Optical Characteristics of a Reduced Bending-Loss Fiber with a Bending Radius of 5 mm

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With the worldwide popularization of fiber-to-the-home (FTTH) service, extremely low-bending-loss optical fibers with a small bending radius are requested from the viewpoint of easy fiber installation and space-saving storage for excess fibers. To meet the demand, we have developed a reduced bending-loss fiber with a bending radius of 5 mm, which is compliant with both ITU-T G.657.B3 and G.652.D recommendations. The newly developed optical fiber shows a satisfactory connectivity to conventional single-mode fibers, and is suitable in use for FTTH system.

1. Introduction

Recently, the optical fiber communication using fiber-to-the-x (FTTx) networks has been increased on a world basis. For instance, it is forecasted that the number of FTTx subscribers will surpass 100 million worldwide by 2012[1)]. Especially, FTTx service in Asian countries such as China has shown remarkable growth.

Fiber-to-the-home (FTTH) system, which is one type of FTTx system, can realize high-speed optical communications by installing optical fibers directly in individual house or building. For the installation operation of optical fibers indoors, optical fiber characteristics of low bending loss are important from the viewpoint of workability and space-saving[2)]. Conventional single-mode fibers (SMFs), which are compliant with International Telecommunication Union Telecommunication Standardization Sector (ITU-T) recommendation G.652, have been generally used in FTTH system. There is a possibility that the increase in the transmission loss affects the system performance when the SMF is bent with a small bending radius. Therefore, great care is needed to handle the SMF during the fiber installation.

If the bending loss of optical fibers is reduced, troubles attributed to the small bending radius can be avoided. For example, communication failures caused by the bending of live-line fibers with a small bending radius during the wiring in telecom offices or during the installation of drop cables can be prevented. Additionally, the decrease in bending loss brings some advantages such as a downsizing of storage for excess fibers, which allows greater flexibility in the choice of the installation location. Another advantage is that the easiness of optical fiber handling enables FTTH users to install optical fiber cords in doors by themselves. Therefore, bending-loss-insensitive fibers are expected to greatly contribute to the reduction of the installation and maintenance costs in FTTH system.

For the aforementioned reasons, Fujikura Ltd. has already released the low-bending-loss optical fibers named FutureGuide®-SR15E and FutureGuide®-BIS-B[3)4)]. In this article, we report on a newly developed fiber that possesses enhanced bending-loss characteristics and shows smaller bending loss with a bending radius of 5 mm.

2. Fiber design

ITU-T recommendation G.657, which concerns about the characteristics of a bending-loss insensitive single-mode optical fiber and cable, has been revised in November 2009. In the new revision of G.657, low-bending-loss fibers are categorized broadly into two categories as shown in Table 1: category A is fully compliant with G.652.D single-mode fibers, and category B is not necessarily compliant with G.652.D. The new revision also includes three sub-categories 1, 2, and 3 in both fiber categories A and B depending on

Table 1. Category classification of ITU-T G.657 and FutureGuide® lineup.

Item			Bending radii at which the bending losses are specified (mm)		
			15, 10	15, 10, 7.5	10, 7.5, 5
		Category	1	2	3
Compatibility with G.652.D	Necessary	A	A1 FutureGuide®-SR15E	A2 FutureGuide®-BIS-B	—
	Not necessary	B	—	B2	B3

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Panel 1. Abbreviations, Acronyms, and Terms.

FTTx—Fiber To The x
FTTH—Fiber To The Home
SMF—Single-Mode Fiber
ITU-T—International Telecommunication Union Telecommunication Standardization Sector
MFD—Mode Field Diameter
CWDM—Coarse Wavelength Division Multiplexing
AdPC—Advanced Physical Contact
IEC—International Electrotechnical Commission
MPI—Multi-Path Interference

the bending losses at several bending radii. The current G.657 specifies four types of optical fibers A1, A2, B2, and B3 according to the bending losses. Our company's lineup of low-bending-loss fibers called FutureGuide®-SR15E and FutureGuide®-BIS-B are compliant with G.657.A1 and G.657.A2, respectively.

