High-Density Weakly-Coupled 4-core MCF with 160-µm Coating for O-band Application

Shota Kajikawa, Mayu Iizuka, Takuya Oda, Katsuhiro Takenaga, and Kentaro Ichii
Optical Technologies R&D center, Fujikura Ltd., 1440 Mutsuzaki, Sakura, Chiba, 285-8550, Japan
shota.kajikawa@jp.fujikura.com

Abstract: We developed weakly coupled 4-core multi-core fiber with 100-µm cladding and 160-µm coating suitable for O-band applications, which achieves an impressive core density of 9.8 times higher than that of conventional single-core fiber. © 2024 The Author(s)

1. Introduction

Space-division multiplexing (SDM) devices, such as reduced cladding fibers [1], high-density cables [2], and multi-core fibers (MCFs) [3], can increase the transmission density of communication networks. Fig. 1 (a) shows the normalized core density of each fiber. A single core fiber (SCF), with a coating diameter of 160 µm, can realize a core density that is 2.4 times higher than that of conventional SCF with a coating diameter of 250 µm [1]. Here, the core density is defined as the “number of cores / fiber cross-sectional area”. The weakly coupled 4-core MCF (4c-MCF) with a coating diameter of 250 µm were reported. They can achieve a core density 4.0 times higher than that of single core fiber [4]. By reducing coating diameter to 200 µm, the core density of the 4c-MCF becomes 6.3 times higher [3]. A high-density MCF with a cladding diameter of 125 µm is an 8-core MCF (8c-MCF), which achieves a core density 8.0 times higher than that of single core fiber if the coating diameter is 250 µm [5]. To increase the cladding diameter, fibers with a higher core count, such as a 12-core MCF (12c-MCF) with a cladding diameter of 180 µm, have been developed, achieving a core density 12 times higher [6]. However, enlarging the cladding diameter is not favored due to concerns with respect to bending mechanical reliability and reduced productivity. Fig. 1 (b) illustrates the normalized core length of each fiber drawn from the same preform size. The 12c-MCF has a shorter core length than the 8c-MCF even though it boasts a higher core density.

Traditionally, strategies for achieving higher-density single-mode MCFs have involved either incorporating more cores within an MCF with the standard cladding diameter of 125 µm [5] or to place more cores in an MCF with a larger cladding diameter [6]. In contrast, our innovative approach focuses on a reduced-cladding MCF. For the first time, we introduce a weakly-coupled 4c-MCF with a cladding diameter of 100 µm and a coating diameter of 160 µm. This achieves a remarkable core density that is 9.8 times greater than conventional single-core fiber. Our primary focus is on short-reach applications, specifically inter- and intra-data center connectivity, aiming for transmission distances of up to 10 km in the O-band.

