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Comparison of microbending loss characteristics between LMA holey fibers and conventional LMA fibers

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Abstract: We fabricated holey fibers with effective area of 130μm^2 and 150μm^2. Advantages of using holey fibers are demonstrated by comparing microbending loss properties with conventional step-index LMA fibers.

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1. Introduction

As the data traffic has been increased by using wavelength division multiplexing (WDM) transmission, the suppressions of nonlinear effects and/or fiber fuse have become critical issues, in particular, in case of long-haul or submarine transmission. These problems can be solved by employing large mode area (LMA) optical fibers, though the index profile needs to be optimized to achieve both LMA and low bending loss, simultaneously. By utilizing the W-shape profile with optimized structure, pure silica core fiber with A_{eff} of 118 μm^2 was proposed [1]. However, further expansion of A_{eff} has been limited because it accompanies the microbending loss increases and/or longer cutoff wavelength than signal wavelengths. In order to overcome these trade-offs between LMA, single mode operation, and low microbending loss, we investigated the new possibilities of using holey fibers (HFs). Up until now, some studies on the microdeformation-induced losses of HFs have been reported [2,3], however, these reports focused on theoretical studies or non-telecom applications.

In this work, we fabricated holey fibers with A_{eff} of about 130 μm^2 and 150 μm^2 for long-haul transmissions. In addition, we also fabricated a conventional solid fiber with A_{eff} of 115 μm^2, which almost corresponds to the upper limit of the conventional solid fiber in terms of low microbending loss. By experimentally investigating the microbending loss properties of all fibers with same fiber outer diameters for the fair comparison, we found out that the microbending losses of the conventional solid fiber with A_{eff} of 115 μm^2 and HF with A_{eff} of 130 μm^2 or 150 μm^2 are the same level. The results obtained indicate that HFs are significantly less sensitive to microbending deformation loss than conventional solid fibers.

2. Design of LMA HFs

We consider the triangular-lattice HFs surrounded by five layers of air holes, where air hole pitch is defined as Λ, and air hole diameter is defined as d. Fig. 1 (a) shows the relationship of HFs between macrobending losses at bending diameter of 20 mm (20 mmϕ) and A_{eff} at wavelength of 1.55 μm calculated by full-vectorial finite element method (FEM). Each solid curve in the fig. 1 (a) indicates different values of d/Λ. It is obviously seen from the fig.1 (a) that the macrobending loss at 20 mmϕ simply increases as A_{eff} increases. In addition, the macrobending loss at 20 mmϕ decreases significantly by increasing the d/Λ, while maintaining the same A_{eff}. However, we should pay attention to the fact that the HFs no longer keep endlessly single mode (ESM) property and has a possibility of multi-mode guidance, when the d/Λ is larger than 0.43 [4]. Next, we show the numerical relationship of conventional solid step-index fibers (SIFs) between macrobending losses at 20 mmϕ and A_{eff} at 1.55 μm in fig. 1 (b). Here, the structural parameters, namely core diameter $2a$ and relative refractive index difference Δ, are adjusted to keep the cutoff wavelength at 1530 nm for any values of A_{eff}. In the same way as HFs shown in the fig. 1 (a), the macrobending loss of the SIFs at 20 mmϕ shown in the fig. 1 (b) also increases by increasing A_{eff}. Interestingly, the result of the HF with d/Λ=0.43, which gives ESM properties, shows the almost same tendency as that of the SIF with cutoff wavelength of 1530 nm. Based on these results, we fabricated the HF with d/Λ=0.43 and A_{eff} of about 130 μm^2, as well as the SIF with the cutoff wavelength of 1530 nm and A_{eff} of about 115 μm^2. Then, we compare the microbending loss properties between the HF and the SIF keeping same fiber outer diameter of 186 μm. Moreover, the HF with larger A_{eff} of about 150 μm^2 at 1.55 μm by changing the d/Λ to 0.35 is also fabricated and the microbending loss of the HF is measured and compared with the SIF.