In the present development, we aim to realize a fiber that is fully compatible with G.652.D and G.657.B3. Recommendation G.652.D concerns about low-water-peak fibers, and G.657.B3 specifies the smallest bending losses at bending radii of 10 mm, 7.5 mm, and 5 mm among the three sub-categories of G.657. We employed a trench index profile as schematically shown in Fig. 1(a), similarly to that of FutureGuide®-BIS-B, to realize enhanced bending-loss characteristics that enable the outstanding workability and space-saving[5]. Compared to a step-index profile as schematically shown in Fig. 1(b), the trench index profile shows a better bending-loss performance at a given mode field diameter (MFD).

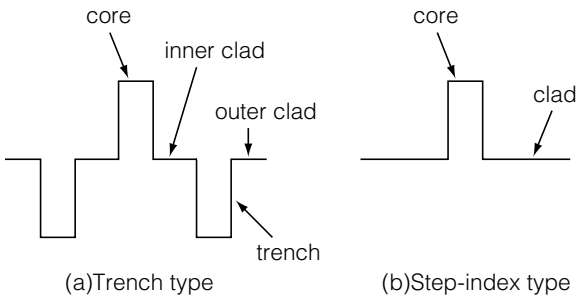

Fig. 1. Schematic refractive index profiles of (a) trench type and (b) step-index type.

Table 2. Typical optical characteristics of developed fiber.

Attribute			Measured value	G.652.D	G.657.B3
Attenuation (dB/km)		1310 nm	0.35	≦0.4	≦0.5
		1383 nm	0.31	(Note 1)	—
		1550 nm	0.20	≦0.3	≦0.3
		1625 nm	0.21	—	≦0.4
Cable cut-off wavelength (nm)			1243	≦1260	≦1260
Mode field diameter (μm)			8.7	8.6 - 9.5	6.3 - 9.5
Zero-dispersion wavelength (nm)			1314	1300 - 1324	TBD
Zero-dispersion slope (ps/nm²/km)			0.090	≦0.092	TBD
Bending loss (dB/turn)	R = 10 mm	1550 nm	0.01	—	≦0.03
		1625 nm	0.02	—	≦0.1
	R = 7.5 mm	1550 nm	0.03	—	≦0.08
		1625 nm	0.05	—	≦0.25
	R = 5 mm	1550 nm	0.08	—	≦0.15
		1625 nm	0.12	—	≦0.45

Note 1: The attenuation shall be less than or equal to the maximum value specified for the range from 1310 nm to 1625 nm after hydrogen aging.

3. Optical characteristics

The typical characteristics of a newly developed fiber are shown in Table 2, where specified values of G.657.B3 and G.652.D are also indicated for reference. The bending losses with the specified bending radii including 5 mm and MFD for the developed fiber are both compliant with G.657.B3.

The bending radius dependence of bending losses at 1550 nm for the developed fiber, FutureGuide®-SR15E, and FutureGuide®-BIS-B is shown in Fig. 2. The bending losses, especially with small bending radii for the developed fiber, are reduced compared to those of FutureGuide®-SR15E and FutureGuide®-BIS-B.

Figure 3 indicates a typical attenuation spectrum of the developed fiber after hydrogen aging. Since the OH-absorption at 1383 nm is substantially reduced, the developed fiber can be applied to optical communications using broad wavelength bands including E-band. Therefore, the developed fiber is also suitable

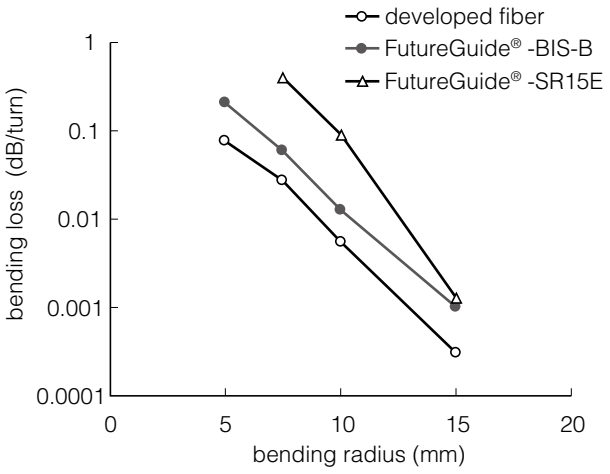

Fig. 2. Measured bending losses at 1550 nm as a function of bending radius.

for coarse wavelength division multiplexing (CWDM) system, which uses broad wavelength bands.

