EFFECT OF LOW-INDEX TRENCH WIDTH ON BENDING LOSS OF BEND-INSENSITIVE OPTICAL FIBER

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Abstract: We report the low-index trenched optical fiber having ultra low bending loss at 1550nm of 0.005dB/loop with Ø10mm bending diameter. As the width of the low-index trench of the fiber increased, the bending loss was found to decrease significantly.

1. INTRODUCTION
Fiber to the home (FTTH) driven interest has led innovative designs of the optical fibers to meet requirements for FTTH applications [1-10]. There are several reported optical fibers that meet and exceed requirements of the ITU-T G657.A and G657.B standards [1,3,11]. The bending loss at 1550 nm has been reported to be 0.03 dB/loop for bending diameter of 10 mm in the case of the optical fiber that incorporated nano-engineered holes around the core [1]. On the other hand, the trenched bend insensitive fiber (BIF) where a low index trench was placed around the core has resulted in the bending loss of 0.05 dB/loop at 1550 nm [1]. Several refractive index designs have been reported to optimize the performance of the BIF, for example, in Ref. 4-6, where the optical fiber has been optimized to reduce the bending loss dramatically but retaining the single mode.

Since no reported experimental results are available on relations of the trench structures with bending loss, the effect of trench width of the BIF on bending loss was investigated, expecting to fabricate better BIF that satisfies the ITU-T G652.D norms for the single mode fiber (SMF) with further reduced bending loss.

In this paper, we have fabricated various optical fibers with various single trenches around the core by using the modified chemical vapor deposition (MCVD) technique for detailed investigations and investigated the effect of the low-index trench width on the bending loss of the BIF.

2. EXPERIMENTS
To investigate the effect of the low-index trench on bending loss, we fabricated the single-mode optical glass fibers with various low-refractive index profiles in the cladding region as shown in Fig.1 and Table 1, by using modified chemical vapor deposition (MCVD) process and high temperature drawing process. To make the low-refractive index trench structure in the cladding region of the fiber, we have used BCl3 gas as a precursor of glass constituent together with SiCl4 and GeCl4 during the MCVD process because boron oxide has a negative refractive index compared to the germano-silicate glass. Then the tube with low-refractive index trench layer was collapsed and jacketed with the fiber core rod prepared to make BIF preform. Then the preform was drawn into a fiber with outer diameter of 125 µm using the draw tower at 2150°C. Typical optical characteristics of the fabricated BIFs with low-index trench especially with various trench width/core

Table 1: Typical optical characteristics of the bend-insensitive optical fibers with low index trench.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Δn_\text{core}</th>
<th>Mode Field Diameter (@1550nm, µm)</th>
<th>Δn_\text{trench}</th>
<th>Width of Trench (C, µm)</th>
<th>Trench Width/Core Diameter (Ratio)</th>
<th>Cut-off Wavelength (nm)</th>
<th>Zero-Dispersion Wavelength [nm]</th>
<th>Chromatic Dispersion [ps/nm/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0046</td>
<td>9.52</td>
<td>-0.0056</td>
<td>7.1</td>
<td>1.01</td>
<td>1.196</td>
<td>1322.6</td>
<td>13.3</td>
</tr>
<tr>
<td>2</td>
<td>0.0053</td>
<td>9.68</td>
<td>-0.0051</td>
<td>7.9</td>
<td>1.00</td>
<td>1.150</td>
<td>1329.1</td>
<td>13.8</td>
</tr>
<tr>
<td>3</td>
<td>0.0051</td>
<td>9.74</td>
<td>-0.0050</td>
<td>7.1</td>
<td>0.89</td>
<td>1.165</td>
<td>1311.1</td>
<td>14.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0056</td>
<td>9.94</td>
<td>-0.0043</td>
<td>6.5</td>
<td>0.76</td>
<td>1.184</td>
<td>1250.8</td>
<td>17.3</td>
</tr>
<tr>
<td>5</td>
<td>0.0054</td>
<td>9.90</td>
<td>-0.0046</td>
<td>5.5</td>
<td>0.61</td>
<td>1.167</td>
<td>1239.4</td>
<td>18.0</td>
</tr>
<tr>
<td>6</td>
<td>0.0056</td>
<td>9.47</td>
<td>-0.0048</td>
<td>4.8</td>
<td>0.51</td>
<td>1.180</td>
<td>1233.1</td>
<td>18.3</td>
</tr>
<tr>
<td>7</td>
<td>0.0057</td>
<td>10.23</td>
<td>-0.0045</td>
<td>3.7</td>
<td>0.38</td>
<td>1.177</td>
<td>1299.2</td>
<td>18.7</td>
</tr>
<tr>
<td>8</td>
<td>0.0058</td>
<td>9.20</td>
<td>-0.0044</td>
<td>2.7</td>
<td>0.28</td>
<td>1.180</td>
<td>1227.3</td>
<td>18.9</td>
</tr>
</tbody>
</table>
diameter (c/2a) are also listed in Table 1. The optical
dispersion of the BIFs was measured by optical
dispersion analyzer (AGLIENT, optical dispersion
analyzer 86038A). The BIFs satisfied the single mode
characteristics specified by the ITU-T [11].

