Asymmetrically Arranged 8-core Fibers with Center Core Suitable for Side-view Alignment in Datacenter Networks

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Abstract: Eight-core multicore fiber with the center core and a cladding diameter of 125 μm is designed and fabricated. Side-view alignment with core identification is realized owing to asymmetrically core arrangement for the first time. © 2020 The Author(s)
OCIS codes: (060.2270) Fiber characterization, (060.2280) Fiber design and fabrication

1. Introduction

The need for higher bandwidth and high-density optical wiring in datacenters has grown due to the drastic increase in traffic. When the range of transmission distance is over several hundred meters, single-mode fibers (SMFs) are replaced with multi-mode fibers in high bandwidth transmission. In addition to employing SMFs, several advanced transmission technologies have been proposed and commercially introduced. For intra-datacenters with a transmission distance of less than 2 km, intensity-modulation direct-detection in O-band is used owing to the low dispersion characteristics of SMFs around 1310 nm. Recently, PAM4 has been introduced for 200GbE and 400GbE transmission [1]. For high-bandwidth inter-datacenter networks with transmission distances of over several tens of kilometers, multi-level modulation such as QPSK utilizing coherent technology in C-band has been introduced. To further enhance the bandwidth from 400 Gbps to 800 Gbps or 1.6 Tbps, DP-64QAM or DP-256QAM may be used in the near future. Space-division multiplexing employing uncoupled single-mode multicore fibers (MCFs) is expected to increase the capacity of fibers in the telecommunication field, and is being actively developed. To further increase capacity in data center networks where cable space is limited, the use of densified optical parallel links with MCFs is a promising method. Several types of MCFs with a cladding diameter of a standard 125 μm have already been proposed for data-center networks. One is an eight-core MCF with one-ring structure with transmission range limited to only the O-band [2]. A heterogeneous five-core MCF with a center core and cladding diameter of 125 μm for O+C band transmission has also been developed [3]. Because splice and connector connection points exist in the current datacenter network, an easy alignment technology of MCFs would be necessary. However, there has not been much investigation about the core arrangement which makes alignment easy, especially from the perspective of side-view alignment.
In this study, we propose eight-core fibers with a center core and an asymmetrically core arrangement. The MCFs proposed have a cladding diameter of 125 μm and 160 μm for the O-band and O+C band transmission, respectively. The MCF with a cladding diameter of 125 μm has been fabricated and it has been experimentally confirmed that the MCF can be aligned by the side-view method with core identification.

2. Alignment

To make lower the connector loss, the core position error must be kept small. However, there must still be some amount of clearance between a ferrule and a fiber; therefore, some misalignment of an MCF inside a ferrule is possible. If an MCF has a center core, the fiber position alignment will follow the alignment scheme of SMFs in SMF connectors. There are mainly two methods for rotational alignment of MCFs, end-view and side-view alignments. The end-view alignment is realized by direct observation of the end-faces of MCFs [4]. If an MCF has a marker, which helps to recognize the core ID, we can align the MCFs precisely with core identification. Typically, this marker is made by

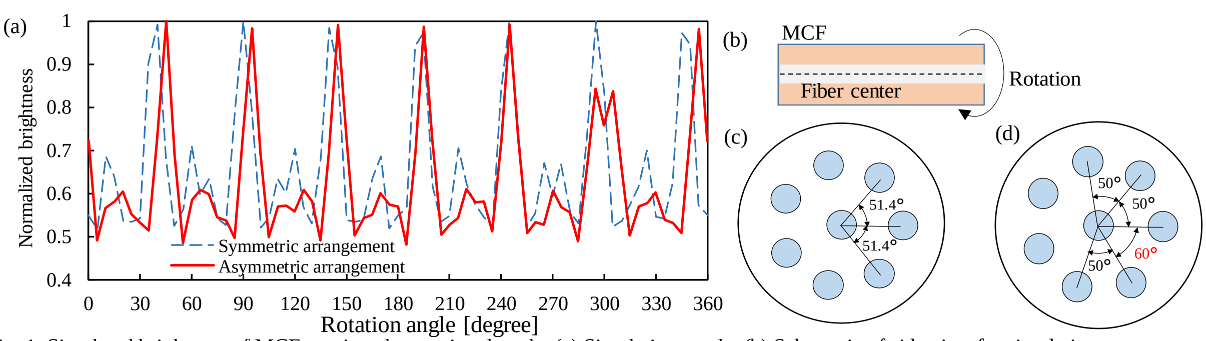

Fig. 1. Simulated brightness of MCFs against the rotational angle. (a) Simulation results (b) Schematic of side view for simulation (c) MCF with symmetric arrangement (d) MCF with asymmetric arrangement

