Core Profile Based Dispersion Optimization in Trench Assisted Bend-insensitive Optical Fibers

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Abstract— We present a new design method to optimize the performance of bend insensitive optical fibers based on the core profile optimization. Validity of this method has been verified by experimentally fabricating ultra-bend insensitive optical fibers.

1. INTRODUCTION

Recently, with increasing deployment of FTTx applications, bend insensitive optical fibers are gaining much attention due to their capability to handle sharp bends by offering very low bending attenuation in premises, thus aiding in the tight power budget of deployment. This has resulted in commercial availability of a range of bend insensitive optical fibers (G.657.A1, A2, B2, B3) [1–3]. However, optical fiber manufacturers often face difficulty in experimental realization of ultra low bending loss fibers due to critical balancing of various optical parameters, such as the chromatic dispersion and the bending loss. It is well known that decrease in the bending loss causes the cable cutoff wavelength as well as the dispersion at 1550 nm to increase beyond recommended values suggested by ITU-T for G.657 category fibers [4]. Thus, a tradeoff between the high bend insensitivity and the dispersion limit at 1550 nm has to be well understood and addressed to obtain optimized parameters.

In the current communication, we present a design method based on the core profile optimization, which gives required balance between the bending loss and the dispersion. We also present experimental results obtained after adopting this method for designing G.657.B3 fibers.

2. THEORY

The trench assisted profile under consideration is shown in Fig. 1. It can be seen that the core is surrounded by inner silica cladding and the low-index trench, which are surrounded by the outer silica cladding.

In Fig. 1, the core of optical fiber has been shown in different shapes, which are defined by *alpha* parameter in the following equation:

$$n(x) = n_{\max}\sqrt{1 - 2\Delta\left(\frac{x}{w}\right)^{\alpha}} \tag{1}$$

where n is the refractive index at radial parameter x, $n_{\max}$ is the maximum value of refractive index, w is the radius of core and Δ is the normalized index difference defined as:

$$\Delta = \frac{\left(n_{\max}^2 - n_{\min}^2\right)}{2n_{\max}^2} \tag{2}$$

Optical parameters of this profile can be obtained by solving the wave equation to get the spectral variation of propagation constant, which can be then used to obtain radial distribution of the mode field, values of chromatic dispersion, a cutoff wavelength, and the bending loss [5–7].

3. ANALYSIS

We select a typical profile of bend insensitive fiber as shown in Fig. 1 with parameters listed in Table 1. Parameter *Delta* used in the description of figures is the normalized refractive index in % (Eq. (2)) where $n_{\min}$ is the minimum value of refractive index in the core. Illustrations of profiles at $alpha = 1$ and $Delta = 0.2$ and 0.4 are shown in Fig. 2.

Effects of *alpha* on the bending loss of bend-insensitive fiber are shown in Fig. 3. It is seen that the bending loss reduces with increasing *alpha*, while the bending loss increases with increasing *Delta*. This happens because increase in the value of *Delta* lowers the cutoff wavelength.

As we discussed earlier, choosing the minimum value of bending loss may affect other optical parameters of the bend insensitive fiber. For example, selecting the value of *alpha* to be 10 gives

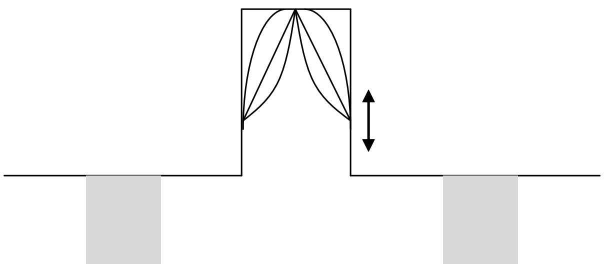

Figure 1: Trench assisted bend insensitive fiber at different alpha values.

