Bundle-type fan-in/fan-out device for 4-core multi-core fiber with high return loss

Kohei Ozaki*, Yoshifumi Koike, and Akito Nishimura
Optical Technologies R&D Center, Fujikura Ltd., 1440, Mutsuzaki, Sakura, Chiba, 285-8550, Japan
*E-mail address:*kohei.ozaki@jp.fujikura.com*

Abstract: We have developed a bundle-type fan-in/fan-out device that can achieve a high return loss by using a multi-core fiber/single-core fiber conversion component comprising a high-precision molded plastic ferrule. © 2022 The Author(s)

1. Introduction

Space division multiplexing using multi-core fiber (MCF) has been proposed in this study. A fan-in/fan-out (FI/FO) device is essential to incorporate an MCF system into existing optics based on the single-core fiber (SCF) system. A FI/FO device can be developed using several approaches [1]. Among those, a bundle-type FI/FO is considered to be one of the most promising methods due to the direct connection between SCF and MCF without any additional components [2]. Since the FI/FO device is an additional component for the network, it must have low insertion loss (IL) and high return loss (RL) to avoid affecting optical network performance as much as possible. High RL is particularly desired for optical components due to modulation scheme advancements such as pulse amplitude modulation 4 (PAM4) [3].

In this study, we fabricated a FI/FO device for a 4-core MCF (4c-MCF). The end faces of the interface between the MCF and fiber bundle parts were polished to the 8 degree to achieve high RL [4]. Since both the MCF and fiber bundle sides have angled end faces, rotationally aligning the cores in advance when assembling the MCF and bundle fibers into their ferrules is necessary. In particular, four SCFs of the bundle fibers are difficult to insert into the ferrule hole and to align rotationally because the outer diameter of the SCFs are thin and the flexural rigidity is approximately 1% of that for standard SCF. Therefore, we used a D-shape fiber hole of the ferrule for the bundle fibers to enable passive alignment for bundle fibers to be inserted. As a result, the RL more than 55 dB was obtained.

2. Structure of bundle-type FI/FO device

Figure 1 shows structure of the FI/FO device fabricated in this study. The ferrules for the MCF and fiber bundle are made of plastic via injection molding. A 4c-MCF with a cladding diameter of 125 μm was used for the same [5]. The four cores were arranged in a square lattice of pitch 40 μm. The MCF was then inserted into the round-holed ferrule and rotationally aligned as shown in Figure 2(a). Next, the fiber bundle was fabricated by inserting four bundle SCFs into the D-shaped ferrule hole, as shown in Fig. 2(b). The cladding diameter of the bundle SCFs was reduced from 125 μm to 40 μm via chemical etching to match the pitch between the cores in the MCF and four bundle fibers.

To achieve high RL, the end faces of the ferrule wherein the MCF and bundle fibers were inserted was angle polished to the 8 degree. The MCF cores were rotationally aligned using the camera view. Additionally, the bundle fibers were self-aligned using the D-shaped hole. The height and diameter of the D-shaped hole were designed to be approximately 88.3 μm and 96.6 μm, respectively, to fit four fibers in it. Fig. 2(c) shows the FI/FO device packaged in a plastic case. The package size was 6 mm × 6.3 mm × 66.4 mm.

