Multi-Core Fibre with Concaved Double-D Shape Cross Section

Takuji Nagashima, Shuhei Toyokawa, Tetsuya Hayashi, Tetsu Morishima, Hirotaka Sakuma, and Tetsuya Nakanishi

Sumitomo Electric Industries, Ltd., Yokohama 244-8588, Japan, nagashima-takuji@sei.co.jp

Abstract *We developed a multi-core fibre with a concaved double-D shape cladding for passive fibre alignment. The cladding dimensions were well controlled in longitudinal and transverse directions, with 150-m/min drawing speed which is the highest ever reported for the rectangular-like fibre.*

Introduction

The rapid growth of the data centre and super computer performance demand high-speed and high-density optical interconnects, and the multi-core fibre (MCF) is expected to realize ultra-high-density interconnects that are unachievable with the conventional single-core fibres. However, MCFs need the additional rotational alignment process for connection/splicing, which results in an assembly cost increase and/or insertion loss degradation. Therefore, MCFs with a noncircular cladding have been proposed for easy fibre alignment[1–3]. It was reported that “great care must be taken during fiber drawing” to supress deformation of cladding shape[1] and the drawing speeds for rectangular-cladding MCFs were reported to be as slow as 2 m/min[2] to 21 m/min[3]. In addition, the longitudinal fibre dimension control is also a challenge for the large-scale production of noncircular fibres.

In this study, we developed an MCF with a concaved double-D shape cross section, which enables the passive rotational alignment. The concaved double-D shape fibre was drawn from the simple double-D shape preform at the practical drawing speed of 150 m/min, which we believe is the highest ever reported for the rectangular-like fibre drawing (more than 7-times higher than that of the earlier reports).

Cladding shape design

Passive fibre alignment based on the asymmetric cladding and ferrule shapes is the key to realize easy MCF connector assembly. However, a ferrule with micro holes would result in high cost due to the difficulty of the precise machining of the noncircular micro holes. To realize low cost assembly, it is preferred to align the noncircular MCF on a corresponding aligning groove with a proper groove angle (90 degrees for rectangle), where the precise groove angle control can be realized by high-throughput machining.

The cladding shape deformation is a key to achieve precise rotational alignment on a groove. Because viscoelastic deformation during drawing process is unavoidable due to the circularly asymmetric cladding shape, the perfect rectangular cross section (Fig. 1(a)) is difficult to achieve, and the drawn fibre may be barrel-/pincushion-distorted as shown in Fig. 1(b,c). We consider that the barrel distortion occurs when surface tension is the dominant cause of deformation, and the pincushion distortion occurs when the radial-tension asymmetry is the dominant cause. Even in the pincushion distortion case, the angles of the rectangular cladding are affected by the surface tension and easily deform asymmetrically. So, both distortions may result in 2-point contact between the cladding and the groove, which cannot restrict the fibre rotation. To balance the above deformations and achieve ideal shape, the earlier studies[2,3] precisely controlled the drawing conditions with very low drawing speed.

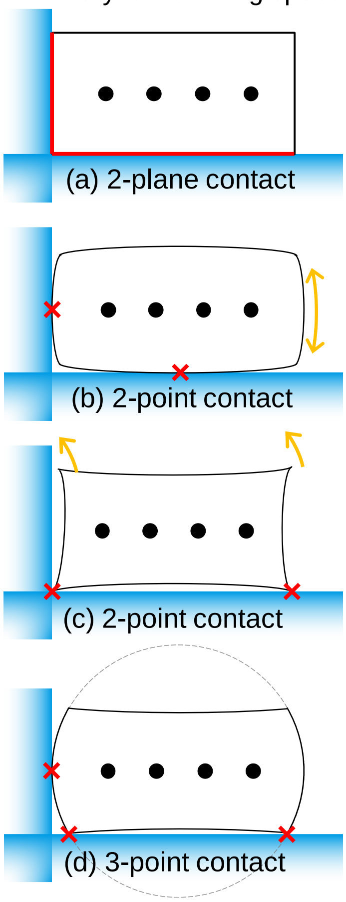

Fig. 1: Schematics showing the rotational alignment accuracies of rectangular-like MCFs whose cross sections are (a) an ideal rectangle, (b) a barrel-distorted rectangle, (c) an asymmetrically pincushion-distorted rectangle, and (d) a concaved double-D shape.

In this study, we employed the concaved double-D shape—i.e., the double-D shape whose planes slightly concave with a negative curvature (shown in Fig. 1(d))— as the target of the cladding cross sectional shape. A convex side arch and two edges of a concave plane can achieve 3-point contact between the cladding and the groove, which restrict the fibre rotation. Furthermore, the convex side arches, and gentle angles between the arches and the concave planes are beneficial to reduce the surface-tension-induced deformation, thus improve fibre diameter controllability.