To investigate the effect of the low-index trench
width on the bending loss, the BIF was spliced
between two commercial single-mode fibers and the
optical power was measured using the optical power
meter (EXFO, FDM-600) and the optical spectrum
analyzer (ANDO, AQ6317B). A broadband amplified
spontaneous emission source (ThorLabs, SOA240)
emitting at from 1300 nm to 1750 nm was used as the
input. The bending loss was measured with a single
loop of 10 mm bending diameter.

3. RESULTS AND DISCUSSION

The measured chromatic dispersions of the various
BIFs are shown in Fig. 2 and listed in Table 1. The zero-dispersion wavelength and the chromatic
dispersion at 1550 nm were slightly different with the various BIFs because of the difference of core
refractive index and mode field diameter of the BIFs.

Prior to fabricate the BIFs, we theoretically
designed to obtain optimized parameters following the
similar procedure adopted by our group 4-6, where we
decided to have theoretical bending loss of at least
0.035 dB/cm for 10 mm of bending diameter. The refractive index difference between core and cladding
(Δn) was selected to follow well-known single
mode fiber, i.e., 0.0053 and we theoretically
optimized the low-index trench refractive index to be
at least 0.003 less than the cladding index. However,
while fabricating the BIF, we chose to overfill the
requirement of trench index so that the trench index
was always less than the cladding index by 0.003; the
fabricated BIFs had the trench and cladding index
difference of -0.004 to -0.0056. Regarding the trench
width, it was theoretically found that the trench width
should be minimum 50% of core diameter to avoid its
impact on the dispersion characteristics of the BIF
(and thereby affecting the ITU-T recommendations
for the single mode fiber) and the increase in trench
width was found to decrease the bending loss,

although the decrement was not sharp. Experimentally,
we obtained the trench width to be over 1.01 to 0.28
times the core diameter for various BIFs.

Figure 3 shows the spectral variation of bending
loss of the BIF with low-index trench (c/2a = 1.00)
and 1 meter length at bending diameter of Ø10 mm
with 1 loop. The bending loss of the BIF at 1550 nm
was found to be 0.005 dB/loop and it was in good
agreement with the simulated result. The decrease in
bending induced optical loss of the BIF was due to the
reduction of the effective refractive index change
upon sharp bending.

The effect of the low-index trench width on the
bending loss of the fabricated BIFs with 1 meter
length at bending diameter of Ø10 mm with 1 loop is
showed in Figure 4. As the width of low-index trench
of the fiber increased, the bending loss was found to
decrease. Note that the trench width did not contribute
to the reduction of the bending loss unless the trench
index difference was lower than -0.003. The bending
loss of the BIF was in good agreement with the
simulated value at various wavelengths [4-6]. The

Fig. 1: The refractive index profile of the simulated bend-insensitive optical fiber preform with low index
trench

Fig. 2: Effect of the low-index trench width on the dispersion vs. wavelength of the bend-insensitive optical
fiber

Fig. 3. Bending loss of the bend-insensitive optical fiber with low-index trench
(bending diameter/loop = 10 mm/1)
decrease in bending induced optical loss of the BIF is from the reduction of the effective refractive index change upon sharp bending. The lowest bending loss of 0.005 dB/loop at 1550 nm for the bending diameter of 10 mm was obtained while satisfied by the ITU-T G.657.B [11].

4. Conclusions

We have fabricated the BIFs with low-index trench through MCVD and DT processes. The BIFs that we developed showed the lowest bending loss of 0.005 dB/loop at 1550 nm for the bending diameter of 10 mm. As the width of low-index trench of the BIFs increased, the bending loss was found to decrease.

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