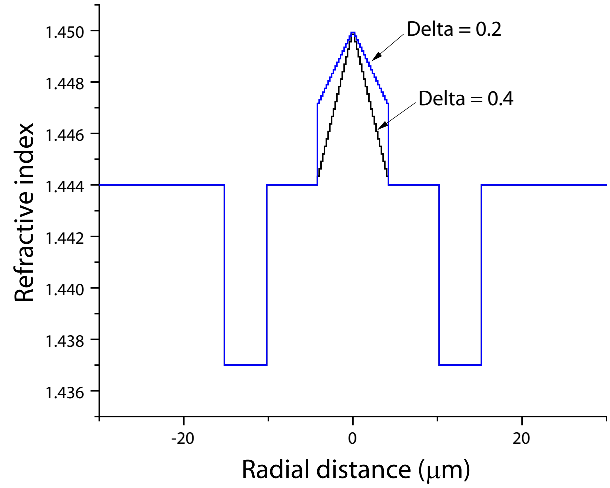

Figure 2: Refractive index profiles at *alpha* = 1, *Delta* = 0.2 and 0.4 and wavelength = 1550 nm.

Table 1: Typical parameters of the bend-insensitive fiber under consideration.

Parameter	**Value**
Maximum refractive index of core at 1550 nm	1.45
Minimum index difference of trench at 1550 nm	1.437
Core diameter (d)	8.4 μm
Separation of trench from the edge of core	$0.72d$
Trench width	$0.6d$

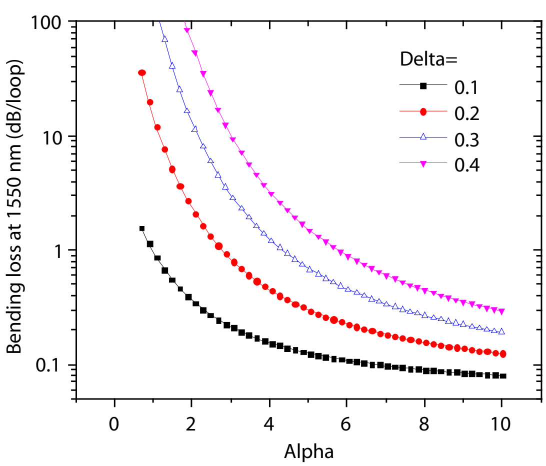

Figure 3: Effects of *alpha* on the bending loss at 5 mm bending radius.

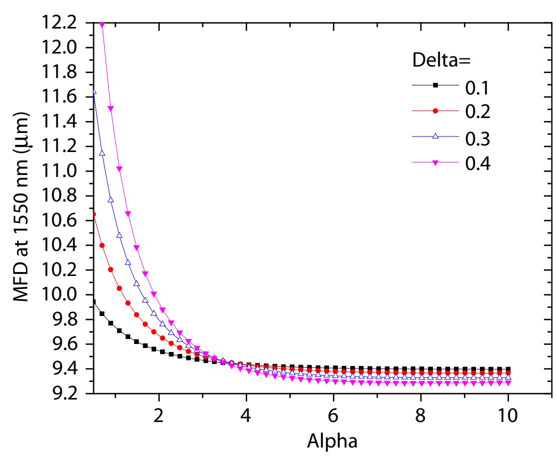

Figure 4: Effects of *alpha* on the mode field diameter at 1550 nm.

low bending loss, however, at the same time reduces the mode field diameter (MFD) at 1550 nm as shown in Fig. 4. It is also interesting to note that at *alpha* > 3.5, the MFD value is the highest for *Delta* = 0.4, while at *alpha* < 3.5, the MFD value is the lowest for *Delta* = 0.4. Reason for this behavior is the effective index, which reduces with reduction in *alpha*.

Finally, the effect of *alpha* on the dispersion is illustrated in Fig. 5. It can be observed that the dispersion has U-shape with respect to *alpha* and there exists minimum value of dispersion at 1550 nm for each *Delta*. This result is very useful to select optimum values of *alpha* and *Delta* so that optical parameters of the bend-insensitive fiber are within the ITU-T specified limits. In Fig. 5, *Delta* = 0.4 gives minimum dispersion values, which is synonym saying that the bending loss will be high as shown in Fig. 3. Based on these results, a new method to design the bend insensitive optical fiber is proposed in the following section.