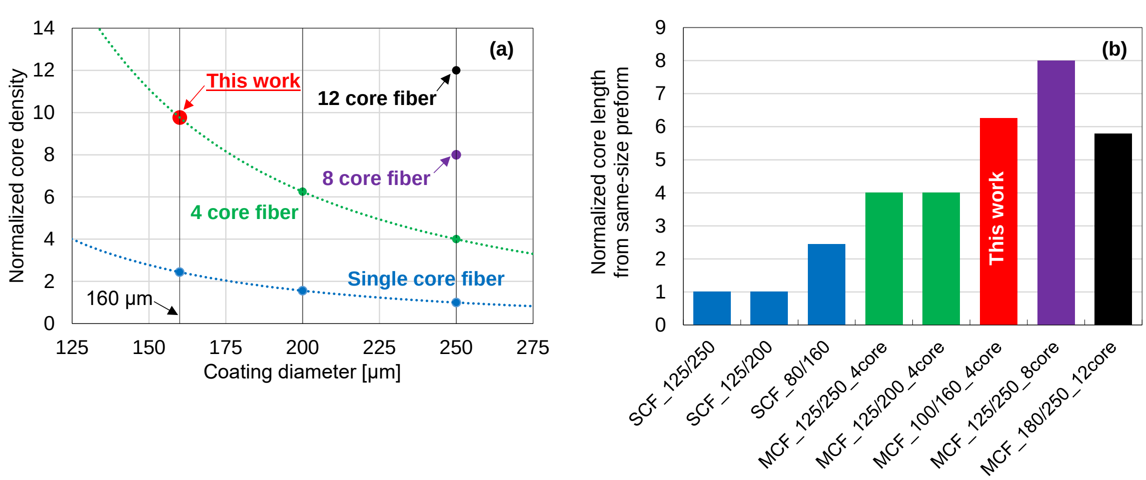

Fig. 1 (a) Normalized core density of each fiber.
(b) Normalized core length of each fiber obtained from the same preform size.

2. Design of reduced cladding MCF

Table 1 details the core parameters utilized in our reduced-cladding 4c-MCF design. We employed a trench-assisted core with a trench depth of –0.3%. This refractive index design, which is well-suited for mass production, was used to suppress crosstalk (XT) and confinement loss. When conceptualizing an MCF where the core is placed in a square layout, the key design factors include core pitch (Λ) and outer cladding thickness (*OCT*), as illustrated in Fig. 2. While Λ influences total-XT, *OCT* has a bearing on confinement loss. Fig. 3 displays the computational outcomes relating to Λ and *OCT* dependency on total-XT and confinement loss at 1.31 μm wavelength, based on the refractive index profile presented in Table 1. By adjusting Λ to 35 μm, we can achieve total-XT and confinement loss values comparable to those of conventional 4c-MCFs with a cladding diameter of 125 μm at 1.31 μm wavelength.

Table 1. Core parameters used for MCF with cladding diameter of 100 μm.

r_1	r_2	r_3	Δ_1	Δ_2	Δ_3
μm	μm	μm	%	%	%
4.4	9.0	17.5	0.34	0.0	–0.3

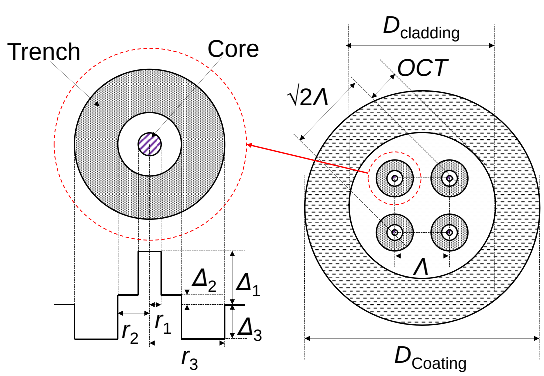

Fig. 2 Cross section of a trench-assisted 4c-MCF.

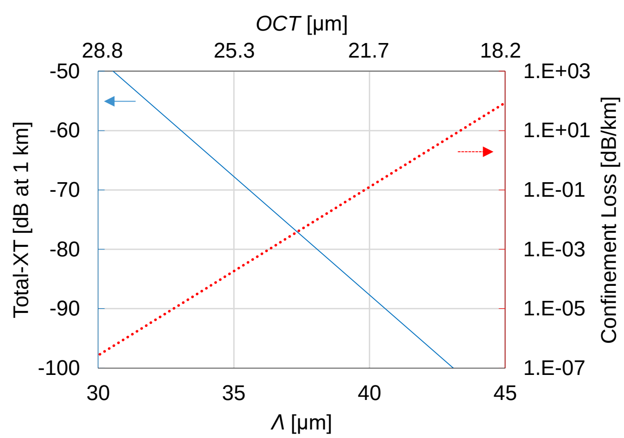

Fig. 3 Calculation results of Λ and *OCT* dependency to total-XT, and confinement loss at 1.31 μm using the refractive index profile shown in Table 1.