3. Experimental results and verification

We fabricated the SIF by the VAD method, where the core material is made of pure silica and the cladding is the fluorine-doped silica. On the other hand, the HFs were fabricated by the stack-and-draw method. These fibers have the same fiber outer diameters of 186 μm, which ensures a fair comparison of the microbending losses. An inset of fig. 2 shows the cross section of the fabricated HF by the stack-and-draw method. It is found that all of the air holes were kept circular. The structural parameters of the fabricated HF were almost the same as those of the design. The air hole pitch Λ was 10.8 μm, d/Λ was 0.426, and the fiber outer diameter was 186 μm. It is noted that the structural parameters of the solid fiber are almost same as the target values since the VAD technology is a matured method.

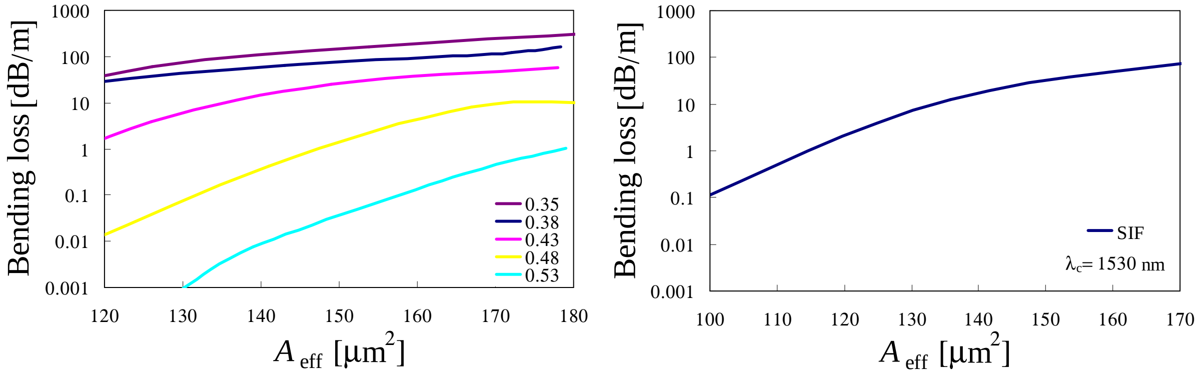
The obtained properties of the HFs and the SIF are summarized in table 1, and fig. 2 shows the attenuation loss spectrum of the HFs and the SIF. As shown in the table 1, the HF with d/Λ of 0.426 has an ESM property, A_{eff} of 130 μm^2, and bending loss of 50 dB/m at 20 mmϕ. The experimental results showed good agreements with the calculated ones though there are little discrepancies in terms of bending loss between experiments and calculations. Even though the HFs considered here may suffer from the bending loss increase at shorter wavelengths, there is no significant loss increase by winding the HFs to the 300 mmϕ bobbin within the measured wavelength range shown in the fig. 2. Moreover, it should be possible to compensate the dispersion of the HFs by using the appropriately designed DCF because the chromatic dispersion of this HF is somewhat similar to that of SMFs. The red curve in the fig. 2 corresponds to an attenuation spectrum of the HF with d/Λ=0.426 and the attenuation loss level is 5.023 dB/km at 1.55 μm. Even though this HF has a relatively high OH absorption loss, this absorption can be reduced by careful optimizations of the fabrication process. On the other hand, the SIF has the cutoff wavelength of 1508 nm, A_{eff} of 114.2 μm^2 at 1.55 μm, and the bending loss of 18.4 dB/m at 20 mmϕ, and the properties agreed with the predicted values again. The attenuation loss level of the SIF is 0.176 dB/km at 1.55 μm, and the spectrum showed no degradations as shown in the fig. 2. Fig. 3 shows the microbending loss comparison between the HF with d/Λ of 0.426 vs. the SIF. In order to obtain the microbending loss spectrum, we measured the difference between the losses obtained by spooling optical fibers into a bobbin with a sandpaper (#1000) and to the same bobbin without the sandpaper maintaining the same winding tension. The red solid curve shown in the fig. 3 corresponds to the HF with d/Λ of 0.426 and the blue curve to the SIF. As we can see, the microbending loss are kept to a similar level for both the HF and the SIF even though HF has larger A_{eff} and larger macrobending loss at 20 mmϕ, while keeping the same fiber outer diameters. It may indicate that the air holes in the cladding have some effects to prevent the microdeformation around the core.

