Low Bending Loss Single-Mode Hole-Assisted Fiber

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As the optical access network expands, there is an increasing demand for optical fiber cables that improve the efficiency of Fiber-to-the-Home (FTTH) network installation and maintenance. To meet this demand, we have fabricated the single-mode hole-assisted fiber (SM-HAF) that satisfies low bending loss requirements of ITU-T G.657.A2 and B3 as well as other specifications of G.652. We have also developed an SM-HAF optical fiber connector, cord and cable, and confirmed their excellent bend insensitive characteristics.

Keywords: single-mode fiber, bend insensitive fiber, hole-assisted fiber

1. Introduction

As the optical access network expands, there is an increasing demand for optical fiber cables that improve the efficiency of Fiber-to-the-Home (FTTH) network installation and maintenance. For this purpose, there is a strong demand for an optical fiber with low bending loss characteristics in order to realize flexible wiring and easy handling of optical fiber cables, particularly for high density optical fiber distribution. In this regard, bend insensitive fibers (BIFs) have been standardized by International Telecommunication Union Telecommunication Standardization Sector (ITU-T) G.657.

Various types of BIFs have been developed to reduce the bending loss with a smaller bending radius[(1)-(5)]. Among the BIFs, hole-assisted fiber (HAF) shows excellent low bending loss characteristics because of the strong light confinement effect by the air-holes surrounding its center core. Recently, it has been reported that the single-mode hole-assisted fiber (SM-HAF) satisfies both low bending loss requirements of ITU-T G.657.B3 and compatibility of ITU-T G.652 by optimizing the air-hole structure[(6)]. With its excellent characteristics, the SM-HAF is expected to find wide applications.

In this paper, we first introduce the characteristics of the SM-HAF, and then present an SM-HAF optical fiber connector. To ensure the high reliability of the SM-HAF, its air holes are sealed by fusion splicing to a standard SMF at the end face, and the splice point is put inside the ferrule. Finally, we describe SM-HAF cord and cable that we have fabricated and report on the confirmed test results on their performance.

2. Structure and Characteristics of the SM-HAF

2-1 Air-hole structure and optical properties

The cross section of the SM-HAF is shown in **Photo 1**. Ten air holes are arranged around the center core and this sectional structure continues along the fiber axis.

Since the refractive index difference between the air hole and background glass is large, the optical properties of the HAF are changed by a small change of the air hole structure. As for the SM-HAF, the bending loss can be lowered by increasing the air hole size, however, higher order mode is also confined strongly, which causes longer shift of the cut-off wavelength. Therefore, the air hole size needs to be optimized. On the other hand, since the dispersion

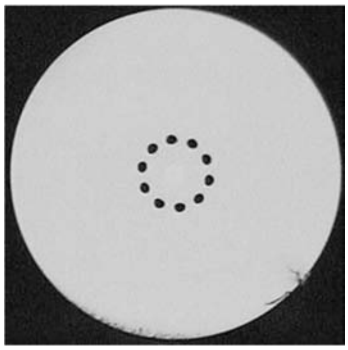

Photo 1. Cross section of HAF

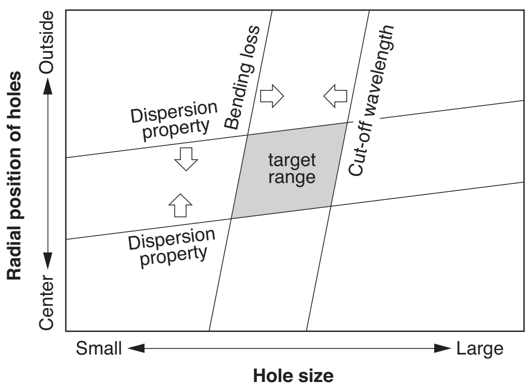

Fig. 1. Relationship between hole structure and optical properties

properties are determined by the distance between the air holes and the center core, the radial position also needs to be optimized. These relationships are shown schematically in **Fig. 1**. In addition, to fully meet the requirements of optical properties, the size and refractive index parameter of the center core should be optimized[(6), (7)].

The precise control of the air hole structure at the fabrication is also indispensable. Therefore, we have developed the fabrication method that enables the submicron control of the air hole structure.

2-2 Characteristics of the SM-HAF

Table 1 shows the characteristics of fabricated SM-HAF in comparison with the ITU-T recommendation. ITU-T G.657, an international standard for the SMF with improved bending performance, includes two categories and each category has two sub-categories. Category A is the SMF fully compliant with the existing ITU-T G.652 standard, and the sub-categories A1 and A2 support macrobending loss specifications at bend radius of 15 mm (R15) and 7.5 mm (R7.5), respectively. The other, category B, is not necessarily compliant with the G.652 but is capable of low values of macrobending losses at very small bend radii. The sub-categories B2 and B3 include bend radius of 7.5 mm (R7.5) and 5 mm (R5), respectively. The fabricated SM-HAF is fully compliant with all of the specified macrobending losses in the G.657 and other optical properties in the G.652 such as dispersion properties, cut-off wavelength, and mode field diameter (MFD).

