Effect of axial index dip on the characteristics of broadband dispersion compensating optical fiber

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The experimental studies of the characteristics of dispersion compensating optical fiber (DCF) with reference to its axial index dip have been reported. The DCF characteristics such as chromatic dispersion, dispersion slope, mode field diameter, bending loss and cut-off wavelength have been altered due to axial index dip in the DCF. This work is useful for the optical fiber communications.

[Keywords: Dispersion compensating fiber, Dispersion compensated link, DWDM]

1 Introduction

In the last decade, 1.3 μm optimized conventional single mode fibers (CSF) were used for transmission of the data over optical fiber link. Millions of kilometres of optical fiber were laid into the ground. Soon it was found that, 1.55 μm window offers low loss transmission. But, when CSF was operated at 1.55 μm, it offered the dispersion coefficient of about 18 ps/km-nm, which in turn, limit the bit-rate carrying capacity of the optical fiber link. Therefore, one needs to compensate this positive dispersion by using the special optical fibers that offer negative at 1.55 μm. These optical fibers with negative dispersion are called as dispersion compensating fibers (DCF). The CSF and DCF combination is used for the dense wavelength division multiplexing (DWDM). Another application of the DCF is to design dispersion-flattened optical fiber link with the non-zero dispersion shifted fibers (NZDSF), where DCF with very less dispersion change in the entire band is preferred1. The DCF with very high negative dispersion has been reported2,5.

When the optical preforms are prepared using MCVD, GeO₂ is commonly used to raise the refractive index of the core and it is deposited over the inner wall of quartz tube. At the time of collapsing of the quartz tube with depositions, the temperature of around 2000 °C is needed. At such high temperature, the germanium monoxide is formed which is volatile and leaves the core. Hence, the refractive index decreases at the center to form the axial index dip. In this paper, the authors present the experimental studies of the effect of axial index dip on the performance of DCF that was fabricated at their laboratory.

2 DCF Design

While designing the DCF, the main aim was to have nearly flattened, negative dispersion in the region 1.45-1.63 μm. The simplified design was chosen so that, it is easier to fabricate the preforms without much complexity in the MCVD and still one should get the reasonably fair negative dispersion characteristics. The authors chose a step-index profile with a very narrow core and with high refractive index difference between the core and cladding to minimize the bending losses. The different parameters chosen are given in Fig. 1.

To find the theoretical chromatic dispersion characteristics the authors have used the numerical method as described in Ref. 4. The radial variation
of electric field and propagation constants has been calculated, and these parameters are used to get the dispersion coefficient that is defined as:

$$D = \frac{\lambda}{c} \frac{d n_r^2}{d \lambda}$$

(1)

where \(n_r\) is the effective index, \(c\) the speed of light in the vacuum and \(\lambda\) the wavelength. The numerical calculations are carried out to find the optimum core radius and the refractive index difference, so that, the maximum dispersion is achieved. The parameters have been further optimized so that, the chromatic dispersion difference between 1.45 and 1.63 \(\mu m\) should not exceed 3 ps/km-nm.

<table>
<thead>
<tr>
<th>Fiber parameter</th>
<th>Magnitude</th>
</tr>
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<tbody>
<tr>
<td>Core diameter</td>
<td>2.9 to 3 (\mu m)</td>
</tr>
<tr>
<td>Total fiber diameter</td>
<td>125 (\pm 1) (\mu m)</td>
</tr>
<tr>
<td>Ovality</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Concentricity</td>
<td>0.33 (\mu m)</td>
</tr>
</tbody>
</table>

### To analyze the effect of axial dip on the performance of the dispersion compensating optical fiber, the axial index dip has been modelled as given below:

$$\Delta'(r) = \frac{\Delta(r)}{d} \quad 0 \leq r \leq a/w$$

$$\Delta'(r) = \Delta(r) \quad a/w < r \leq a$$

$$\Delta'(r) = N_{cl'} \quad \text{elsewhere}$$

(3)

where \(\Delta(r)\) is the normalized index difference in the absence of dip and is given as:

$$\Delta = \frac{N_o^2 - N_{cl}^2}{N_{cl}^2}$$

\(N_o\) is the refractive index of core, \(N_{cl}\) the cladding index, \(d\) the depth parameter, \(w\) the width parameter, \(a\) the core radius, \(r\) the radial parameter and \(\Delta'\) the normalized index difference in presence of dip.