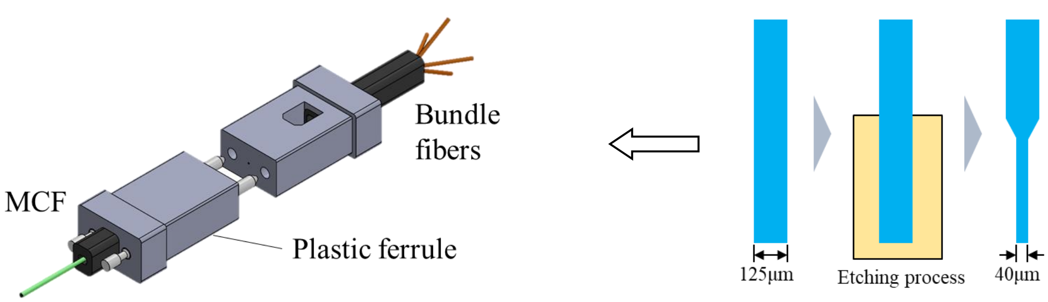
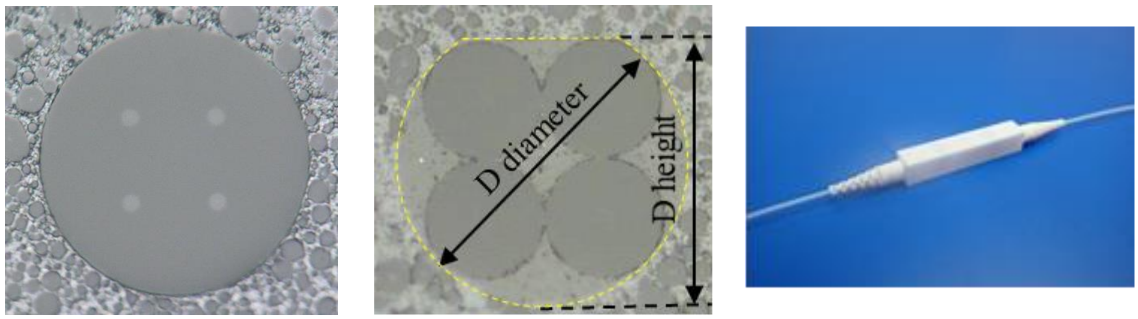


Fig. 1 Schematic diagram of bundle-type FI/FO device



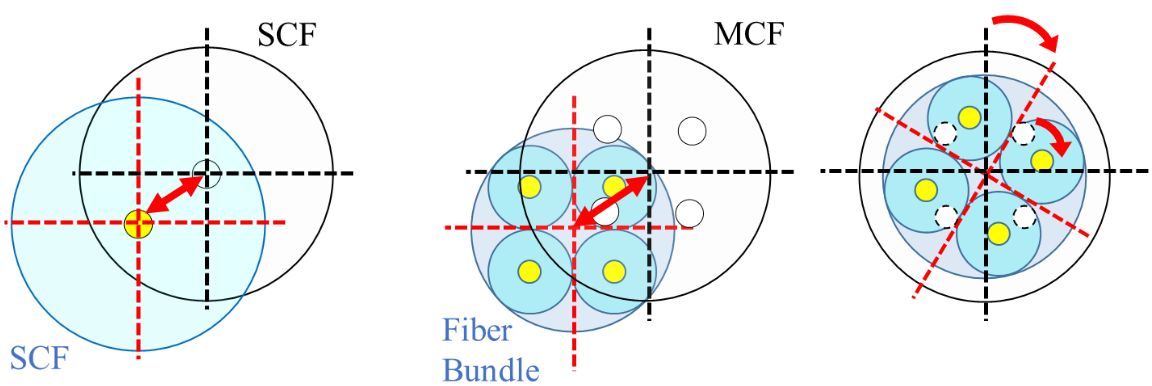
(a) MCF (b) Fiber bundle (c) Appearance of FI/FO device

Fig. 2 MCF and fiber bundle end-face and appearance of FI/FO device

3. Alignment of fiber bundle and D-shaped hole

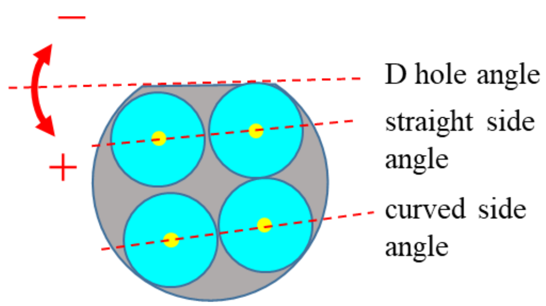
This section focus on the passive alignment mechanism of the fiber bundle and D-shaped hole. Generally, connection loss is primarily caused due to misalignment between the connected cores. As shown in Figure 3(a), for an SCF, the misalignment is determined by the amount of positional shift between the two fibers. Conversely, when connecting an MCF with the fiber bundle, as shown in Fig. 3(b), not only positional but also rotational angle shift is a cause of misalignment. Therefore, rotational angle misalignment must be minimized to achieve low loss.