3. Weakly coupled 4c-MCF with a cladding diameter of 100 μm and a coating diameter of 160 μm

We fabricated 8.2 km of the reduced-cladding 4c-MCF. During the 1% proof tests, no breakages were recorded. Fig. 4 presents a photograph of the reduced-cladding 4c-MCF, where the four cores are arranged in a square configuration with a pitch ranging between 35.1 and 35.6 μm. Their optical specifications are outlined in Table 2. Attenuation at 1,310 nm wavelength was measured using OTDR, while attenuations at 1,260 nm and 1,360 nm were determined through the 2-m cutback method, utilizing a broadband light source alongside an optical spectrum analyzer. In the O-band, there was no increase in attenuation due to the reduced cladding. The MFD at 1,310 nm wavelength were measured as 8.7 μm. The 22-m cutoff wavelength and macrobending loss (MBL) at 1,550 nm were less than 1,228 nm and 0.03 dB/turn at a radius (*R*) of 10 mm, respectively. These optical characteristics are compliant with ITU-T G.657.A2 in 1.31 μm wavelength. Since the values of total-XT at wavelengths 1,530 nm and 1,590 nm were measured as –29dB and –24dB at 1 km, respectively, the total-XT at 1,360 nm was estimated to be –48dB at 1 km. The variation in the core's refractive index due to drawing tension can be a contributing factor to the discrepancy between the simulated outcomes and actual measurements in Fig. 3. We also confirmed the splicing loss by splicing the fabricated MCFs with side-view method employed in a splicer (FSM-100P). After 10 tests, the average splice loss was 0.08dB, with a maximum of 0.19dB and a standard deviation of 0.06dB. These values are in line with the splicing loss seen in a standard-cladding 4c-MCF [7].

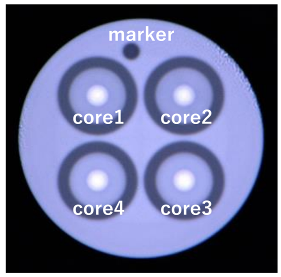

Fig. 4 Photograph of manufactured reduced cladding 4c-MCF.

Table 2 Optical characteristics of manufactured MCF.

Data	Attenuation			MFD	Cutoff wavelength	MBL	Total XT
Unit	dB/km			μm	nm	dB/turn at R=10 mm	dB at 1 km
λ, nm	1,260	1,310	1,360	1,310	n/a	1,550	1,360
core1	<0.47	0.35	<0.35	8.7	1,228	0.02	
core2	<0.47	0.35	<0.35	8.7	1,213	0.03	<–48
core3	<0.47	0.35	<0.35	8.7	1,222	0.02	
core4	<0.47	0.35	<0.34	8.7	1,228	0.02	
ITU-T G657.A2	<0.47	<0.40	<0.40	8.6–9.2 ±0.4	<1,260	<0.1	-

4. Concept of the 4c-MCF with a cladding diameter of 100 μm and a coating diameter of 160 μm

The proposed 4c-MCF method offers several advantages.

- The fiber was designed for mass production.
- A normalized core density, which is 9.8 times higher when compared to those of the conventional single-core fibers.
- A normalized core length increase by 1.56 times per preform when compared to the 4c-MCF with a cladding diameter of 125 μm.
- Enhanced bending mechanical reliability due to the reduced cladding.
- Increased tolerance for the rotational alignment accuracy in the MCF-to-MCF connection via a closer core pitch of 35 μm when compared to that of 40 μm pitch in the 4c-MCF with a cladding diameter of 125 μm.

5. Conclusions

The developed 4c-MCF features a cladding diameter of 100 μm and a coating diameter of 160 μm was developed for O-band applications. The core design that can be realized for manufacturing conventional SMFs was employed and demonstrated optimal MCF design compliant with ITU-T G.657.A2 in the O-band. Remarkably, the proposed 4c-MCF exhibits a higher core density when compared to the 8c-MCF [5] and exhibits a more extended normalized core length than the 12c-MCF [6]. The 4c-MCF which cores placed in square is the most mature MCF structure that is being considered for standardization, and peripheral technologies such as FIFO [8] and fusion splicing [7] are also being actively developed. The proposed 4c-MCF realize the highest core density compared to previously reported 4c-MCFs.

6. References

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