The above-mentioned merits of the developed fiber facilitate the installation and maintenance of fibers, and enable to substantially reduce the total costs of FTTH system.

4. Connection characteristics

The connection characteristics to conventional SMFs are important in order to widely use the developed fiber in the existing FTTH system. We evaluated the connection losses via SC connectors and the fusion splice losses both between the developed fiber and a conventional SMF, and between the developed fibers. The mode field diameters at 1310 nm were 8.6 μm and 9.2 μm for the measured developed fiber and SMF, respectively. For the measurement between the developed fiber and SMF, we intentionally used the developed fiber with a large core eccentricity of 0.4 μm in order to evaluate the worst level.

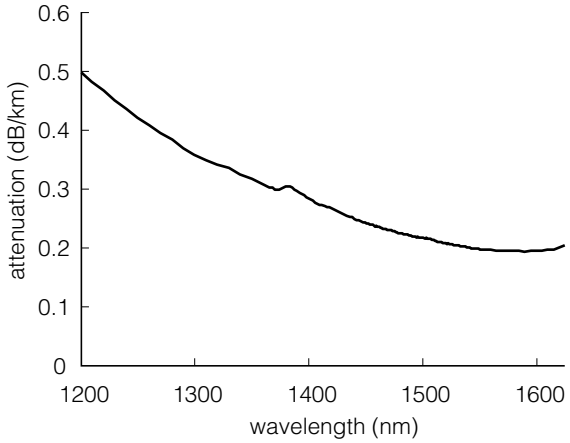

Fig. 3. Typical attenuation spectrum of developed fiber.

Figures 4 and 5 show the connection losses via SC connectors at 1310 nm and 1550 nm, respectively. The fiber length for measurements was 3 m, and the end face of ferrule was polished using the advanced physical contact (AdPC). The average connection losses to SMF at 1310 nm and 1550 nm were 0.17 dB and 0.18 dB, respectively. These values were similar to those between the developed fibers and between SMFs.

Figures 6 and 7 show the fusion splice losses at 1310 nm and 1550 nm, respectively. Splicing was carried out using a commercial fusion splicer (Fujikura FSM-60S) with the cladding alignment method and the standard splice condition. The maximum splice losses at 1310 nm and 1550 nm were both below 0.1 dB.

These results indicate that the connection characteristics of the developed fiber are sufficient from a practical viewpoint, and that the developed fiber has high compatibility with SMFs concerning the connection characteristics.

5. Hydrogen-resistant characteristics

It is known that the transmission losses around 1380 nm increase when hydroxyl groups are formed by the

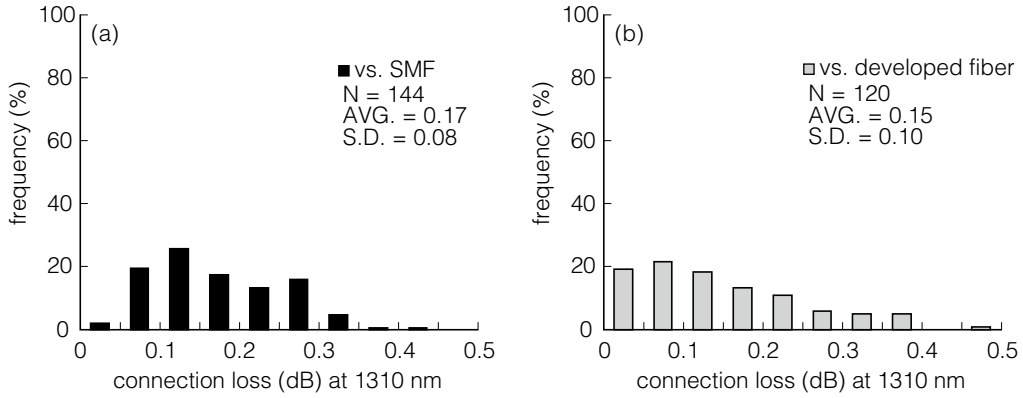

Fig. 4. Connection losses via SC connectors at 1310 nm: (a) developed fiber vs. SMF; (b) developed fiber vs. developed fiber.

