kilometer by[2]

$$\alpha_s = A/\lambda^4 \qquad \ldots\ldots\ldots\ldots(2)$$

For a single-component glass such as SiO2,

$A = 8\pi 3n08p2\beta kT/3$

The Rayleigh scattering loss is given by[2]

$$\alpha s = 8\pi 3n08p2\beta kT/3\ \lambda 4 \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

Where, n0 is the refractive index, p is the photoelastic coefficient, β is the thermal compressibility, k is the Boltzmann coefficient, and T is the absolute temperature of the sample and A is termed as Scattering amplitude.

1.3 Ultraviolet absorption model

Ultraviolet or UV absorption results from electronic absorption bands in the ultraviolet region. The electronic absorption bands are associated with the band gaps of amorphous glass materials. Absorption occurs when a photon interacts with an electron in the valence band and excites it to a higher energy level. The UV absorption at any wavelength can be expressed as a function of the mole fraction ‘x’ of GeO2[2]:

$$\alpha_{UV} = 10^{-2}\,\frac{154.2x}{46.6x+60}\exp\left(\frac{4.63}{\lambda}\right) \qquad \ldots\ldots\ldots\ldots (4)$$

Where,

x is the mole fraction of the impurity (GeO2) and λ is wavelength

UV loss is small compared to scattering loss in the near infrared region.

1.4 OH-radical absorption model

The dominant absorption factor in fibers prepared by the direct-melt method is the presence of impurities in the fiber material. Impurity absorption results predominantly from transition metal ions, such as iron, chromium, cobalt, and copper and from OH (water) ions. The OH radical of H2O molecule vibrates at a fundamental frequency corresponding to IR light wavelength of λ = 2.8µm. Since the OH radical is slightly a harmonic, “overtones” can occur. These cause OH absorption lines to occur at λ =1.39, 0.95, and 0.725µm, the second, third, and fourth harmonics of fundamental frequencies, respectively. Broad peaks can appear[4].

OH absorption can be characterized by fitting the absorption lines by Lorentzian or Gaussian method[3, 4].

Lorentzian fit method:

$$\alpha_{OH}(\lambda) = \sum_{i=1}^{7} \frac{A_i}{1+\left(\frac{\lambda-\lambda_i}{\sigma_i}\right)^2} \qquad ………… (5)$$

Gaussian fit method:

$$\alpha_{OH}(\lambda) = \sum_{i=1}^{7} A_i \exp\left[-\left(\frac{\lambda-\lambda_i}{\sigma_i}\right)^2\right] \qquad …………. (6)$$

In the above two equations, A i is amplitude, λ_I is absorption peak position, and σ_i is the width of the i-th absorption line. Using up to seven absorption lines fits the OH absorption spectrum here. In contemporary state-of-the-art fibers the hydroxyl-group absorption is greatly reduced, and only the peak atλ=1.38-1.39 μm still retains some practical importance.

1.5 Infrared absorption model

Infrared or IR absorption is associated with the characteristic vibration frequency of the particular chemical bond between the atoms of which the fiber is composed. An interaction between the vibrating bond and the electromagnetic field of the optical signal results in a transfer of energy from the field to bond, thereby causing absorption. This absorption is quite strong because of the many bonds present in the fiber. An empirical expression for the infrared absorption in dB/Km is[2]

$$\alpha IR = A \exp(-B/\lambda)$$

Where A is Amplitude of the exponential fit curve, B is exponential 1/ wavelength decay coefficient. For GeO2 – SiO2 glass (A = 7.81x1011 and B = 48.48) is,

$$\alpha_{IR} = 7.81\times10^{11}\exp\left(\frac{-48.48}{\lambda}\right) \qquad ………… (7)$$

2. ANALYSIS OF ANALYSIS OF MATERIAL LOSSES

The fiber samples used for analysis are the silicon fibers with composition of doped silica. The preform consists of GeO2 doped silica core and either Sio2 or Fluorine doped silica cladding. The pure silica material is known as host material and by adding the doping material when the refractive index of material get increased is known as 'dopant+' and when it decreased is known as 'dopant-' The properties of the material **used are defined by the Sellmeier theory and Sellmeier formula[6].**