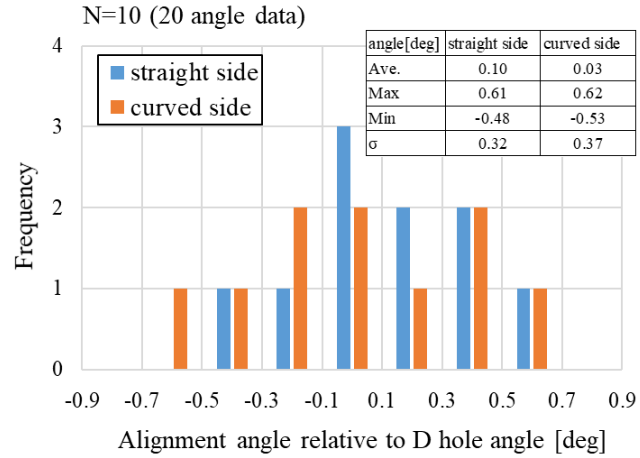
The angular accuracy of the fiber bundle with respect to the D-shaped hole was evaluated. The alignment schematic and results are shown in Figure 4. We measured the angle between each line connecting the two horizontally aligned SCFs and the straight portion of the D-shaped hole, hereinafter denoted as the D hole angle, as shown in Fig. 4(a). Fig. 4(b) shows the histograms of the relative angle for 10 samples, for the straight and curved sides, respectively. The alignment accuracy is approximately within ±0.6 degree. This is equivalent to ±0.3 μm in terms of core misalignment.



(a) Positional shift (b) Positional and rotational angle shift

Fig. 3 Schematic diagram of core misalignment for (a) an SCF and (b) bundle-type FI/FO device





(a) Fiber bundle alignment by D-shaped hole (b) Histogram of alignment angle relative to D hole angle

Fig. 4 Schematic diagram of the D-shaped hole fiber bundle arrangement and angular accuracy of fiber bundle

4. Optical characteristics of fabricated FI/FO device

The IL and RL of the 10 fabricated FI/FO devices were measured at 1310 nm and 1550 nm, respectively. Figure 5 shows the IL measurement results, which were 0.35 dB/device at 1310 nm and 0.30 dB/device at 1550 nm on average. Figure 6 shows the RL measurement results. A high RL of over 70 dB was obtained for all samples.

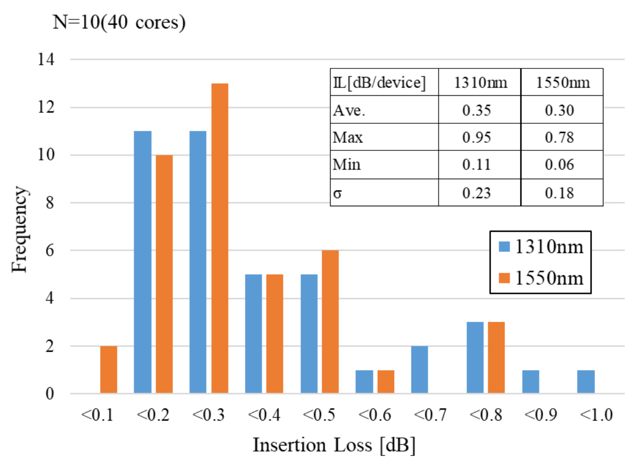


Fig. 5 Insertion loss of 10 FI/FO devices

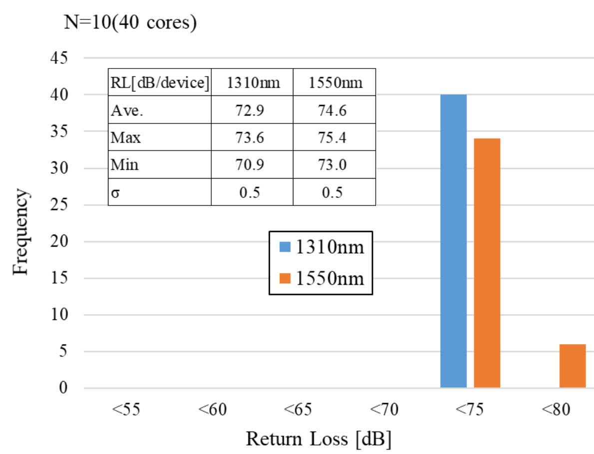


Fig. 6 Return loss of 10 FI/FO devices

5. Summary

Bundle-type FI/FO devices with passive alignment design and high return loss were developed. The fiber bundle was passively aligned using a D-shaped hole with good alignment angle accuracy of approximately ±0.6 degree. An average IL of 0.35 dB/device at 1310 nm and 0.30 dB/device at 1550 nm was achieved, and a high RL of over 70 dB was achieved using angled polished end faces.

3. References

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