

# The Characterization of Step Index Single Mode Silica Fiber for Long Haul Signal Communication

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The optical properties of single mode fibers, which are drawn from the silica preform made by MCVD technique, have been studied. The properties such as cutoff wavelength, chromatic dispersion, and polarization mode dispersion (PMD) were studied for 2.3 km length of single mode fiber (SMF). The cutoff wavelength was measured by fiber optic test procedure (FOTP)-80 which was found to be 1179 nm. The chromatic dispersion was measured by FOTP-169 at various wavelengths, the zero dispersion being observed at 1503 nm. The PMD was measured by interferometric method, and exhibited the magnitude of 0.07 ps at 1550 nm. The results are discussed to assess the suitability of these fibers for long haul communication systems.

**Keywords:** optical fiber, cutoff wavelength, chromatic dispersion, polarization mode dispersion

## 1. Introduction

There is ever increasing demand for larger capacity of transmission of signal through optical fiber. With advent of recent technique, large number of processes has been developed<sup>1,2</sup> in characterization of single mode fibers (SMF). Much stress is given to the fact that these fibers should have stable transmission characteristics in long lengths<sup>3,4</sup> with maximum reproducibility. Therefore, characterization of the fibers plays a crucial role for optical signal transmission, which is carried out mainly by observing attenuation using optical time domain reflectometer (OTDR), mode field diameter and core clad geometry<sup>5</sup>. Beside these factors, cutoff wavelength, chromatic dispersion and polarization mode dispersion also play an important role to define the properties of single mode optical fiber. Previously numerous techniques<sup>6</sup> have been reported for measurement of cut-off wavelength. The measured effective cutoff wavelength<sup>7</sup> differs slightly from theoretical cutoff wavelength, calculated from the core diameter and refractive index profile. Chromatic dispersion factor is mainly applied for modern high bit rate transoceanic, terrestrial and telecommunication systems. In single mode fiber, chromatic dispersion results from the interplay of two effects viz; the material and waveguide dispersion. Different types of techniques are used for measuring chromatic dispersion such as phase shift method and differential phase shift method<sup>8</sup>. Polarization mode dispersion (PMD) is one of the major limiting factors of ultrahigh bit rate optical fiber communication systems. Currently, PMD is a big concern while upgrading the installed fiber network to higher bit rate capacity of more than 10 Gb/s, wherein the maximum acceptable amount<sup>3</sup> of PMD is 10 ps. This is one of the drawbacks for long link communication system, which degrades the signal eminence of SMF. PMD arises in fibers when the cylindrical symmetry is broken due to noncircular symmetric stress and it is the division of signal energy into orthogonal polarization modes with different speeds of propagation. PMD is considered as a bandwidth limiting factor. The various methods such as four wave mixing<sup>9</sup>, poicare sphere, polarimetric methods<sup>10</sup> have been reported for measuring the PMD. In this paper we report the characterization of single mode silica fibers that were made by MCVD technique<sup>5</sup> described by us previously. The optical properties

reported in this paper are useful in assessing the drawn fibers<sup>5</sup> for long haul communication systems.

## 2. Preform Fabrication and Fiber Drawing

Numerous techniques are developed for fabrication of glass fibers so as to get better optical properties suitable for optical communication, and also to combat with ever increasing demand of fiber in diverse application areas. First, preform fabrication<sup>5</sup> was carried out by means of conventional MCVD technique by using various dopants such as SiCl<sub>4</sub>, GeCl<sub>4</sub>, POCl<sub>3</sub>, and CCl<sub>2</sub>F<sub>2</sub> (freon 12). After fabrication, this preform was subjected to fiber drawing process. The performance of optical fibers, specifically the transmission losses, bandwidth and strength, is strongly influenced by the fiber drawing and coating process. Fiber drawing proceeds<sup>5</sup> by heating the tip of the preform to a molten state and allowing it to extend under the force of gravity downward into a fine-diameter filament without the use of any die mechanism whereas pulling and winding mechanism sustains a drawing force. Then it immediately enters into the coating applicator. Polymer coating is applied concentrically in sufficient thickness and later solidified instantly using ultra-violet radiation curing technique.

## 3. Characterization

### 3.1. Cutoff wavelength

The cutoff wavelength is an important parameter for single mode fiber as it determines the wavelength range of its operation as a single mode. It is defined as

$$\lambda_c = [(2\pi)/V] (a n_1) \sqrt{(2\Delta)} \quad (1)$$

where  $a$  is the radius of core,  $n_1$  is the refractive index of core,  $V$  is normalized frequency.

Thus for a given index profile, the cutoff wavelength  $\lambda_c$  depends on the core radius and relative index difference ( $\Delta$ ). The dependence of  $\lambda_c$ , on 'a' and ' $\Delta$ ', plays important role in the design of single mode

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fibers. However, for practical SMF, the cutoff wavelength is not a well defined wavelength as equation (1) suggests. Cutoff wavelength defines the borderline between the presence and the absence of the  $LP_{11}$  mode as the wavelength is varied. The measurement of this borderline depends on the power in the  $LP_{11}$  mode as it approaches the cutoff wavelength. However, its power is spread largely beyond the core and is easily lost due to even small imperfections in the fiber structure due to bends and microbends. Thus in practice, the  $LP_{11}$  mode ceases to exist in the fiber at substantially lower wavelength than actual  $\lambda_c$ .