We simulated viscoelastic deformation during the drawing process using a 3-dimentional finite element method to assess the productivity of the concaved double-D shape fibre. Figure 2 shows the preform dimensions and the vertical temperature profile in the furnace, which were used in the simulation. For simulation simplicity, we also assumed a uniform temperature in each cross section, and uniform F-doped silica glass core rods (each core rod consists of a Ge-doped core surrounded by an F-doped depressed cladding in actual fabrication). When the furnace temperature was 2300 K and the drawing speed was 150 m/min, the cladding was deformed as shown in Fig. 3. Thus, we numerically confirmed that the concaved double-D shape fibre can be drawn from the double-D shape preform without

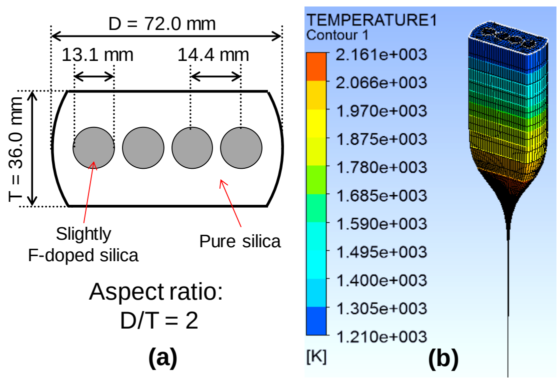

Fig. 2: (a) Preform dimensions and (b) furnace temperature profile, used in the deformation simulation.

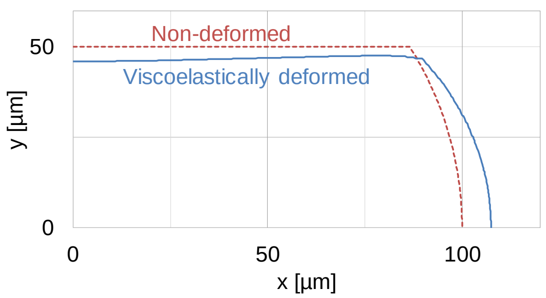

Fig. 3: Calculated deformation of the double-D shape fibre during the drawing at the furnace temperature of 2300 K and the drawing speed of 150 m/min. Only the first quadrant was simulated because of the preform symmetricity.

concaves at the practical drawing speed of 150 m/min, which is more than 7-times faster than that of the earlier studies.

Fibre fabrication

We validated the simulation by fibre fabrication. In the fabrication, we employed Ge-doped cores with slightly F-doped depressed cladding. The pure silica outer cladding was ground to shape two flat planes of the double-D shaped cross-section. The preform dimensions were the same with those shown in Fig. 2(a), and the aspect ratio of the double-D shape was 2.00. The preform was drawn to the fibre with the furnace temperature of 2300 K and the drawing speed of 150 m/min, which are the same with the simulation conditions.

In order to measure and control the cladding diameter of the double-D shaped cross-section, we allocated four diameter monitors (DMs) where each DM's monitoring angle was shifted by 45 degrees, as shown in Fig. 4. At least any one of the four DMs always measures the diameter of the circular part of the double-D shape, when the aspect ratio of the double-D shape is lower than √2. So, we can easily measure and control the

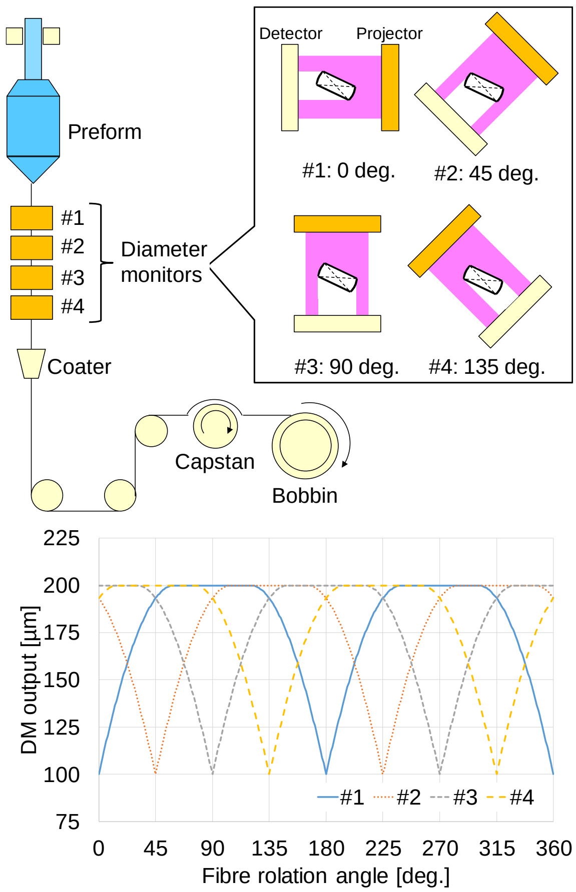

Fig. 4: Schematics of the diameter monitoring of the double-D shape fibre with the aspect ratio of 2. (Upper) Four DMs were arranged with 45-degree offsets, and (lower) any one of the DMs always measures the diameter of the circular part of the cross section.

cladding diameter of the fibre. The target of the cladding diameter was 200 μm. Thus, the design core pitch was 40 μm if there is no deformation, but the deformation may slightly change the core pitch. According to the simulation, the core pitch is expected to be 39.8 μm between the inner two cores, and 40.1 μm between neighbouring inner and outer cores. Figure 5 shows the measured cladding diameter fluctuation during the drawing process. The cladding diameter was well controlled to be 200 ± 0.8 μm over 6 km except a few irregular points.

