OPTIMUM DESIGN OF TRENCHED OPTICAL FIBER FOR ULTRA LOW BENDING LOSS AT 5 mm BENDING DIAMETER

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Abstract: We propose a bend insensitive optical fiber with optimized design for the ultra low bending loss at 1550 nm for 5 mm of bending diameter, with a wide cutoff wavelength tolerance.

1. INTRODUCTION

With the aim of bringing the optical fibers to the home, where sharp bends are unavoidable, many specialized optical fibers have been commercially available with the bending loss of as low as 0.05 dB/loop and 0.03 dB/loop at 1550 nm (at 10 mm of loop diameter, \( \phi 10 \)); former utilizing the low index trench around the core and the later using the nano-engineered air holes around the core [1, 2]. Recently, bend insensitive optical fiber (BIF) with double low index rings around and separated from the core and having the bending loss as low as about 0.01 dB/loop at 1550 nm (\( \phi 10 \)) has been reported in a successful laboratory realization [3], similar experimental development has also been reported for visible light region [4]. However, actual commercialization of these BIFs has faced major hurdles: (i) shift of the LP\(_{11} \) cutoff wavelength to higher wavelength and (ii) when the \( \phi 10 \) optimized BIF is used at the sharp bending loop of 5 mm diameter (\( \phi 5 \)), the bending loss increases at least by ten times as compared to that of \( \phi 10 \) BIF. For example, the bending loss of several BIFs was found to be between 1.5 dB/loop to 27 dB/loop at \( \phi 5 \) (1550 nm).

To deal with the problem faced during manufacturing of BIFs, major issue is the change of the cutoff wavelength for small modifications in trench radial parameters. Therefore, firstly, need is to allow a wide flexibility in choosing parameters of the optical fiber, so that experimental realization is fruitful. Secondly, another set of optimized parameters of BIF are needed if we are looking for bend insensitivity at the sharp bend of 5 mm diameter. In the current communication, we report the optimized parameters with a wide cutoff wavelength tolerance and an ultra low bending loss (<0.05 dB/loop) for 5 mm of loop diameter at 1550 nm.

2. THEORY AND SIMULATION

The macro-bending loss in the units of dB/km, was calculated using [5, 6, 7]:

\[
\alpha_{macro} = \frac{10}{\log_{10} 10} \left( \frac{pV^2}{|g|} \right)^{1/2} \exp \left( -\frac{4\pi r \Delta W}{3\pi V^2} \right) \left[ \int_0^r (1-g)F_g r^2 dr \right]^{1/2}
\]

(1)

where \( F_g \) is the radial field of fundamental mode, \( r \) denotes the fiber core radius, \( r_b \) is the bend radius, \( n_{max} \) and \( n_{min} \) are the maximum and minimum values of refractive index and other parameters appearing in above equation are given by:

\[
g = \frac{n(r)^2 - n_{min}^2}{n_{max}^2 - n_{min}^2} ; \ V = k_0 r \sqrt{n_{max}^2 - n_{min}^2}
\]

\[
\Delta = \frac{n_{max}^2 - n_{min}^2}{2 n_{max}^2} ; \ W = \beta \left( \sqrt{1 - (k_0 n_{max})^2} \right)
\]

We used the commercial FiberCAD code to solve the propagation equations and to calculate the bending loss of optical fiber [7].

For the bend insensitivity in optical fibers, we chose the trench optical fiber, because it has already been optimized for \( \phi 10 \) operation and we can readily use these results for \( \phi 5 \) optimized BIF. Optical fiber parameters were chosen from the commercial single mode fiber: (i) the mode field diameter (MFD) at 1310 = 8.3 \( \mu \)m to 9.1 \( \mu \)m, (ii) cutoff wavelength <= 1210 nm, and (iii) theoretical bending loss <= 0.0037 dB/loop for \( \phi 5 \) at 1550 nm. It is noted that as per our earlier experimental studies regarding the BIF, the theoretical bending loss of 0.0037 dB/loop calculated by [5-7] for 5 mm of bending diameter (at 1550 nm) corresponds to the experimental bending loss of approximately 0.05 dB/loop. For the core part, we chose typical step index single mode fiber parameters, i.e., the core diameter of 8.2 \( \mu \)m and the core-cladding index difference of 0.005. The BIF under consideration is shown in Fig. 1.
We have simulated a non-optimized BIF profile to understand the effects of these parameters on the cutoff wavelength. The fiber parameters are: $\Delta n = 0.005$, $a = 4.1 \mu m$, $b = 8.2 \mu m$, $c = 4.1 \mu m$ and $\Delta n_{\text{Trench}} = -0.007$, unless the parameter is varied. As shown in Fig. 2, the cutoff wavelength shows increment with increase in $c/a$, while it decreases with increasing $\Delta n_{\text{Trench}}$. Thus, these two parameters can be used to counter the shift in the cutoff wavelength. As shown in Fig. 3, the cutoff wavelength is very sensitive to the separation of trench from the core. However, selecting $b$ equal to any value up to $b_{\text{max}}$ can ensure the single mode operation at desired wavelength; our task is then to determine this maximum value of $b$, i.e., $b_{\text{max}}$.

### 3. RESULTS

To obtain the bending loss $\leq 0.0037$ dB/loop for $\phi 5$ at 1550 nm, it was found that the trench index depth must be below -0.0072, other parameters cause slight modification in the value. So, initially, $\Delta n_{\text{Trench}}$ was fixed at -0.0072. As shown in Fig. 2, at the worst case scenario of shift in the cutoff wavelength, $c/a$ was also initially fixed at 0.5. Using these parameters, we changed $b/a$, which gave the optimized $b/a = 0.8$. By imposing the dispersion and mode field diameter condition, the range of $b/a$ was taken to be 0.8-1 as shown in Fig. 4.

By using the optimized range of $b/a$, variation of the bending loss for various values of $\Delta n_{\text{Trench}}$ and $c/a$ are shown in Fig. 5. Using these results, the optimized BIF parameters can be extracted as per need. For an instance, $\Delta n_{\text{Trench}} = -0.008$, $c/a = 0.5$ to 2 and $b/a = 0.8$ to 1 will always give the bending loss $\leq 0.0037$ dB for a loop of 5 mm diameter at 1550 nm.

Actual variation of the bending loss, the mode field diameter and the dispersion is shown in Fig. 6 and Fig. 7 for the typical parameters (chosen from the optimized range): $\Delta n_{\text{Trench}} = -0.008$, $c/a = 1$ and $b/a = 1$, where the bending loss of 0.001/loop dB for $\phi 5$ at 1550 nm can be observed. The cutoff wavelength for this BIF design is 1206 nm.
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REFERENCES

[1] Draka (2009), BendBrightXS at http://www.drakafibre.com

Fig. 5. Various BIF parameters and their effects on the bending loss.

Fig. 6. Spectral variation of the bending loss of optimized BIF.

Fig. 7. Spectral variations of the dispersion and the mode field diameter of optimized BIF.

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