Characteristics of Over 600-km-Long 4-core MCF Drawn from a Single Preform

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Abstract: This report presents details of the successful production of a 4-core MCF, with 125-μm cladding and a length greater than 600 km. This is the champion data for MCF length drawn from a single preform. © 2022 The Author(s)

1. Introduction

1.1. SDM Fiber

Practical applications of multi-core-fiber (MCF) in space-division multiplexing (SDM) technology have been actively developed in recent years [1]. In particular, efforts have been targeted towards the standardization of uncoupled optical fibers with four cores and 125-μm cladding [2]. These MCFs have sufficient mechanical reliability and compatibility with other devices. In addition, an uncoupled MCF obviates the requirement of multiple-input and multiple-output digital signal processing (MIMO-DSP) to compensate crosstalk.

1.2. MCF Preform

MCF cost remains a problem that hinders practical application. Compared to single-mode fibers (SMFs), whose preforms are manufactured by vapor-phase axial deposition (VAD) and outside vapor deposition (OVD) methods, MCF requires several unique manufacturing processes. Consequently, it incurs high manufacturing costs. For example, in terms of the drilling method, MCF requires cutting, cylindrical grinding, drilling, cleaning, inserting, and assembly processes as shown in Figure 1.

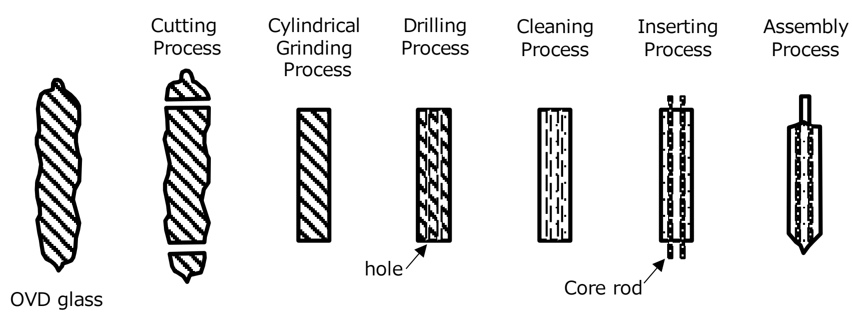


Fig. 1 Manufacturing processes of the MCF using the drilling method.

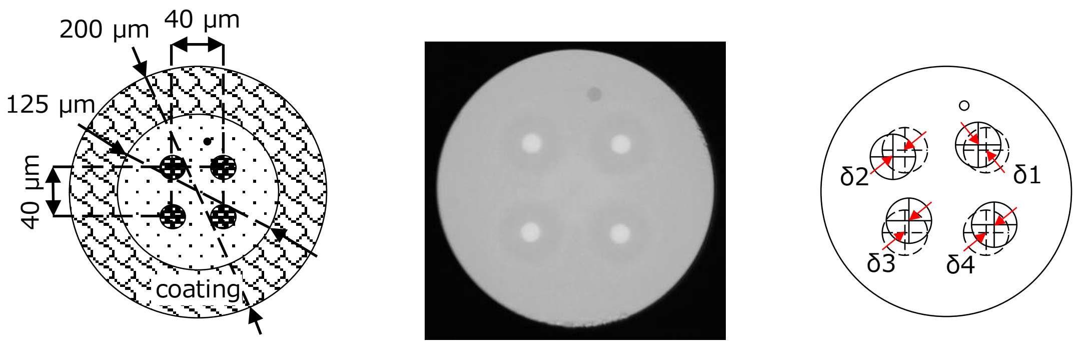
In recent years, SMF prices have decreased owing to oversupply due to the entry of new manufacturers. By contrast, the ratio of raw material cost in MCF prices has increased owing to increasing raw material costs. However, when considering the raw material cost per core number, its value for MCF should be lower than that for SMF. For example, if the raw material costs of a 4-core MCF (4c-MCF) and an SMF are same, the 4c-MCF cost per core is 75% less than the SMF cost. Thus, the processing cost is more important than the material cost in MCF production. Increasing the preform size is the most effective method for reducing the MCF processing cost. During cleaning and insertion, the manufacturing man-hours is constant regardless of the preform size. In addition, considering the man-hours required for the preparation and cleanup of each process and material losses during drawing, increasing preform size is an effective solution.

