Fiber Bundle Fan-in/Fan-out (FIFO) for Coupled MCF with High-Δ 4-Core Fiber Pitch Converter

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Abstract: Low-loss fiber bundle FIFO with stretched high-Δ 4-core fiber pitch converter is developed. Core pitch and insertion loss of the FIFO are reduced to 18.4 μm and 0.84 dB including splice loss to CC-MCF.

1. Introduction

Space division multiplexing (SDM) transmission technology is attracting attention to realize large capacity optical communication systems [1]. Large-capacity transmission technology using coupled MCFs (CC-MCFs) with standard cladding diameters has been reported [2]. To apply MCFs into practical applications, fan-in fan-out (FIFO) is required to couple each core of MCFs and standard single-mode fibers (SMFs). We have been developing a low-loss, compact fiber bundle FIFO (FB-FIFO) using pitch conversion fiber [3] for CC-MCFs. In this result, low-loss FIFO with a core pitch of 20 μm was realized using the FB-FIFO and the pitch conversion fiber, however a connectivity with the CC-MCF for a transmission line and a package size of the FIFO were not considered.

In this report, we developed a 4-core FB-FIFO for a CC-MCF using a pitch conversion fiber. As a result, we fabricated a FIFO with a core pitch of 18.4 μm successfully. Insertion loss of this FIFO, including the splice loss to the CC-MCF, was reduced to 0.84 dB per core. The FIFO is packaged into one 3.0 x 3.5 x 45 mm metallic package and two Φ1.3 x 25 mm sleeves.

2. Design of 20 μm pitch FIFO

It is difficult to fabricate 20 μm pitch FB-FIFO for CC-MCF due to fabrication process constraints. Therefore, as shown in the previous report [3], we designed narrow pitch CC-MCF FIFO comprised of 30 μm pitch FB-FIFO and stretched high-Δ MCF (HΔ-MCF) pitch conversion fiber. Figure 1 shows the configuration of narrow pitch FIFO. The advantage of this design is that a low-loss pitch-conversion fiber was realized by stretched HΔ-MCF. When fabricating a pitch conversion fiber by stretching HΔ-MCF, not only the core pitch but also the core diameter changes depending on the ratio of the fiber diameters before and after stretching. Figure 2 shows the relationship between a core diameter and a bending loss at a wavelength of 1550 nm for a fiber equivalent to SMF. When converting a core pitch from 30 μm to 20 μm, if the core diameter before stretching is 9 μm, the core diameter after stretching will be 6 μm. When the core diameter changes from 9 μm to 6 μm, the bending loss increases from about 8×10^{-6} dB/m to about 15 dB/m. To solve this problem, all fiber based FIFO using vanishing-core bridge fiber (VCBF) has been reported [4]. When VCBF is used, the problem is that the core structure becomes complicated and excessive loss is likely to occur before and after stretching. As shown in the previous report [3], a four-core HΔ-MCF with a high-Δ core with W-shaped refractive index profile was used for the pitch conversion fiber. This core has a higher refractive index difference Δ between the core and the cladding than SMF, so it has strong resistance against fiber bending. This characteristic makes it possible to achieve lower bending loss than SMF even when the core diameter becomes small after stretching and succeeded in suppressing excess loss in the pitch conversion fiber to less than 0.05 dB. Since the MFD of the HΔ-MCF is about 4.5 μm at a wavelength of 1550 nm, a large MFD mismatch loss will occur when coupling with the FB-FIFO that has an MFD of about 10 μm. To avoid MFD mismatch loss, as shown in Figure 1, Thermally diffused Expanded Core (TEC) technique to expand the MFD is applied to the A side of the HΔ-MCF. By optimizing the W-shaped refractive index profile, excess loss at the TEC part is suppressed to less 0.05 dB. CC-MCF for a transmission line needs to be spliced to the B side of HΔ-MCF. To reduce MFD mismatch loss with the CC-MCF, TEC processing was applied on the B side, resulting a large excess loss. To investigate the cause of this excessive loss, refractive index profile of the HΔ-MCF on A side and B side were observed. Figure 3 shows the schematic image of the refractive index profile of the HΔ-MCF and SMF.