inserting a high-index or low-index rod into a unique point in a cladding glass in addition to the core rods, which gives rise to a unique index contrast to the cladding. However, the end-view system is relatively complicated and a splicer with an end-view system cannot be used practically in the field. On the other hand, the side-view alignment has been developed to align conventional SMFs and does not require a complex observation system. The interrelationship profile alignment (IPA) method was proposed for the precise side-view alignment of PANDA fibers [5]. This method permits the simplification of the alignment of MCFs. However, the marker is hard to recognize from the side-view due to its small size and the position difference between the cores. Therefore, we investigated a core arrangement that facilities a side-view alignment utilizing the IPA method. The method uses the brightness at some points of the rotating fibers as shown in Fig. 1 (b). Figure 1 (a) shows the simulated brightness at the fiber center when an MCF is rotated 360°. Ray tracing was used for the simulation. MCFs used for the simulation are assumed to have a center core and seven outer cores in a one-ring-structure as shown in Figures 1 (c) and (d). One of them has a symmetrical core arrangement with each of the seven outer cores forming an equal angle with the center core of 360° / 7 = 51.4°. All core pitches between outer cores are same. The other has an asymmetrical core arrangement with angles of 50° and 60°. One of core pitches between outer cores is much wider than others. In the Fig. 1 (a), the brightness peaks appeared at the same interval and height in the case of a symmetrical arrangement. In contrast, in the case of the proposed asymmetrical arrangement, it can be seen that there is a unique point around 300°, providing a distinctive IPA profile.

3. Fiber design

Figure 2 shows a core profile and Table 1 summarizes the core parameters used for fiber design. The core has an index trench. From the perspective of suppressing crosstalk (XT), it is preferable to use deep Δ_2, however it requires a large amount of fluorine dopant in the fabrication process and it leads to increased fiber fabrication cost. We chose Δ_2 as a moderate trench depth of –0.4% that can be realized by small modifications of the equipment for manufacturing conventional SMFs. The MFD at 1310 nm and 22-m cutoff wavelength was set to be 8.2 μm and a value less than 1260 nm, respectively. The inner cladding radius r_2 was controlled for a zero-dispersion wavelength to be around 1315 nm. Those values satisfy ITU-T G.652 standards. We designed an eight-core MCF for transmission in the O-band within a 20-km distance. Figure 3 (a) shows the calculated core pitch dependence of total XT at a bending radius *R* of 500 mm and the excess loss of outer cores at *R* of 140 mm. This core-pitch is defined as the distance between the nearest cores assuming a core layout of Fig. 1 (d) and the cladding diameter was assumed to be 125 μm. The wavelength was 1310 nm. It is found that a core pitch of around 32 μm enables the total XT to be less than –50 dB/km and the outer cladding thickness (OCT) of 24 μm enables the excess loss to be less than 0.01 dB/km at 1310 nm simultaneously. We also designed an eight-core MCF for transmission within 100 km utilizing low-loss C-band transmission. Figure 3 (b) shows the same calculations at a wavelength of 1565 nm. To realize a DP-256QAM 100-km transmission, a low total XT of less than –36 dB/100km is required assuming a Q-penalty of 1.0 dB and BER of 10^{-3} [6]. It leads to a core pitch of larger than 44 μm. If we set the threshold excess loss as 0.01 dB/km, an OCT of 28 μm is required. Therefore, we can realize an eight-core fiber with a cladding diameter of 160 μm, which enables a coating diameter of 250 μm which is the same as that of conventional SMFs [7].

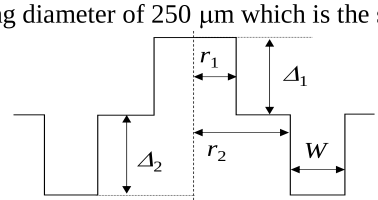

Fig. 2. Core profile used for the calculations.

Table 1. Core parameters.

Item	r_1	r_2 / r_1	W / r_1	Δ_1	Δ_2
Unit	μm	–	–	%	%
Value	3.7	2.3	1.5	0.38	–0.40

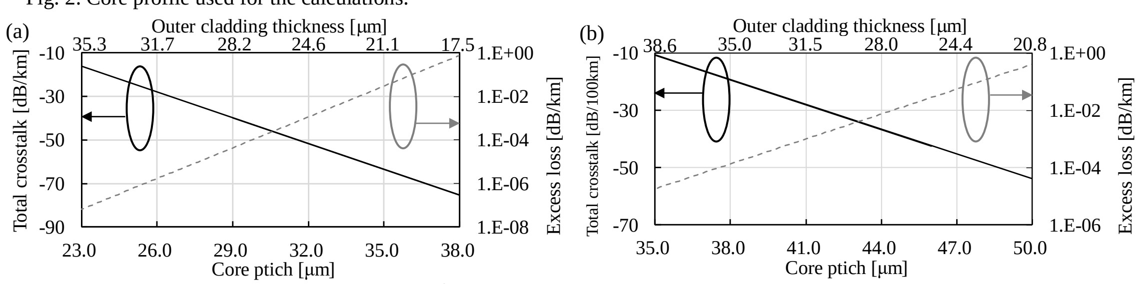

Fig. 3. Calculated core pitch dependence of total XT and the excess loss (a) at 1310 nm and (b) at 1565 nm.