Another problem plaguing MCF is its connection to other devices. The cores of the 4c-MCF are not positioned at the center of the cladding, that is, core misalignment is greater than that of SMF and depends on the radius and angle [3]. Increasing the preform size also solves the core misalignment problem because of the dimensional tolerance of holes and core rods, and because the positional tolerance of the holes is relatively small.

Herein, the details of the successful production of a 4c-MCF with 125-μm cladding are presented. We manufactured a preform measuring 625 km in fiber length, and fabricated a 4c-MCF longer than 600 km. The manufactured MCF was also tested for optical characteristics through cabling.

2. Fabrication of the 4c-MCF

Figure 2 (a) shows the design of the manufactured MCF. Four cores were arranged in a square with a pitch of 40 μm. The 125-μm cladded fiber was coated with 200-μm resin. We fabricated the MCF preform by a drilling process. The cladding material was manufactured employing the VAD and OVD methods. Furthermore, the outer circumference of the cladding material was grinded and drilled with four holes for cores and one hole for a marker, which were cleaned using buffered hydrofluoric acid. Before the inserting process, the cladding material was gas etched for further cleaning. Four core rods and one marker rod were inserted into the holes of the cladding material, and the drawing preform was constructed. The volume of the drawing preform was estimated to be 625 km in fiber length. Consequently, an MCF longer than 600 km with four cores and 125-μm cladding was manufactured from a 625-km preform. A proof strength test at 1% yielded a breaking time of 2 in total length and a frequency of breaking fiber of 0.003 times/km. Figure 2 (b) shows the picture of the manufactured MCF. Table 1 shows the optical characteristics of the manufactured MCF. The optical characteristics are compliant with ITU-T G.657.A1. The inter-core total crosstalk (XT) was less than –36 dB/km at 1,550-nm wavelength.



(a) (b) (c)

(a) Design of the MCF. (b) Manufactured MCF. (c) Conceptual diagram of core misalignment.

Fig. 2 Geometric properties of the MCF.

Table 1 Optical characteristics of the manufactured MCF.

Data	Attenuation			MFD	Cutoff Wavelength	Macro Bending Loss (R = 10 mm)	Polarization Mode Dispersion	Inter-Core Total XT
Unit	dB/km			μm	nm	dB/turn	ps/√km	dB/km
λ, nm	1,310	1,550	1,625	1,310	n/a	1,550	1,550	1,550
#1	0.33	0.19	0.21	8.4	1,187	0.03	0.02	< –36
#2	0.33	0.19	0.21	8.4	1,198	0.03	0.02	
#3	0.33	0.19	0.21	8.4	1,184	0.04	0.03	
#4	0.33	0.19	0.21	8.4	1,201	0.03	0.02	
ITU-T G657.A1	< 0.4	< 0.3	< 0.4	8.6–9.2 ±0.4	< 1,260	< 0.75	< 0.20	-

Figure 2 (c) shows a conceptual diagram of core misalignment. Figures 3 and 4 show the histogram of δ for all cores and δ of each length position, respectively. The average and standard deviation of δ were calculated as 0.08 and 0.06 μm, respectively. Fusion splicing tests of 120 different fibers (N = 480 cores) showed that the average splice loss was 0.09dB at 1,550-nm with a standard deviation of 0.09dB. Thus, the manufactured 4c-MCF has excellent connectivity to other devices.