The cross section of the fabricated MCF is shown in Fig. 6. As predicted in the simulation, the flat planes of the fibre were slightly concaved by the deformation. The cladding diameter (D) and thickness (T) were 200.3 μm and 97.4 μm, respectively. So, surprisingly, the aspect ratio (D/T) of the fabricated fibre was 2.06 and the original shape of the preform was quite preserved whilst achieving the concaved double-D shape cross section, though the simulation predicted a somewhat larger deformation with the aspect ratio of 2.26. We consider this discrepancy would be caused by the inaccuracy of the assumption of the furnace temperature profile in the simulation, and would like to improve it in the future. On the other hand, the core positions were quite well controlled, as summarized in Tab. 1 where the coordinates are shown in Fig. 7. The core positions in x direction were multiples of 40 μm in design, and the deviation of the measured values from the design were ≤0.7 μm. The core positions in y direction were 48.7 ± 0.2 μm (= T/2 ± 0.2 μm).

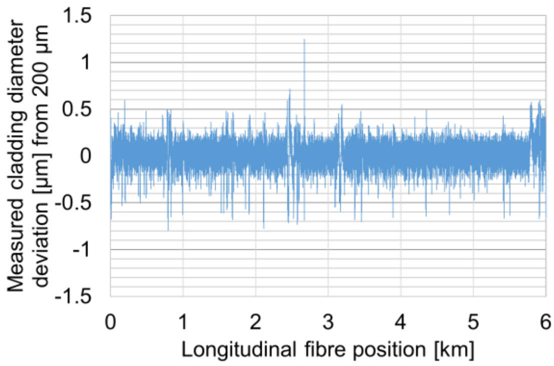

Fig. 5: Cladding diameter fluctuation during the drawing.

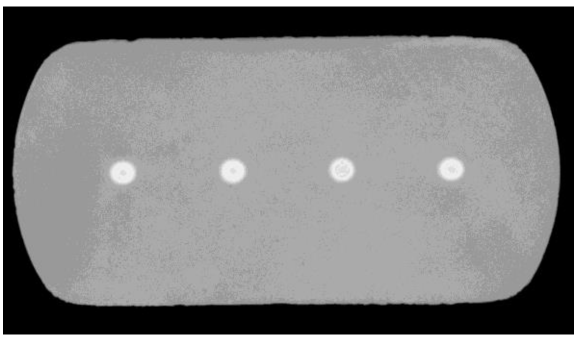

Fig. 6: Cross-section of the fabricated MCF.

The optical properties were measured at 1550 nm. The transmission loss was 0.201 to 0.203 dB/km, the mode field diameter was 9.7 μm, the inter-core crosstalk was −36.6 to −35.3 dB for 1-km propagation, and the cable cutoff wavelength was 1274–1336 nm, which are good enough for short-reach C-band transmissions but can be further improved by simply employing a trench-assisted index profile.

Though we have to confirm the fabrication repeatability of the fibre dimensions, the observed results showed a strong potential of the passive fibre alignment based on the concaved double-D shape cladding.

Tab. 1: Measured core positions of the fabricated MCF.

	x [μm]	y [μm]
#1	40.2–40.5	48.6–48.7
#2	80.0–80.7	48.5–48.9
#3	119.7–120.3	48.5–48.9
#4	159.8–160.2	48.7–48.8

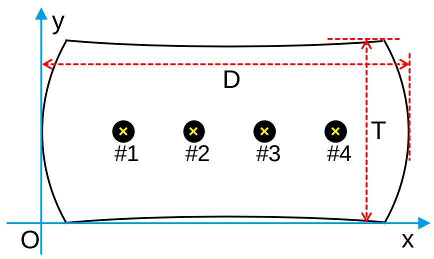

Fig. 7: Schematics of the local coordinates and the dimensions of the fibre cross section.

Conclusions

We developed a multi-core fibre with the concaved double-D shape cross section, which enables passive fibre alignment by 3-point contact between the fibre and an aligning groove. The concaved double-D shape fibre was able to be drawn from the simple double-D shape preform at the practical drawing speed of 150 m/min. The cladding dimensions were well controlled in both the longitudinal and transverse directions at a sub-micrometre order.

This research is supported in part by the National Institute of Information and Communications Technology (NICT), Japan.

References

[1] L. J. Cooper et al., “High-power Yb-doped multicore ribbon fiber laser,” Opt. Lett., Vol. **30**, no. 21, pp. 2906–2908 (2005).

[2] O. N. Egorova et al., “Multicore fiber with rectangular cross-section” Opt. Lett., Vol. **39**, no. 7, pp. 2168–2170 (2014).

[3] G. A. Mahdiraji et al., “Multicore Flat Fiber: A New Fabrication Technique,” Photon. Technol. Lett., Vol. **26**, pp. 1972–1974 (2014).