### 3.2. Chromatic dispersion

The direct consequence of chromatic dispersion is that the refractive index of a medium is a function of wavelength. In a fiber, a pulse gets broadened due to the dispersion in silica medium, and this material dispersion changes drastically as the wavelength varies and in fact, it vanishes for a wavelength around 1.274  $\mu\text{m}$ . However, material dispersion is not the only contribution to pulse broadening in a single mode fiber. Even if the refractive index is assumed constant over a range of wavelengths, the propagation constant ( $\beta$ ) of the mode changes with wavelength contributing to pulse broadening. This contribution to dispersion is thus due to the waveguiding property of the fiber and hence, is termed as the waveguide dispersion. The total dispersion due to both the material and waveguide effects is called the chromatic dispersion. For a small refractive index change of 0.1 percent, the wavelength dispersion is 1 to 2 orders of magnitude smaller than the material dispersion. However, it should be noted that the two different dispersions are of different signs. Thus the dispersion associated with the material of fabrication and the dispersion associated with the waveguide structure can be balanced near a zero dispersion wavelength where maximum data transmission is achieved.

### 3.3. Polarization mode dispersion

Polarization doesn't matter in multimode fibers, but it can be important in single mode fibers. The reason is that single mode fibers actually carry two modes with orthogonal polarizations. From the waveguide theory, the two modes are degenerate, i.e., they are functionally identical, so light can shift easily between the two polarization modes. Polarizations have little practical impact for communication, if the circular symmetry of the fiber is perfect. However, the fiber symmetry is never absolutely perfect. In addition, the forces affecting the fiber are never applied symmetrically around the fiber. Due to this fact, the two polarization modes experience different travel conditions with slightly different speeds resulting in differential group delay.

## 4. Experimental

### 4.1. Cutoff wavelength

In experimental part, the cutoff wavelength was measured using bend reference technique described by fiber optic test procedure (FOTP)-80, on a 2 meter single mode fabricated silica fiber using the experimental setup viz; GN-Nettest Model 2200. Initially the fiber is bend in circular manner with a bend radius of 140 mm. The fiber having 140 mm bend radius gives the spectral output power  $P_s(\lambda)$  consisting of  $LP_{01}$  and  $LP_{11}$  mode. Without changing this arrangement, an additional loop of 30 mm was inserted so as to suppress  $LP_{11}$  mode, and the bending power  $P_b(\lambda)$  was measured. At this point cutoff wavelength (only  $LP_{01}$  mode) was detected by calculating the bend attenuation  $A_b(\lambda)$  using the following equation.

$$A_b(\lambda) = 10 \log [P_s(\lambda) / P_b(\lambda)] \quad (2)$$

Figure 1 shows the power spectral plot for cutoff wavelength, which clearly signifies the cutoff wavelength of 1179 nm.

### 4.2. Chromatic dispersion

The chromatic dispersion was measured by phase shift method (GN Nettest Model S-18). The test fiber was linked between source and detector. The tunable edge emitting LED source (1270 nm – 1625 nm) was used which modulates high frequency. The modulation frequency was supplied to LED and then directly to a reference of the receiver circuit using a coupler. The source was placed in a controlled temperature. The precise control of temperature is necessary because the value of the  $\lambda_0$  is temperature dependent. The detected optical signal was amplified by low noise amplifier. This signal was applied to phase comparator where it compares with reference signal and gives the corresponding phase change. The dispersion measurement was performed by recording the phase from phase comparator while tuning the LED over the wavelength region of interest. Each data point consists of wavelength value and its corresponding phase. The group delay of the fiber is measured using the calculation of phase delay changes with wavelength according to equation (3). The wavelength at which zero phase difference was observed is considered as zero dispersion wavelength. Figure 2 shows the dispersion plot and the slope  $S_0$  of single mode optical fiber is obtained by the three term sellmeier expression. The measured zero chromatic dispersion was

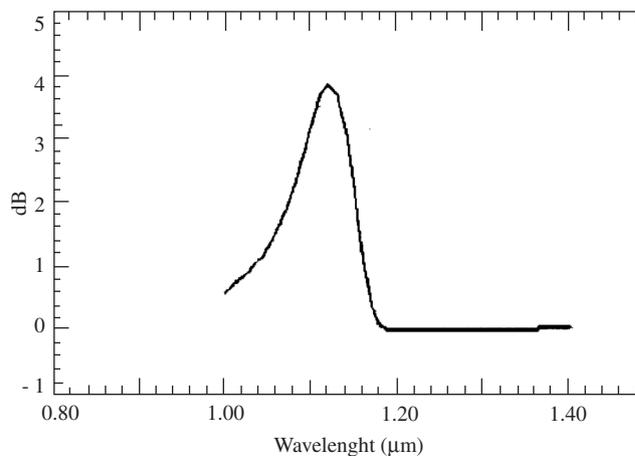


Figure 1. The power spectral cutoff plot using bend reference technique.