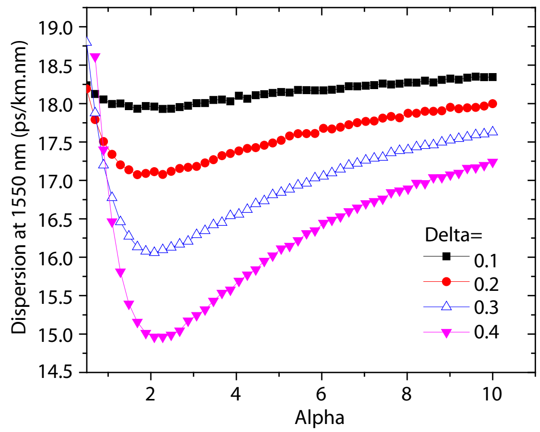

Figure 5: Effects of alpha on the dispersion at 1550 nm.

4. CORE PROFILE BASED OPTIMIZATION METHOD

The core profile based dispersion and bending loss optimization method is explained as follows. Firstly, an index profile similar to the well known single mode fiber is selected. A low-index trench is added to the profile at a distance from the core; we need to select trench index, width and its position from the core so that required macro-bending loss is obtained. It is noted that this may affect dispersion properties of the fiber, however, it is ignored at this stage.

Secondly, the shape of the core profile is changed by changing an *alpha* parameter as shown in Fig. 1. Optical parameters are calculated for this profile by solving the wave equation. Thus, we obtain a set of optical parameters for different *alpha* values. Typically, the curve representing variation in dispersion with respect to the *alpha* parameter is U-shaped and there exists *alpha* parameter value where the dispersion is minimum.

Finally, the optimum *alpha* profile is selected where all required optical parameters are obtained. If the dispersion value is still above the limit specified by ITU-T, then we need to start over from step one, where the trench position and dimensions are varied.

5. EXPERIMENT AND RESULTS

Various samples of the bend-insensitive fiber of G.657.B3 category were fabricated using the in-house facility. The design approach adopted for all these fibers was same as explained in Section 4. Measured optical parameters of these fibers are listed in Table 2, where it can be observed that dispersion values at 1550 nm are within the specification (i.e., < 18 ps/km·nm) with the bending loss has ultra low value. When the dispersion is < 17 ps/km·nm, the zero dispersion wavelength is near the higher limit of the specification (i.e., 1324 nm); this issue can be managed by targeting the dispersion to be 17–17.5 ps/km·nm. In all cases, the bending loss at 1550 nm was far below the specification (i.e., 0.15 dB/loop at 5 mm of bending radius).

Table 2: Measured optical parameters of the bend-insensitive optical fiber. BL is the bending loss at specified bending radius.

Sample No. G.657.B3	**MFD (μm)**	**Cable cutoff (nm)**	**Dispersion at 1550 nm (ps/km·nm)**	**Zero dispersion wavelength (nm)**	**BL 5 mm (dB/loop)**	**BL 7.5 mm (dB/loop)**
1	8.58	1238.5	16.68	1321.81	0.067	0.03
2	8.62	1231.5	17.29	1319.27	0.063	0.052
3	8.736	1259	17.15	1318.25	0.086	0.036
4	8.67	1239.5	16.77	1322.08	0.079	0.04
5	8.57	1247	17.2	1315.7	0.051	0.017
6	8.62	1238	17.49	1315.19	0.057	0.032
7	8.68	1229.07	16.92	1321.16	0.084	0.046

6. CONCLUSION

We presented a method to optimize the performance of bend insensitive optical fiber by using the core profile optimization, where dispersion and bending loss are optimized. Bend insensitive fibers of category G.657.B3 were fabricated and measured parameters were well below the limits suggested by ITU-T.

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