Figure 2 shows the bending loss spectrum of the SM-HAF in comparison with G.652 standard SMF and G.657 A1 SMF. The SM-HAF shows excellent low bending loss performance at wide wavelength band as expected.

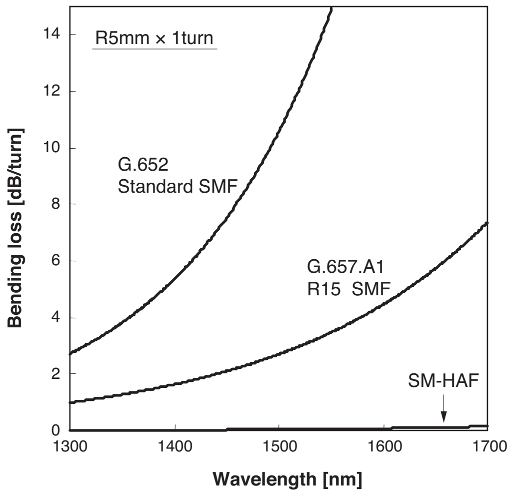

Fig. 2. Comparison of wavelength dependence of bending loss

3. Splicing of SM-HAF

3-1 SM-HAF optical connector

The existence of open air holes at the fiber end face might cause optical loss or degradation in the reliability when contaminants penetrate into the air holes. To prevent these problems, the sealing technique of air holes, for example, filling resin, collapsing holes, or splicing solid fiber, can be effective. We have adopted the splicing method and developed the SM-HAF connector shown in **Fig. 3**. The air holes are sealed by fusion splicing to standard SMF, and the splice point is put inside the ferrule.

Table 1. ITU-T recommendation and compatibility SM-HAF

			ITU-Trecommendation (extract)			SM-HAF compatibility
			G.652 Standard SMF	G.657 bending-loss insensitive SMF		
				A2	B3	
Bending loss	R30	1625nm	≦0.1dB/100turn		—	✔
	R15	1550nm	—	≦0.03dB/10turn	—	✔
		1625nm	—	≦0.1dB/10turn	—	✔
	R10	1550nm	—	≦0.1dB/turn	≦0.03dB/turn	✔
		1625nm	—	≦0.2dB/turn	≦0.1dB/turn	✔
	R7.5	1550nm	—	≦0.5dB/turn	≦0.08dB/turn	✔
		1625nm	—	≦1.0dB/turn	≦0.25dB/turn	✔
	R5	1550nm	—	—	≦0.15dB/turn	✔
		1625nm	—	—	≦0.45dB/turn	✔
Mode field diameter (1310nm)			8.6 - 9.5μm	8.6 - 9.5μm	6.3 - 9.5μm	✔
Core concentricity error			≦0.6μm	≦0.5μm	≦0.5μm	✔
Cable cut-off wavelength			≦1260nm	≦1260nm	≦1260nm	✔
Attenuation (1550nm)			≦0.3dB/km	≦0.3dB/km	≦0.3dB/km	✔
Zero dispersion wavelength			1300-1324nm	1300-1324nm	—	✔
Zero dispersion slope			≦0.092ps/nm²·km	≦0.092ps/nm²·km	—	✔

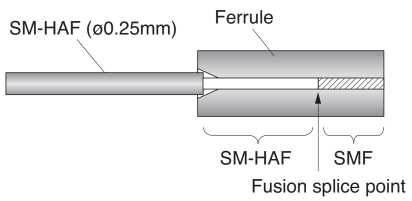

Fig. 3. Structure of SM-HAF connector

3-2 Fusion splice loss

The air hole structure is deformed to some extent around the splice point by the heat at the fusion splice process, as shown in **Photo 2**. This might cause excess splice loss due to the MFD change of the HAF. However, the influence of air hole structure on MFD becomes smaller as the radial position of air holes is away from the center core[8]. As described above, in the case of the SM-HAF, the radial position of air holes is apart from the center core to optimize dispersion properties. Therefore, MFD mismatch caused by the deformation of air holes at the fusion splice is small. The result of the fusion splice tests (N = 100) between the SM-HAF and SMF is shown in **Fig. 4**. The average splice loss was 0.06 dB and 0.08 dB, at the wavelength of 1310 nm and 1550 nm, respectively. This is low enough for practical use.