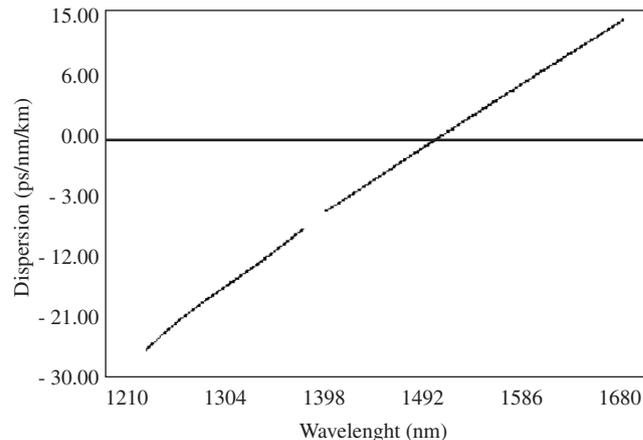


Figure 2. Dispersion as a function of wavelength for single mode fiber. The experimental setup measures the dispersion in two different wavelength bands (window); i.e. 1230 to 1380 nm and 1420 to 1600 nm respectively.

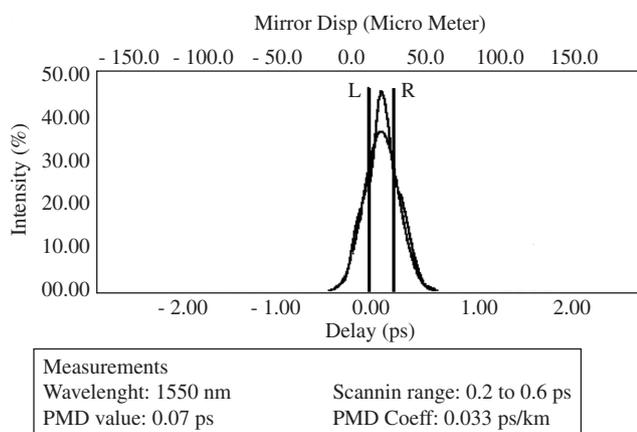
observed at 1503 nm. In addition, the slope  $S_0$  obtained at 1550 nm is 0.08 ps/nm<sup>2</sup> km.

$$T(\lambda) = T(\lambda_0) + [\lambda - (\lambda_0^2 / \lambda)]^2 (S_0 / 8) \quad (3)$$

Here  $T(\lambda_0)$  is the relative group delay minimum at zero dispersion wavelengths,  $S_0$  is the zero dispersion slope, and  $\lambda_0$  is the wavelength at which the chromatic dispersion value goes to zero.

#### 4.3. Polarization mode dispersion

The PMD was measured using interferometric method<sup>2,11</sup>. In principle, it measures the differential group delay and principle state of polarization as a function of frequency. In our work, fiber under test was coupled between transmitter and receiver. The collimated light from a broad band light emitting diode was polarized and split into two mutually coherent beams and passed over two mirrors. One mirror can be scanned in a position, creating a differential delay between the two orthogonal polarizations, which were recombined and directed through the fiber under test. When photocurrent was measured as a function of differential interferometer delay, coherent fringes can be observed only when this differential delay was compensated by the differential group delay of the fiber under test. This measurement is closely related to the direct measurement in the time domain: it essentially measures the autocorrelation of the outgoing "light pulses". The coherence time of the light sources is playing the role of the pulse width. This coherence time determines thus the smallest measurable polarization mode delay. The Figure 3 shows the plot of differential group delay observed due to polarization mode dispersion. The central peak occurs when the interferometer arms are of equal lengths. The outlying occurs when the movable mirror introduces a delay equal to the differential group delay of the test device. L peak is due to interference between slow mode light originating in the fixed mirror path and fast mode light delayed by the movable mirror. The R peak is due to interference between fast mode light originating in the fixed mirror path and slow mode light advanced by an identical movement of the mirror in the opposite direction. The time separation



**Figure 3.** The differential group delay in PMD using interferometric method.

of the central and either of the outer peaks L and R, is the differential group delay of the device. PMD in relation to the coherence time of the source was noted as 0.07 ps at 1550 nm.

## 5. Conclusions

The fabricated single mode fiber is characterized for cutoff wavelength, chromatic dispersion, and PMD. The cutoff wavelength for fabricated single mode fiber is 1179 nm. The zero chromatic dispersion wavelength is 1503 nm and the slope  $S_0$  at 1550 nm is 0.08 ps/nm<sup>2</sup> km, where as polarization mode dispersion is found to be 0.07 ps at 1550 nm. These parameters show the suitability of fabricated fibers for long haul signal communication network with very high bit rate.

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