Proposal of Reliable Cutoff Wavelength Measurement for Bend Insensitive Fiber

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Abstract *Reliable technique to determine the cutoff wavelength using single-mode fiber as a reference is newly proposed. This technique identifies cutoff wavelength of 1st higher-order-mode in BIF precisely, which is difficult with existing techniques.*

Introduction

There are growing demands for broadband services, which are delivered over optical access network. As for the optical fibers deployed in the FTTx, a bending loss should be suppressed to minimize installation spaces and costs. Up to now, various types of bend-insensitive fibers (BIFs) whose refractive index profiles with W-cladding[1], trench-assisted[2,3], void-assisted[4], and hole-assisted[5] have been developed and actual installation is ongoing.

Recently, it has been actively discussed the multi-path interference (MPI), which is the interference between fundamental mode and remaining higher order modes (HOMs) in the fiber[6], so as to avoid degradation of system performance. Because the BIFs could confine tightly the fundamental mode and also HOMs, measuring the cutoff wavelength (λc) precisely is important. However, it is reported that, λc of some BIFs can not be measured by proven bend reference technique (Bend tech.)[7], since bending losses of HOM are also very low. Hence, a multimode reference technique (MM tech.)[7] is often employed[8,9]. However, λc measured with MM tech. is often affected by ripples due to leaky modes[10] and ambiguity of its definition of baseline.

In this paper, we propose and demonstrate a novel method to measure the λc, so-called single-mode reference technique (SM tech.). In this technique a fiber having λc shorter than the measurement wavelength range is used as a reference. In the wavelength range longer than λc of a tested fiber, only the fundamental mode can be propagated for both reference and sample measurements, thus a power difference between the reference and sample is expected to be zero. Moreover, ripples owing to leaky HOMs will not appear. These features are especially effective for determining λc of 1[st] HOM in BIFs more precisely than existing techniques.

Measurement set up and verification of SM tech.

Figure 1(a) shows measurement setups of SM tech., MM tech., and Bend tech., respectively. To determine the λc of fiber under test (FUT), a transmitted power spectrum of FUT, Ps(λ), is compared to a reference transmitted power spectrum, Pr(λ), by applying the equation, $A(\lambda) = 10 \log [Ps(\lambda)/Pr(\lambda)]$.

All of three techniques, the Ps(λ) is measured in the same way. In the SM tech., a fiber having shorter λc than that of FUT is used as a reference to measure Pr(λ). In this study, we employed a 5m-long standard SMF (hereafter Ref. SMF) having MFD of 9.0μm. In order to make λc as short as 1120nm, the Ref. SMF is coiled 60mm in diameter. Then A(λ) is plotted against wavelength. A straight baseline is fitted to the long-wavelength range of A(λ), displacing it upward by 0.1dB, as shown by the dashed line in Fig.1 (b). Finally, its subsequent intersection with A(λ) denotes the λc.

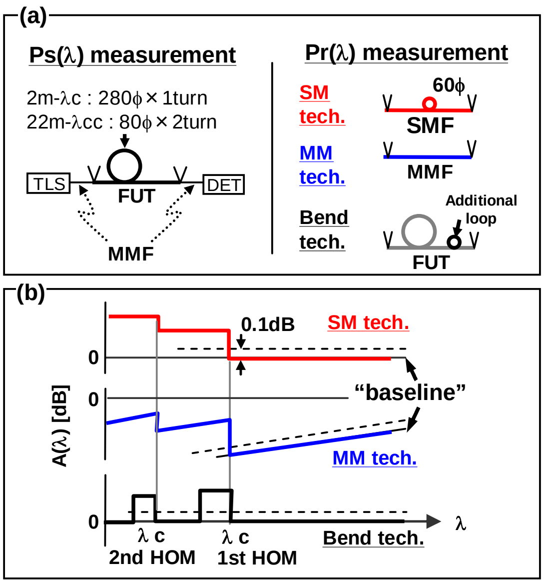

Fig. 1: (a) Measurement setup of λc and (b) measured A(λ) of SM tech., MM tech., and Bend tech. (TLS: Tunable light source, DET: Detector)

In principal, wavelength range longer than the λc of FUT, only fundamental mode can propagate in both FUT and Ref. SMF, thus A(λ) is expected to be almost zero. Therefore, as shown in Fig. 1 (b), SM tech. has advantageous features as follows,

1) λc of 1[st] HOM can be specified uniquely, because only at the wavelength region longer than the 1[st] HOM λc of FUT, A(λ) becomes close to zero.
2) A(λ) can be obtained, even though the HOM is strong to a bend.

Furthermore, smooth Pr(λ) is expected because leaky HOMs cut off at the wavelength longer than the λc of Ref. SMF.