Sellmeier Formula

The Sellmeier formula is as[6]:

$$n^{2}(\lambda)-1=\frac{A_1\cdot\lambda^2}{\lambda^2-\lambda_1^2}+\frac{A_2\cdot\lambda^2}{\lambda^2-\lambda_2^2}+\frac{A_3\cdot\lambda^2}{\lambda^2-\lambda_3^2} \qquad ……… (7)$$

Where, n is the wavelength-dependent or non-linear refractive index, A1, A2, and A3 are the Sellmeier amplitudes, and λ1, λ2, and λ3 are the Sellmeier resonance wavelengths. The elements of "Parameters of Material" are described below. The Sellmeier coefficients and non-linear refractive index of different materials are given by S. Kobayashi et al[7] as shown in the Table 1

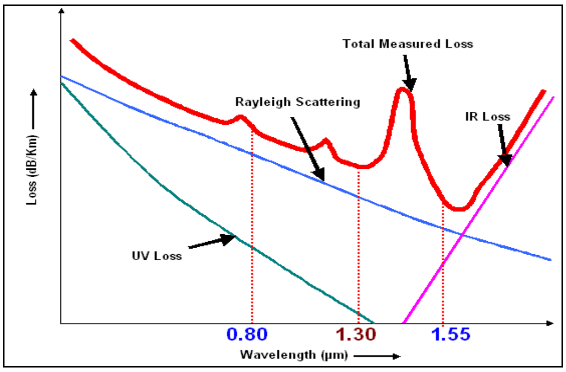

Figure1: A typical variation of total attenuation with wavelength in silica based optical fibers. The figure also shows the attenuation curves due to Rayleigh scattering, Infra-Red absorption and Ultra Violet absorption in SiO2 (From T.Miya et al[5])

Table 1: Sellmeier coefficients and non-linear RI

Coefficients	Pure Silica	Germania-doped Silica	Fluorine-doped Silica
A_1	0.6961663	0.7028554	0.693200
A_2	0.4079426	0.4146307	0.397200
A_3	0.8974760	0.8974541	0.860080
λ_1	0.0684043 μm	0.0727723 μm	0.672398 μm
λ_2	0.1162414 μm	0.1143085 μm	0.117140 μm
λ_3	9.8961612 μm	9.8961609 μm	9.776098 μm
NRI	4e-016 cm^2/w	5e-016 cm^2/w	2e-016 cm^2/w

A typical variation of total attenuation with wavelength in silica-based optical fiber is as shown in figure 1 and it shows that the loss curve has minima at around λ = 1.310 μm and λ = 1.55 μm. These low loss regions generally referred to as the second and third low loss windows. The ultraviolet absorption loss[9] is obtained for GeO2-doped silica glass data and it is very small as far as window II and III. The infrared absorption curve is obtained from loss characteristics of GeO2-doped silica core fiber at higher wavelengths and it shows the steep rise on the long wavelength side of λ = 1.55 μm. The Rayleigh scattering loss component is determined by the slope of curve proportional to λ-4. The addition of all these losses produces the total Attenuation or Material loss[8].

