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Splice Characteristics of Trench-Assisted Bend-Insensitive Fiber Having Equivalent Dispersion Characteristics to SMF

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Abstract:

Splice characteristics of trench-assisted bend-insensitive fibers with optimized dispersion characteristics are presented. Since the electrical fields of the fibers are very close to a Gaussian distribution, the fibers have high compatibility with the C-SMF.

1. Introduction

Fiber To The Home (FTTH) service has been spreading rapidly in Japan. Conventional single-mode fibers (C-SMF) that are compliant with ITU-T Recommendation G.652 are widely used for FTTH systems since an economical 1.3-μm Fabry-Perot laser diode is applicable in the system. However, C-SMF used in FTTH is required to have improved bending loss [1], [2], [3]. For instance, the C-SMF for indoor cables and drop cables may be bent in a small radius in a closure or at the corner of a wall.

C-SMF has a trade-off between a bending loss and a mode field diameter (MFD). The MFD of commercially available bend-insensitive fibers with a step-index profile is smaller than that of the C-SMF with a 9.2-μm MFD. However, the small MFD is not preferable in the viewpoint of splice loss.

We have proposed a bend-insensitive fiber with a trench-assisted index profile (hereafter "trench fiber") [4]. The trench fiber has unique characteristics that the bending loss of the fiber with the same MFD as the C-SMF can be smaller than that of the C-SMF.

Recently, bend-insensitive trench fibers that are compliant with G.652 have been presented [5], [6]. We have reported the design optimization on a trench position for a dispersion characteristic equivalent to the C-SMF. In addition to dispersion characteristics, the trench position should be carefully designed in the viewpoint of the splice loss because the distortion of an electric field distribution may be caused by the existence of the trench [7].

In this paper, we investigate the splice characteristics of the trench fiber that shows equivalent dispersion characteristics to the C-SMF.

2. Fiber Design and Fabrication

Figure 1 shows a refractive index profile of a trench fiber. We experimentally fabricated three trench fibers with different MFDs to investigate the splice characteristics of the trench fiber. According to the results presented in [6], r_2 / r_1 were designed from 3.5 to 4.0 to realize equivalent dispersion characteristics to the C-SMF.

Table 1 shows the measured characteristics of the fabricated trench fibers. The multi-mode reference technique was employed for measuring the cutoff wavelengths of the manufactured fibers [8]. All optical properties meet G.652 Recommendation. Even fiber C, which has the largest MFD among the fabricated fibers, shows a bending loss of 0.09 dB/turn at 1550 nm for a bending radius of 10 mm. The bending losses of each fiber are about one-tenth of those of C-SMF having the same MFD as the trench fiber. Also, the chromatic dispersions are very close to that of the C-SMF.

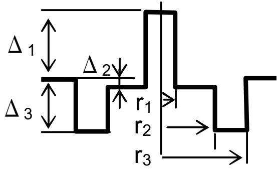

Fig. 1 Refractive index profile of trench fiber.

Table 1 Measured characteristics of fabricated trench fibers.

		fiber A	fiber B	fiber C
Attenuation [dB/km]	1310 nm	0.374	0.338	0.371
	1550 nm	0.226	0.192	0.204
Cable cutoff wavelength [nm]		1257	1215	1188
Mode field diameter [μm]	1310 nm	8.40	8.51	9.31
	1550 nm	9.40	9.57	10.50
Zero-dispersion wavelength [nm]		1316	1314	1310
Zero-dispersion slope [ps/nm^2/km]		0.088	0.086	0.086
Chromatic dispersion at 1550 nm [ps/nm/km]		16.59	16.31	16.80
Bending loss at 1550 nm [dB/turn]	r=15 mm	0.00	0.00	0.01
	r=10 mm	0.00	0.03	0.09
	r=7.5 mm	0.02	0.09	0.23

3. Electric field distribution of trench fibers

If single-mode fibers have Gaussian electric fields, the splice loss between two fibers is calculated by Eq. (1) [9].

$$T = \left(\frac{2w_1 w_2}{w_1^2 + w_2^2} \right)^2 \cdot \exp\left(-\frac{2d^2}{w_1^2 + w_2^2} \right) \tag{1}$$

, where T is a power transmission coefficient, $2w_1$, $2w_2$ are MFDs of the fibers, and d is a lateral offset between the centers of electric fields of the fibers. Since the electric field of C-SMF is very close to a Gaussian distribution, the splice loss can be estimated by Eq. (1).