In order to verify the proposed SM tech., we have compared with existing techniques using step index

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fibers (Fiber-A, B). As is shown in Table 1, it is confirmed that both λc with fiber condition (2m-λc) and cable condition (22m-λcc) measured by SM tech. are in good agreement with those by existing Bend tech. and MM tech. for Fiber-A and B.

Table 1: Characteristics of fabricated fibers and measured cutoff wavelength.

	Index profile type	ITU-T category	MFD λ=1310nm [μm]	Bending loss @R5mm λ=1550nm [dB/turn]
A	Step	G.657A	8.9	1.84
B	Step	G.657B	6.2	<0.01
C	Trench	G.657B	9.2	0.07

	2m λc			22m λcc		
	Bend tech. [nm]	MM tech. [nm]	SM tech. [nm]	Bend tech. [nm]	MM tech. [nm]	SM tech. [nm]
A	1277	1276	1279	1218	1218	1217
B	1266	1266	1270	1200	1197	1195
C	N/A	1397-1465	1460	N/A	1250-1260	1242

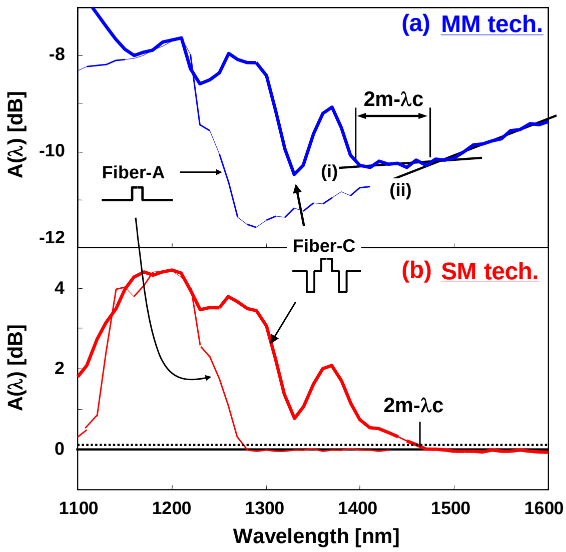

Fig. 2: A(λ) of Fiber-A (Thin line) and Fiber-C (Bold line) measured by MM tech.(a) and SM tech.(b).

λc measurement of BIF

Then we measured λc of fabricated BIF of Fiber-C listed in Table 1. Fiber-C has trench-assisted profile and fully compatible with G.652D, while keeping the bending loss of 0.07dB/turn at 5mm radius at 1550nm.

The A(λ) of Fiber-C measured by Bend tech. was not observed and the 2m-λc could not be determined like as reported[8,9]. As for MM tech., wavelength range where baseline to be fitted must be specified. A(λ) of Fiber-C by MM tech. is shown in Fig. 2 (a). The spectral shape is more complex as compared with that of Fiber-A with a step index profile. Presence of such curvature and humps on A(λ) makes baseline determination difficult, and the baseline can be defined in various ways as shown by slant solid straight line (i) or (ii) in Fig.2 (a). Therefore, determined λc can change by the definition of baseline as listed in Table 1. On the other hand, for the case of SM tech., flat baseline without ripples was obtained as shown in Fig.2 (b), thus 2m-λc of 1st HOM can be uniquely specified.

Baseline offset of A(λ) in SM tech.

When a difference of MFD between FUT and Ref. SMF is large, the baseline would not be zero. We examined the baseline offset dependence on MFD difference between FUT and Ref. SMF for SM tech.. As shown in Fig. 3, the baseline offset is well below +/- 0.1dB, as far as the MFD difference is within +/- 0.5μm. This result indicates that a Ref. SMF with MFD at 1310nm of around 9.0μm can cover λc measurement of FUTs with MFD range of 8.6~9.5μm as a nominal value, which is recommended by ITU-T G.652[11].

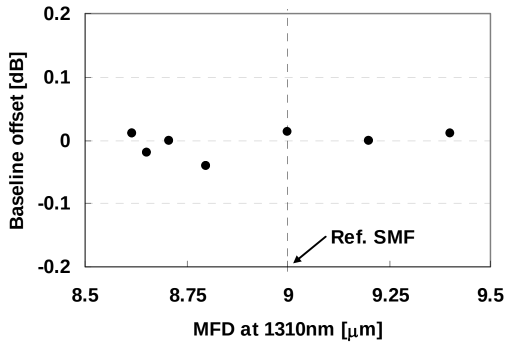

Fig. 3: Measured baseline offset as a function of MFD.

Conclusion

We have demonstrated the novel single-mode reference technique, which can be used to determine the reliable λc of BIFs. We confirmed that this technique gives the same result as with existing techniques in step index fiber. Although, BIF with trench-assisted profile often has very small bending loss of HOM and its A(λ) spectrum measured by existing techniques tends to be complex, λc of 1st HOM can be clearly specified by applying this technique.

References

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