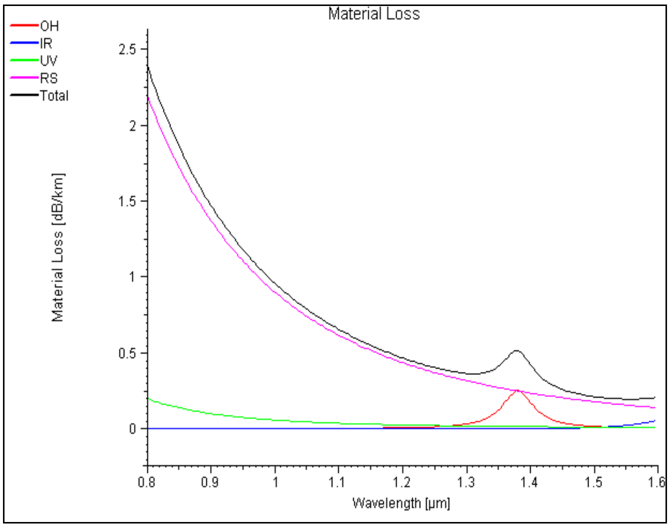

Figure 2: Material Loss Vs Wavelength for GeO_2 doped silica core (3.1%) and Fluorine doped silica cladding (1.0%) with pure silica as host material

Table 2: Experimental Material losses of fiber at different windows

Material Loss dB/Km	**λ = 0.80 µm**	**λ = 1.310 µm**	**λ = 1.55 µm**
RS	2.1973	0.3074	0.1551
UV	0.1984	0.0173	0.0096
OH	0.0002	0.0082	0.0015
IR	0.7361e-14	0.8524e-4	0.023022
Total	2.3959	0.3293	0.1892

The fiber used for analysis is having host material of pure silicon and 3.1% GeO_2 doped silica core and 1.0% fluorine doped silica cladding[10]. Thus GeO_2 is used as Dopant+ whereas fluorine used as Dopant-. The analysis of this fiber for absorption and scattering losses is as shown in figure 3.10 and Table 2.

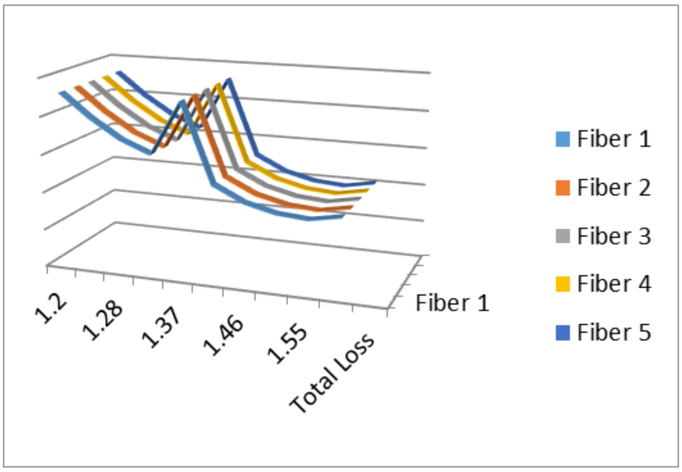

Figure 3: Material Loss Vs Wavelength of All fibers

The infrared absorption curve is obtained from loss characteristics of GeO_2-doped silica core fiber at higher wavelengths and it shows the steep rise on the long wavelength side of λ = 1.55 µm. Thus infrared absorption is not a major problem at lower wavelengths but dominated at higher operating wavelengths and can be minimized by controlling the concentration of GeO_2-doped silica core. The analysis shows that the total loss of the germania-doped silica-core fibers can be separated into the inherent ultraviolet absorption loss, the scattering loss and the inherent infrared absorption loss. It is also seen that the ultraviolet absorption loss and the scattering loss are dominated at the short wavelengths below 1.2 µm and the infrared absorption loss is dominated at longer wavelengths above 1.5 µm. To summarize the above results, dopants have a great effect on the transmission loss of high-silica glass optical fibers at long wavelengths. When an optimum dopant is selected for making a doped-silica optical fibers and OH content is greatly reduced, a phenomenally broad window where the loss is below 1 dB/Km can be achieved.

3. Conclusion

In conclusion, an ultimate lower loss SMF has been fabricated by reducing the excess loss due to imperfections of waveguide as much as possible. The loss mechanism in the optical fiber discussed has been also analyzed. Transmission losses have been reduced almost down to the intrinsic material loss and the minimum loss is 0.20 dB/Km at 1.55 µm. The dispersion characteristics also analyzed at long wavelength the dispersion is minimized, thus it is confirmed that the single mode fibers are most applicable for long distance and large capacity transmission.

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