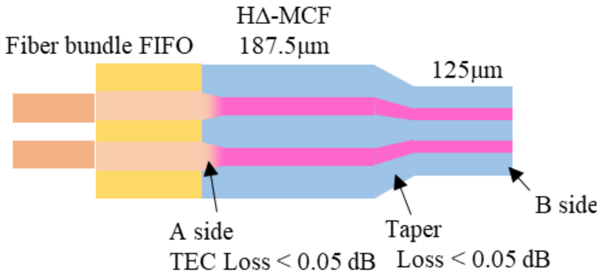

Fig. 1 Structure of narrow pitch FIFO

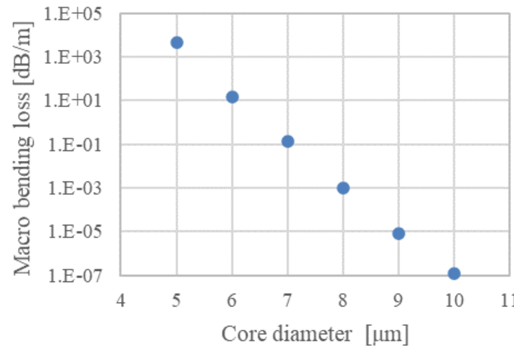

Fig. 2 Macro bending loss for various core diameter of SMF

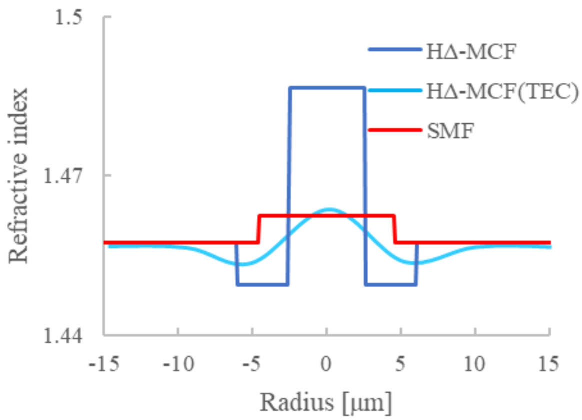

Fig. 3(a) Refractive index profile of HΔ-MCF

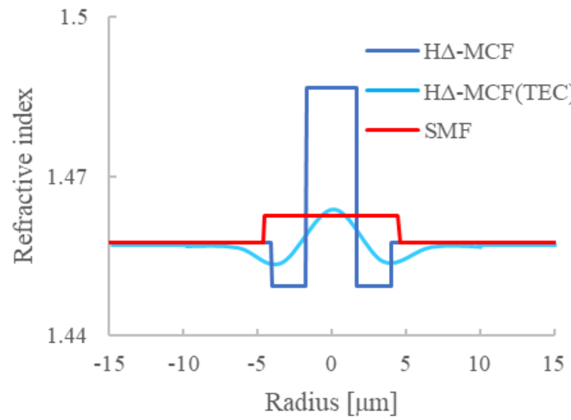

Fig. 3(b) Refractive index profile of HΔ-MCF after stretching.

The core diameter on the B side is smaller than that on the A side. By using HΔ-MCF, almost no excess loss was observed even if the core diameter became small on the B side because of the strong light confinement of the HΔ-core. However, after TEC, the core Δ decreases to the same level as SMF. As the result, excessive loss occurred by the effect of the small core diameter. To solve this problem, a HΔ-MCF which has the same core as the HΔ-MCF before stretching with a cladding diameter of 125 μm and a core pitch of 20 μm, was spliced to the B side. Since 125 μm HΔ-MCF has the same MFD to stretched HΔ-MCF on the B side, MFD mismatch loss on the B side was suppressed. Opposite side of the splice point to the B side is processed with TEC in the same way as the A side to reduce MFD mismatch loss to the CC-MCF. As the result, low-loss splice between HΔ-MCF and CC-MCF was performed.

3. Characteristics of fabricated narrow pitch FIFO

Table 1 shows the characteristics of the fabricated HΔ-MCF. In this study, a 125 μm HΔ-MCF with a core design equivalent to the 187.5 μm HΔ-MCF before stretching and a core pitch after stretching was newly designed and fabricated.