4. Fabricated fiber

We fabricated an eight-core homogeneous MCF with a cladding diameter of 125 μm and having an asymmetrical core arrangement. Figure 4 shows a cross-section of the fiber with a core ID. Table 2 summarizes the measured optical characteristics of outer cores and the center core at 1310 nm. The core size of the center core was small. We believe this is due to the incomplete fabrication process and will be improved so that it possess the same optical characteristics of the outer cores. The measured cladding diameter was 124.5 μm. The averaged core pitch between the nearest cores (Λ) and OCT were 32.2 μm and 23.5 μm, respectively, which satisfied the target values. The distance between Core 1 and Core 7 was 40.3 μm, which was sufficiently larger than Λ. Figure 5 shows measured XT between the nearest outer cores in the O-band at R of 80 mm. The fiber length was 10.3 km. The measured XT at 1310 nm was less than −50 dB. Total XT after 1-km transmission is expected to be less than −50 dB, and the low XT characteristic of the fabricated MCF in the entire O-band was confirmed.

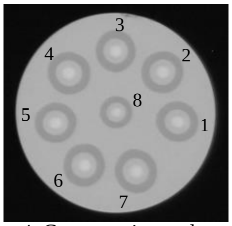

Fig. 4. Cross-section and core ID of the fabricated MCF.

Table 2. Measured optical characteristics.

Item	Unit	Outer	Center
MFD	μm	8.3	7.7
A_{eff}	μm^2	53.2	48.1
Cutoff wavelength	μm	1.23	1.10
Attenuation	dB/km	0.377	0.362
Zero-dispersion wavelength	nm	1315	1322

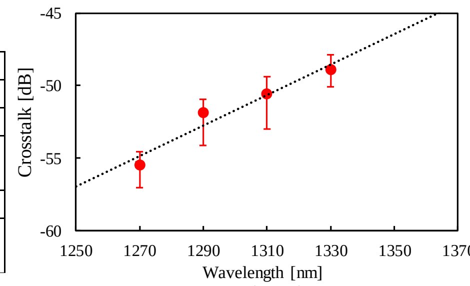

Fig. 5. Measured XT of the fabricated MCF.

5. Alignment experiment

We confirmed the side-view alignment concept described above by splicing the fabricated MCFs with IPA method employed in a splicer (FSM-100P+). Figure 6 (a) shows an example of measured IPA profiles obtained from the splicer under the condition that the same fabricated MCFs were set before alignment. It can be found that there are asymmetrical points in both the left and right side MCFs. Alignment is realized by rotation of both left side and right side MCFs such that their IPA profiles match as shown in Fig.6 (b). Figure 7 shows the measured splice loss distribution of Core 1 at 1310 nm. The averaged splice loss was 0.53 dB and distributed from 0.3 ~1.1 dB. This experiment was performed with an alignment angle step of 3°. The improved IPA method with the more precise alignment step will lead to low splice loss characteristics. However, we confirmed that side-view alignment with core identification was possible by using the fabricated MCF. The IPA method is not limited to the splice use. Also on an occasion of fabricating connectors, the fabricated MCF with the IPA method permits side view alignment including core ID information without the necessity to observe the end facets.

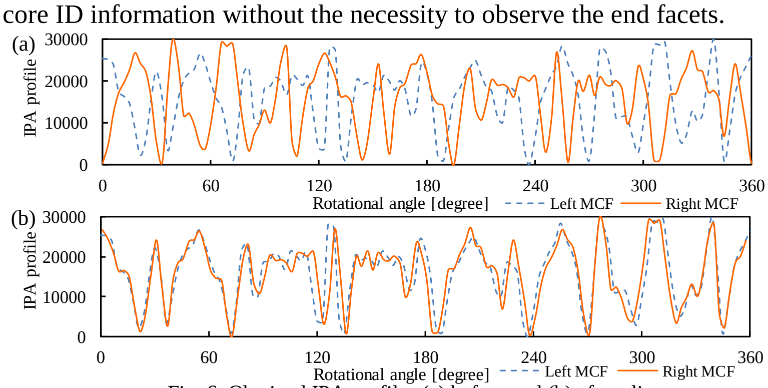

Fig. 6. Obtained IPA profiles (a) before and (b) after alignment.

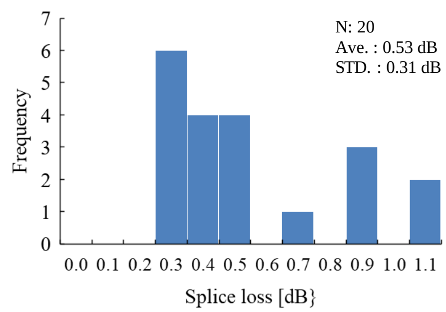

Fig. 7. Histogram of measured splice loss.

6. Conclusion

Our simulation has clarified that an asymmetrical design enabled the side-view alignment with the core identification. Based on this concept, we designed and fabricated an eight-core MCF with a cladding diameter of 125 μm. The XT was sufficiently small for the entire O-band transmission. The effectiveness of an asymmetrical core arrangement for side-view alignment with core identification was experimentally confirmed for the first time.

7. References

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