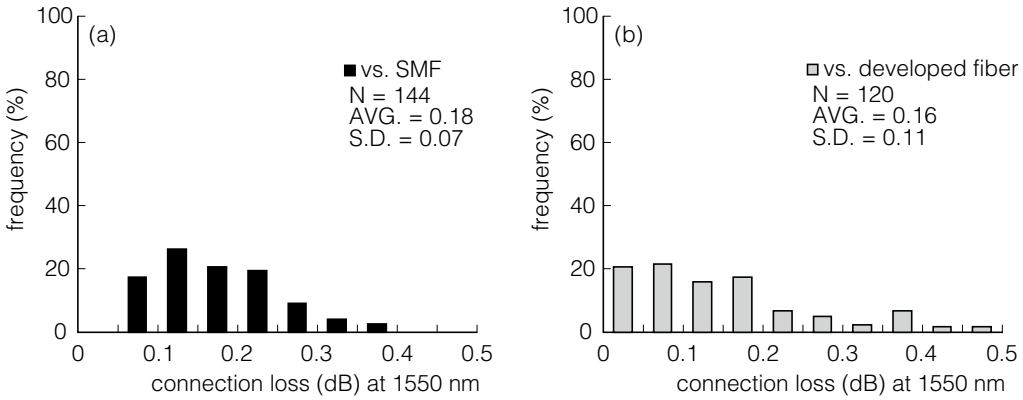

Fig. 5. Connection losses via SC connectors at 1550 nm: (a) developed fiber vs. SMF; (b) developed fiber vs. developed fiber.

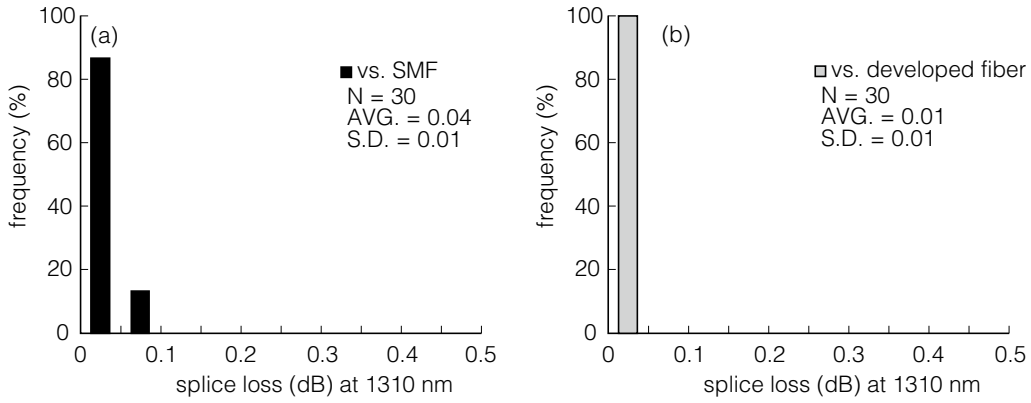

Fig. 6. Fusion splice losses at 1310 nm: (a) developed fiber vs. SMF; (b) developed fiber vs. developed fiber.