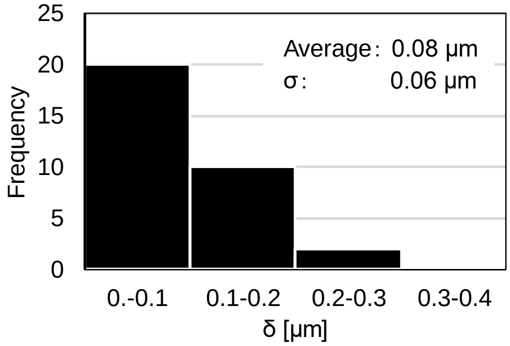


Fig. 3 Histogram of δ for all cores.

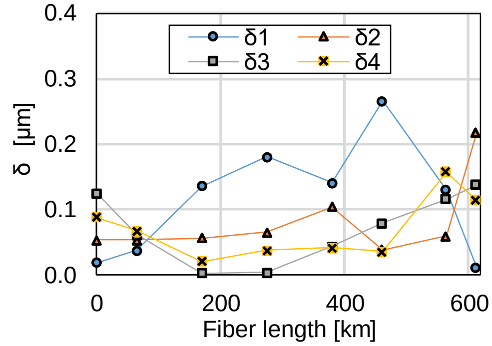


Fig. 4 δ of each length position.

3. Cabling test of the 4c-MCF

The manufactured MCF was tested for optical characteristics by cabling. We fabricated an Air-Blown Wrapping Tube Cable™ (AB-WTC) having 288 4c-MCFs [4]. Figure 5 shows the cross-sections of the MCF cable schematic and a photo of a part of the fabricated MCF cable. The cable length and the diameter were 2 km and 9.3 mm, respectively. The cable contained 24 bonded ribbons with 12 4c-MCFs each. Figure 6 shows the attenuation and the XT of MCF, ribbon, and cable. The error bars indicate the maximum and minimum values of the measured data. Through the cabling, the attenuation increased from 0.19 to 0.20 dB/km, and the XT decreased from –36 to –37 dB/km. The increase in attenuation was the same as that reported in previous experiments [5]. The decrease in XT was caused by the measurement conditions because of the large variation.

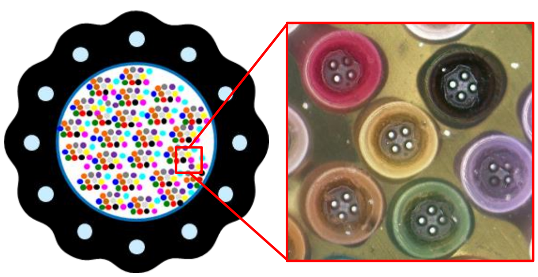


Fig. 5 Cross-sectional view of the fabricated MCF cable.

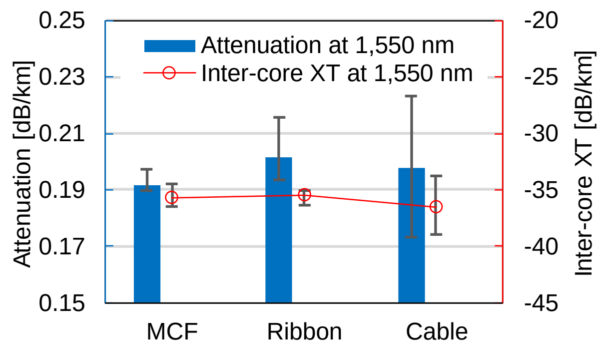


Fig. 6 Attenuation and XT of each situation.

4. Conclusion

A 4c-MCF more than 600 km in length with 125-μm cladding was successfully manufactured from a 625-km preform. The optical characteristics were compliant with ITU-T G.657.A1. Results of fusion splicing tests show that the manufactured 4c-MCF has excellent connectivity to other devices. A cabling test confirmed the feasibility of the manufactured MCF in terms of attenuation and XT. Thus, the results of this study are expected to have considerable implications in practical applications.

5. Acknowledgement

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6. References

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