### 3 Experimental Details

The preform was fabricated for the DCF design using Heathway UK make MCVD system, at an optimum temperature, so as to avoid the bubble formation during deposition of index raising materials. The narrow core was obtained, using pre-collapse deposition of the GeO\(_2\). The preforms were analyzed for refractive index (RI) profile using York Technology P104 Preform Analyzer. A few hundred meters of optical fiber was drawn from the preform, using Heathway UK-make 6-metre fiber drawing tower. The fiber was drawn at a total diameter of 125 \(\mu m\) with variation of \(\pm 1 \mu m\) from the fixed value of 125 \(\mu m\). The observed RI scaled in the dimensions of the optical fiber is shown in Fig. 1.

The chromatic dispersion of the fiber was measured, using York Technology chromatic dispersion measurement set-up (Model No.: CD S18). The principle of the instrument is based on phase shift method. The phase shift between the transmitted signal and the original signal is found, using phase comparator and this is used to get the group delay and the chromatic dispersion. The geometry of the fiber for ovality and concentricity were verified by using Video Fiber Analyzer (York Technology, Model No. S20). Bending loss, experimental cut-off and mode field diameter (MFD) had been measured by using PC-based Bentham optical characterization system containing DM150 double monochromator, PMC 3B/IEEE programmable monochromator controller, Lock-in amplifier model 223 with integrated ADC and DH InGaAs detector. The monochromator had an error limit less than 0.02 %. All measurements were repeated many times.

### Table 2 — Comparison of experimental and theoretical values of the effect of dip on DCF characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Experimental</th>
<th>Theory (with dip)</th>
<th>Theory (without dip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) MFD</td>
<td>3.72 (\mu m)</td>
<td>3.8 (\mu m)</td>
<td>3.6 (\mu m)</td>
</tr>
<tr>
<td>2) LP(_{11}) cutoff wavelength</td>
<td>1165.35 nm</td>
<td>1287 nm</td>
<td>1289.5 nm</td>
</tr>
<tr>
<td>3) Bend induced transition loss at 1550 nm</td>
<td>0.000039 dB</td>
<td>0.0000352389 dB</td>
<td>0.0000366585 dB</td>
</tr>
</tbody>
</table>
4 Results and Discussion

The results shown in Figs 1-4 are measured for the experimentally fabricated DCF and they are compared with the theoretical results obtained with and without consideration of the axial index dip. The geometrical parameters of the fibers are listed in Table 1. The effect of dip on the dispersion properties of the DCF has been illustrated in Fig. 2.
illustrates the effect of dip on dispersion slope ($S$) and the ratio of dispersion with dispersion slope ($D/S$). Both the quantities show wide variation with the presence and absence of the axial index dip. Effects of the axial index dip on other parameters of the DCF have been shown in Table 2. It can be seen that, the MFD has been improved and the bending loss has been decreased with the dip. Measured transition loss due to bending in the fiber at various bend radius ($R_b$) and different wavelengths at a bend section of 100 cm is shown in Fig. 4. The bending section of a few metres has been considered in measurements for ease and accuracy and from these results, the transition loss with a bend section of 100 cm has been calculated. It can be observed that, the transition loss is much lower and increases with the wavelength.

5 Conclusion

The authors have experimentally shown that, the performance of the DCF is affected with the presence of axial index dip. The axial index dip causes decrease in negative dispersion and little increment in the MFD. Hence, the axial index dip must be considered, while designing the DCF and while optimizing the optical fiber link containing DCF. This work will be very useful in optical fiber communications for determining the actual length of the DCF required for the dispersion compensation of conventional optical fiber operated at 1.55 µm.

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References