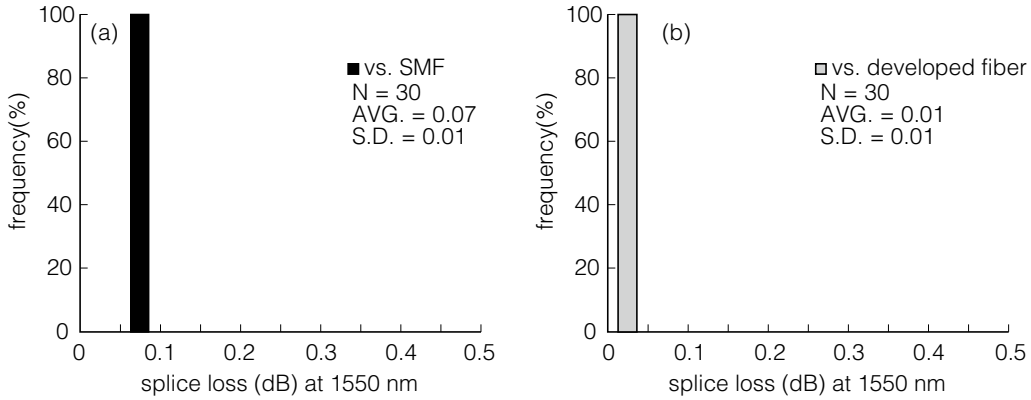

Fig. 7. Fusion splice losses at 1550 nm: (a) developed fiber vs. SMF; (b) developed fiber vs. developed fiber.

binding of diffused hydrogen, which is generated from the constituent materials of optical cables, to defects in the network structure of silica glasses[6]. The increase in loss incurs a risk that the optical transmission using E-band becomes almost impossible if fibers are exposed to hydrogen atmosphere for a long period. Therefore, it is important to evaluate the hydrogen-resistant characteristics of fibers from a viewpoint of long-term reliability. We evaluated the hydrogen-resistant characteristics of developed fiber by the method based on IEC60793-2-50. The increase in loss at 1383 nm after the hydrogen aging test was as small as 0.01 dB/km. This result shows that the developed fiber has sufficient hydrogen-resistant characteristics equally to conventional SMFs.

6. MPI performance evaluation

Multi-path interference (MPI) results from the interference between several modes propagating through the fiber core. MPI is one of degrading factors for the transmission characteristics in optical communication systems, and it is reported that MPI interferes with transmission performance if the value of MPI exceeds −30 dB[7].

If fibers are connected at short intervals as schematically shown in Fig. 8, there is a possibility that LP_{11} mode, which is a higher-order mode generated at a connecting point, recouples to the fundamental LP_{01} mode at another connecting point. This interference between LP_{01} mode and LP_{11} mode degrades the value of MPI. Additionally, there is a possibility that MPI also occurs by higher-order modes excited by bending of a fiber or by whispering-gallery modes if the fiber is bent with a small bending radius. Since the developed fiber is supposed to be used with a short length or a small bending radius in an individual house or building, it is important that the degrading in transmission characteristics by MPI should be sufficiently small.

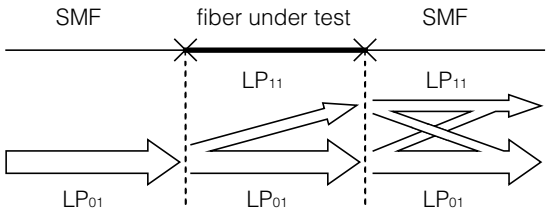

Fig. 8. Schematic figure of MPI induced by fiber connections.

The MPI measuring system for the present evaluation is shown in Fig. 9. A variable-wavelength LD with high output stability was used for the light source. The fiber under test was fusion spliced to SMFs at both ends during measurements. The developed fiber with a cable cut-off wavelength of 1255 nm, which is nearly the upper limit of the cable cut-off wavelength specified in G.652.D and G.657.B3, was used for measurements because such a fiber frequently induces MPI by

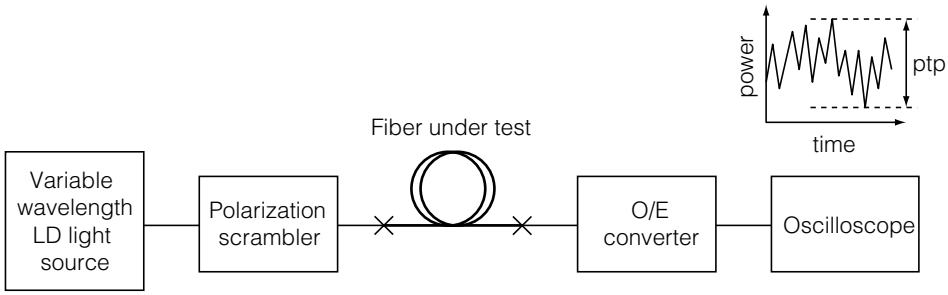

Fig. 9. Schematic figure of MPI measurement setup.