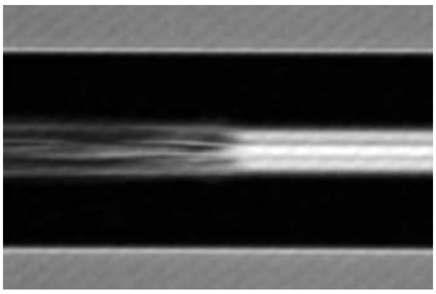

Photo 2. Side view around fusion splice point

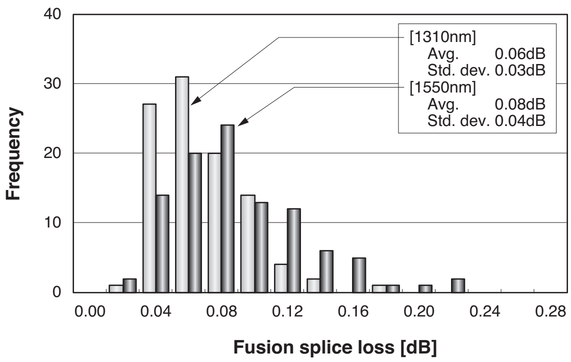

Fig. 4. Histogram of fusion splice loss between SM-HAF and SMF

In case of accidental fiber breaking after the SM-HAF is installed, there will be a necessity of the fusion splice between the SM-HAFs for repair. **Figure 5** shows the average splice loss between the SM-HAFs, which almost equals to **Fig. 4**.

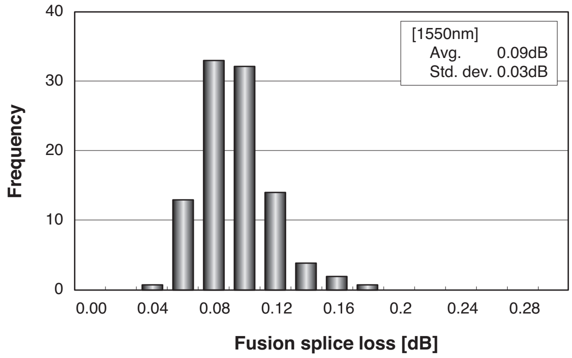

Fig. 5. Histogram of fusion splice loss between SM-HAFs

3-3 Connector insertion loss

The insertion loss of the SM-HAF patch cord, which has the optical connector of **Fig. 3** at both ends, is shown in **Fig. 6**. The average insertion loss was 0.13 dB and 0.17 dB, at the wavelength of 1310 nm and 1550 nm, respectively. This is also sufficiently low for practical use.

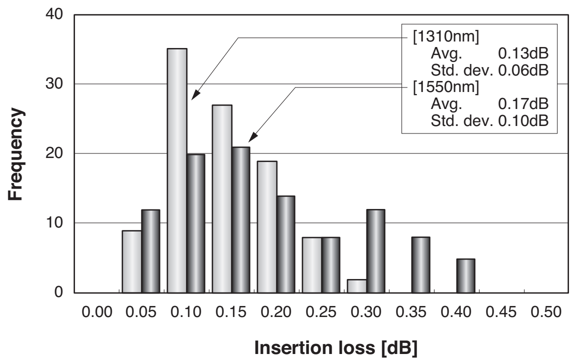

Fig. 6. Histogram of SM-HAF patch cord insertion loss

4. SM-HAF Cables

We have developed the SM-HAF optical cord and cables as shown in **Fig. 7**, and investigated the optical, mechanical and thermal properties of the cables. As a result, the SM-HAF cables were confirmed to be comparable with the existing SMF cable in all the properties and satisfy low bending loss requirements of the G.657. The SM-HAF enables flexible wiring and easy handling of optical cables, and consequently will improve the efficiency of FTTH network installation and maintenance.

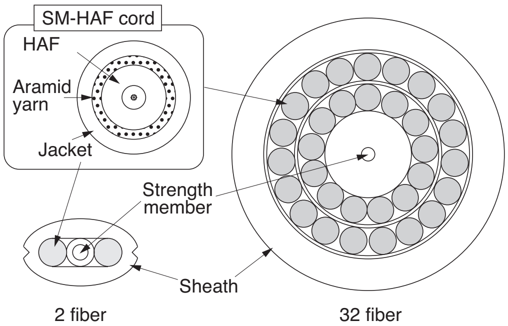

Fig. 7. Cross section of SM-HAF cable

5. Conclusion

We report on the characteristics of the SM-HAF, its splice technique, optical fiber connector, and the application for cables. We have optimized the design and fabrication method of the air holes of the SM-HAF and confirmed that it satisfies low bending loss requirements of ITU-T G.657 and other specifications of G.652 simultaneously. We have also succeeded in the highly reliable splicing of the SM-HAF by adopting fusion splice technique and developing a new optical fiber connector structure. The SM-HAF cables significantly improve the bending loss and show excellent performance, while keeping optical compatibility with existing networks. The SM-HAF and related techniques are expected to have expanded applications in the future optical networking.

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