Table 1. Characteristics of fabricated HΔ-MCF

		Cladding diameter	Core pitch	MFD
187.5 μm HΔ-MCF	Before stretching	187.5 μm	29.2 μm	4.5 μm
	After stretching	124.9 μm	18.3 μm	4.6 μm
125 μm HΔ-MCF		124.9 μm	18.4 μm	4.6 μm

Narrow pitch FIFO for CC-MCF was fabricated using these MCFs. First, a 30 μm pitch FB-FIFO was fabricated. Next, 30 μm pitch FB-FIFO was coupled to the 187.5 μm HΔ-MCF. Since the MFD of the HΔ-MCF at a wavelength of 1550 nm was 4.5 μm, the MFD of the 187.5 μm HΔ-FIFO was adjusted to the MFD of the FB-FIFO by TEC processing to reduce the MFD mismatch loss between the FB-FIFO and the HΔ-MCF. As a result, the insertion loss of the FIFO including the coupling loss between the FB-FIFO and the 187.5 μm HΔ-MCF was reduced to 0.28 dB. After coupling to the FB-FIFO, the HΔ-MCF was stretched to a cladding diameter of 125 μm. The core pitch and the MFD after stretching were 18.3 μm and 4.6 μm, respectively. The 125 μm HΔ-MCF with a core pitch of 18.4 μm, and an MFD of 4.6 μm was spliced to the stretched HΔ-MCF. The other side of the 125 μm HΔ-MCF was subjected to TEC processing to expand the MFD to 10.4 μm. By fusion splicing TEC-processed 125 μm HΔ-MCF and the CC-MCF with cladding diameter of 125 μm and core pitch of 19.2 μm, we achieved a narrow pitch FIFO for CC-MCF. Splice loss between 125 μm HΔ-MCF and the CC-MCF is 0.26 dB. Total insertion loss of the narrow pitch FIFO was successfully reduced to 0.84 dB per core. As shown in figure 4, fabricated FIFO is packaged into one 3.0 x 3.5 x 45 mm metallic package and two Φ1.3 x 25 mm sleeves.

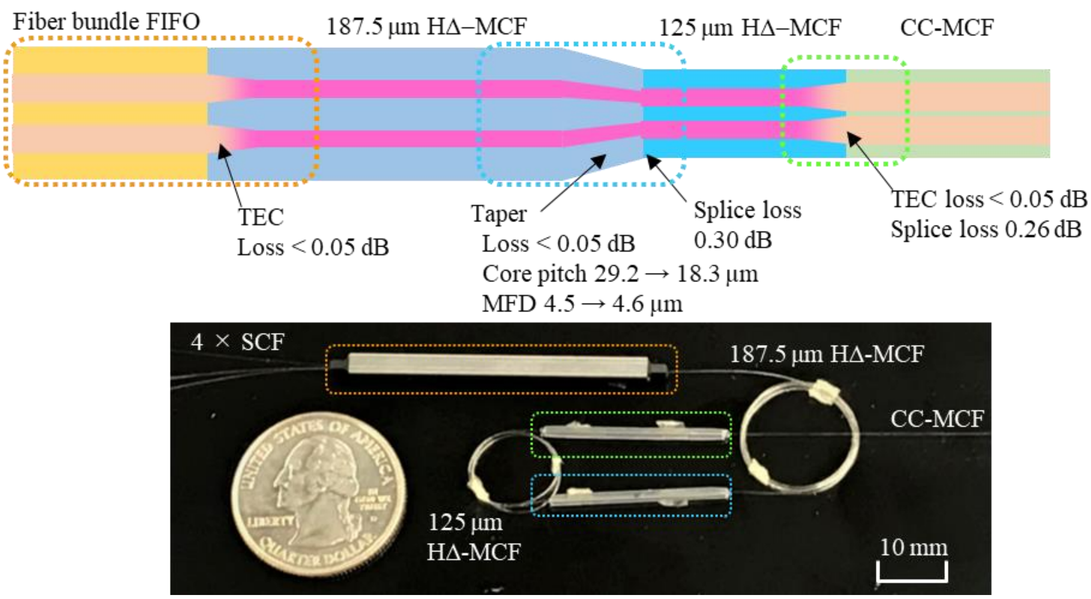

Fig. 4 Structure of narrow pitch FIFO

4. Conclusion

By combining a FB-FIFO and a pitch conversion fiber using HΔ-MCF, we have achieved a narrow pitch FIFO for CC-MCF with a core pitch of 18.4μm. The insertion loss of the FIFO is 0.84 dB per core, realizing a low-loss FIFO for CC-MCF. The FIFO is packaged into one 3.0 x 3.5 x 45 mm metallic package and two Φ1.3 x 25 mm sleeves, allowing FIFO to be stored in a small package.

5. Acknowledgement

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6. References

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