As a next step, we also studied about the properties of a HF with d/Λ=0.342. This HF has larger A_{eff} of 154.9 μm^2 and large bending loss of 157.6 dB/m at 20 mmϕ as shown in the table 1. The HF has a same fiber outer diameter as previous ones, namely 186 μm. The macrobending loss becomes large because larger A_{eff} was obtained by decreasing the d/Λ. The attenuation loss of the HF, which is shown in the green curve in the fig. 2, is 1.022 dB/km at 1.55 μm. In the fig. 3, the microbending loss spectrum of the HF with d/Λ=0.342 is shown as a green curve. Although the HF with d/Λ=0.342 has large macrobending loss of about 150 dB/m at 20 mmϕ, microbending loss is still low enough, about 0.3 dB/km, which is comparable with that of the SIF with A_{eff} of 115 μm^2. As a result, we confirmed that the microbending loss of the HF with A_{eff} of 150 μm^2 is still similar to that of the SIF with A_{eff} of 115 μm^2 and the HFs have the possibilities of keeping the microbending loss low in spite of very large A_{eff}, e.g. 150 μm^2, due to existence of their air holes.

4. Conclusions

We fabricated HFs with ESM and A_{eff} of about 130 μm^2 or 150 μm^2 and compare the microbending loss of the HFs with that of the conventional solid SIF having the cutoff wavelength of 1508 nm and A_{eff} of 115 μm^2. We found out from the experimental results that the micronbending loss can be suppressed by using HFs even if A_{eff} of the HFs is very large, such as 130 μm^2 or 150 μm^2. Moreover, it should be added that HFs have merits in terms of not only the improvement of LMA and microbending loss trade-off, but also endlessly single mode operation.

The new experimentally-confirmed finding through this study; HFs have a merit in terms of less sensitivity to the microbending deformation loss, in addition to the well-know merits of the HFs such as ESM, opens a new possibility of HFs for long-haul telecom applications.



(a) Holey fiber (b) Conventional solid fiber

Fig. 1. Relationship between bending loss at 20-mm bending diameter and A_{eff} at 1.55 μm.

Table 1. Properties of fabricated large A_{eff} HF and SIF (λ=1.55 μm)

Fiber Type	λ_c	Bending Loss @20mmϕ	Chromatic Dispersion	Dispersion Slope	A_{eff}	PMD
	[nm]	[dB/m]	[ps/nm/km]	[ps/nm^2/km]	[μm^2]	[ps/$\sqrt{\text{km}}$]
HF (d/Λ=0.426)	ESM	53.3	27.03	0.068	131.5	0.164
HF (d/Λ=0.342)	ESM	157.6	26.02	0.067	154.9	0.582
SIF	1508	18.4	19.95	0.059	114.2	0.059

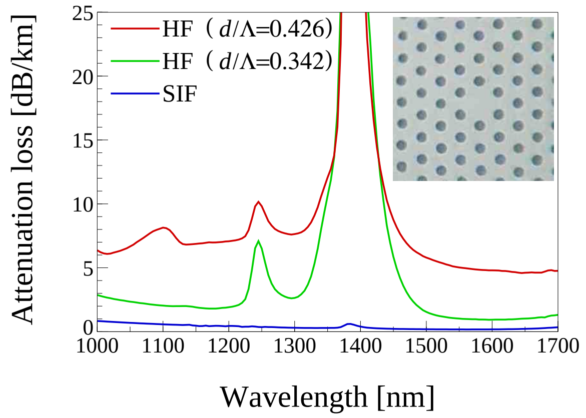


Fig. 2. Attenuation loss spectrum of HFs and SIF.
(Inset: Cross section of fabricated HF)

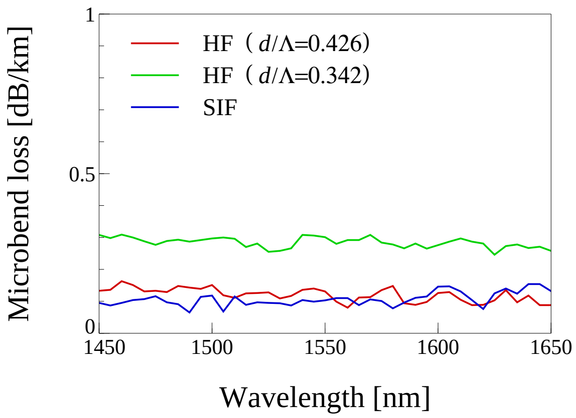


Fig. 3. Wavelength dependence of microbending losses
of HFs and SIF.

5. References

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