On contrast, a fiber with a non-Gaussian electric field, a splice loss is calculated by Eq. (2) [10].

$$T \approx \frac{\left[\int_0^\infty rE_1(r)E_2(r)dr\right]^2}{\int_0^\infty rE_1^2(r)dr \int_0^\infty rE_2^2(r)dr} - \frac{1}{2}\left[\left(\frac{d}{w_1}\right)^2 + \left(\frac{d}{w_2}\right)^2\right] \qquad (2)$$

, where $E_1(r)$, $E_2(r)$ are the electric fields of the fibers. If the electric field of a fiber is distorted from the Gaussian, splice losses calculated by Eq. (1) and Eq. (2) are different.

Table 2 shows the calculated splice losses between the fabricated trench fibers and the C-SMF. The MFD of the C-SMF was 10.42 μm at 1550 nm. Since the calculated splice losses using Eq. (2) are equivalent to those using Eq. (1), the electrical fields of the dispersion-optimized trench fibers are very close to the Gaussian.

Table 2 Calculated splice losses of trench fibers to C-SMF.

	Splice loss [dB]		
	fiber A	fiber B	fiber C
By Eq. (1)	0.05	0.03	0.00
By Eq. (2)	0.05	0.02	0.00

4. Measurement results on splice loss

We demonstrated splice tests on the fabricated trench fibers using a commercially available fusion splicer (Fujikura Ltd. fusion splicer FSM-40F) without splice condition modified from that for C-SMF. The wavelength for measurement was 1550 nm.

Table 3 shows the measured heterogeneous splice losses between the fabricated trench fibers and C-SMF on 30 samples. Figures 2, 3 and 4 show histograms of measured heterogeneous splice losses respectively. Averaged splice losses are 0.01 to 0.06 dB, which are equivalent to the calculated values. Moreover, the measured homogeneous splice loss of the fiber B is 0.01 dB in average on 30 samples, which is equivalent to that of the C-SMF. These results indicate that the dispersion-optimized trench fiber shows high compatibility with the C-SMF even in terms of splice characteristics.

Table 3 Measured splice losses of trench fibers to C-SMF.

	Splice loss [dB]		
	fiber A	fiber B	fiber C
Average	0.06	0.04	0.01
Maximum	0.08	0.05	0.02
Minimum	0.05	0.03	0.01
Standard deviation	0.01	0.01	0.01

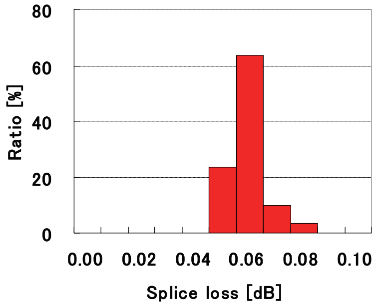

Fig. 2 Measured splice losses of fiber A to C-SMF.

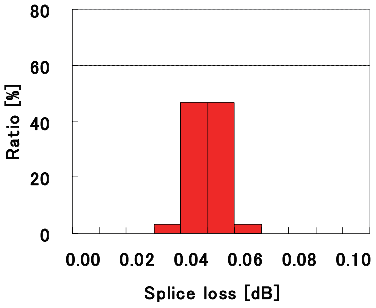

Fig. 3 Measured splice losses of fiber B to C-SMF.

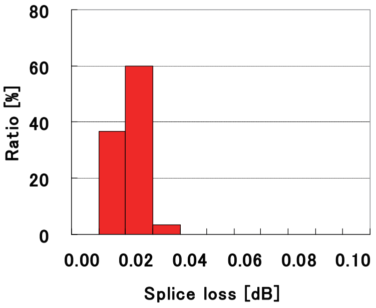

Fig. 4 Measured splice losses of fiber C to C-SMF.

5. Conclusion

We have shown the splice loss characteristics of the trench fibers that their trench positions are optimized for equivalent dispersion characteristics to the C-SMF. Excess splice losses due to distortion of the electric fields from a Gaussian distribution have been confirmed to be negligible. The heterogeneous splice losses between the trench fibers and the C-SMF are less than 0.06 dB in average. The homogeneous splice loss of the trench fiber is 0.01 dB in average, which is equivalent to that of the C-SMF. The dispersion-optimized trench fiber has high compatibility with the C-SMF in the viewpoint of the splice characteristics.

6. References

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