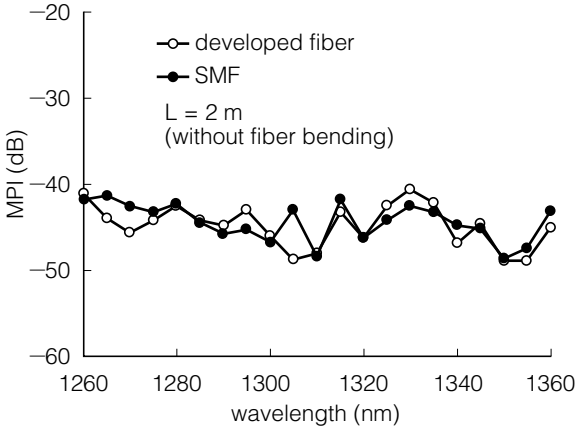

Fig. 10. MPI spectra in O-band.

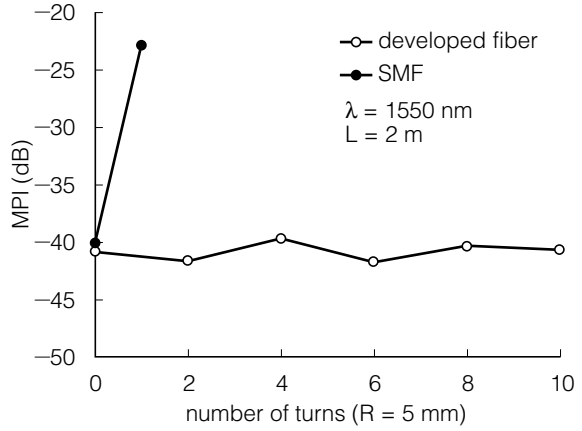

Fig. 11. MPI as a function of the number of turns at 1550 nm (R = 5 mm).

the residual higher-order modes. The value of MPI is defined by Equation (1).

$$MPI = 20\log\left(\frac{10^{ptp/20}-1}{10^{ptp/20}+1}\right) \cdots\cdots \quad (1)$$

The evaluation results of MPI attributed to the residual higher-order modes are shown in Fig. 10. The length of fiber under test was 2 m, and MPI was measured at O-band (1260 − 1360 nm). The values of MPI for the developed fiber and SMF were almost the same level, and were both below −40 dB. This result indicates that the developed fiber has stable transmission characteristics even if the fiber length is as short as 2 m.

The evaluation results of MPI attributed to a fiber bending with a small bending radius are shown in Fig. 11. The length of fiber under test was 2 m, and MPI was measured at 1550 nm as a function of the number of turns. The bending radius was 5 mm, which is the smallest bending radius specified in G657.B3. The value of MPI for SMF increases by 17 dB only by adding one turn. Meanwhile, the value of MPI for developed fiber does not change from around −40 dB even by adding 10 turns.

These results indicate that the developed fiber is suitable for use in FTTH system, where the fibers are supposed to be installed at short lengths or with small bending radii.

7. Conclusion

We report the typical characteristics of the newly developed fiber that has reduced bending loss with a bending radius of 5 mm. The developed fiber has low-bending-loss characteristics, which is compliant with ITU-T G.657.B3 recommendation, and realizes a low water-absorption peak, which is compliant with ITU-T G.652.D recommendation. These superior properties enable the developed fiber to possess a high compatibility with the conventional SMFs, and a broad applicability to FTTH system. We expect that the developed fiber and its application products contribute to the future prevalence of FTTH system.

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