4-Core Fiber Narrow Pitch Fanout Comprised of Tapered High-Δ MCF

Masanori Takahashi, Tsubasa Sasaki, Ryuichi Sugizaki, and Yoshihiro Arashitani
Furukawa Electric Co., Ltd.
6, Yawata-kaigandori, Ichihara, Chiba 290-8555, Japan
takahashi.masanori@furukawaelectric.com

Abstract: Narrow pitch all fiber base fanout comprised of fiber bundle fanout and high-Δ 4-core fiber is developed. Core pitch and insertion loss of the fanout are reduced to 19.4 μm and 0.6 dB, respectively. © 2022 The Author(s)

1. Introduction

In recent years, against the background of various cloud services and enhancement of online contents, internet traffic is steadily increasing, and optical communication system is also required to have a further large capacity. However, it has been suggested that the expansion of transmission capacity is approaching to theoretical limit in transmission systems using conventional single-mode fibers (SMF). Space division multiplexing (SDM) transmission technology is attracting attention as a technology to overcome this limit [1]. Development of multicore fiber (MCF) is underway as a fiber for SDM transmission system, and the results of large-capacity transmission experiments using various MCFs have been reported [2]. Especially, MCFs with standard cladding diameter [3, 4] are developed for practical use of MCF. To use MCF for practical applications, fan-in fan-out (FIFO) to connect MCF and SMF is required, and various FIFO have been reported. These FIFOs are roughly classified into fiber type [5-10], waveguide type [11, 12], and free space optics type [13, 14]. Among these FIFOs, the fiber bundle type FIFO (FB-FIFO) [5-7], which is classified as a fiber type, has advantages in terms of low loss, low polarization dependent loss, high reliability, and good connectivity with SMF. On the other hand, FB-FIFO has difficulties in connection with coupled MCF (CC-MCF) which has small core pitch [15].

In this paper, narrow core pitch converter is investigated. We succeeded in reducing core pitch to 19.4 μm by using a high-Δ 4-core (HΔ-4CF) fiber and FB-FIFO with a core pitch of 30 μm. Core pitch of FB-FIFO is converted from 30 μm to 19.4 μm by HΔ-4CF applying fused taper technology [16]. Excess loss of HΔ-4CF based pitch converter is less than 0.05 dB, and insertion loss of the narrow pitch fanout is less than 0.6 dB.

2. Design of narrow pitch FIFO with High-Δ 4-Core Fiber pitch converter

A FB-FIFO consists thin cladding fibers with the same cladding diameter as the core pitch of the MCF. Thin cladding fibers are inserted into a capillary and thin cladding fibers are aligned to square lattice structure by controlling inner diameter of the capillary. Therefore, if the core pitch of the MCF becomes small, the cladding diameter of the thin cladding fibers also becomes small. Considering the productivity when bundling thin cladding fibers and inserting them into the capillary, the lower limit of the cladding diameter of the thin cladding fiber is 30 μm.

Therefore, in order to apply FB-FIFO to CC-MCF with a core pitch of 20 μm or less, a core pitch conversion device is necessary. A HΔ–4CF having a refractive index profile shown in Fig. 1 was used for the core pitch conversion device. Cladding diameter and core pitch of the HΔ-4CF were set to 187.5 μm and 30 μm, respectively. Core pitch of HΔ-4CF was converted from 30 μm to 20 μm by stretching HΔ-4CF from 187.5 μm to 125 μm with fused taper technology. Figure 2 shows the calculated mode-field diameter (MFD) at wavelength of 1550 nm related to core diameter. Since core diameter of the HΔ-4CF was set to 5 μm when the clad diameter is 187.5 μm, core diameter became 3.3 μm when the HΔ-4CF was stretched to 125 μm. The MFDs before and after stretching were 4.2 μm and 4.0 μm, respectively. By optimizing the design of the HΔ-4CF, the MFDs before and after stretching were controlled to become the same, and the design also allows single-mode propagation before and after stretching. When SMF is used for this application, as the core diameter becomes smaller, the cutoff wavelength shifts to the shorter wavelength side, increasing bending loss. The same effect can be seen also in HΔ fiber, however, since HΔ fiber has inherently very strong resistance to bending, it can be used even if the cutoff wavelength is shifted to the short wavelength side. FB-FIFO with core pitch of 30 μm was attached to HΔ-4CF before stretching. Since the MFD of the thin cladding fibers used for FB-FIFO is around 10 μm, which is the same MFD as SMF, the MFD of HΔ-4CF was expanded to 10 μm at the connection point with FB-FIFO by thermally expanded core (TEC) technology.

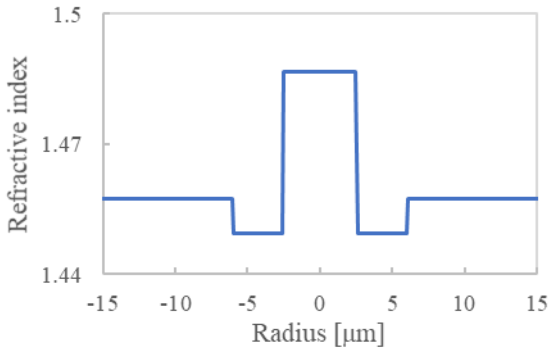

Fig. 1 Refractive index of HΔ-4CF

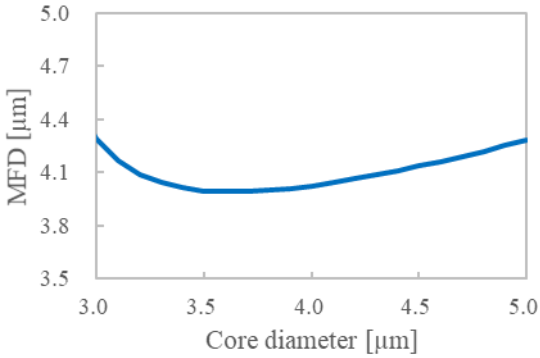

Fig.2 Calculated MFD of HΔ-4CF

3. Fabrication of Narrow Pitch FIFO

Table 1 shows characteristics of fabricated HΔ-4CF. A narrow pitch all fiber base 4-core fanout was fabricated by using FB-FIFO with core pitch of 30 μm and HΔ-4CF. Core pitch of the HD-4CF with cladding diameter of 187.5 μm was 29.2 μm. FB-FIFO with 30 μm core pitch is attached to this fiber with low core misalignment. HΔ-4CF was stretched to 125 μm by fused taper technology, and core pitch was converted to 19.4 μm. The MFD before and after stretching were 4.5 μm and 4.4 μm, respectively. Excess loss of HΔ-4CF pitch conversion fiber was less than 0.05 dB. Fig. 3 shows a configuration of a narrow pitch conversion device. FB-FIFO was attached to HΔ-4CF. For the FB-FIFO, 80 μm cladding fiber with MFD of 10 μm at wavelength of 1550 nm was used. 80 μm fiber was chemically etched to 30 μm and four etched thin cladding fibers were bundled, inserted into a glass capillary, and fixed with an UV adhesive to fabricate a 30 μm pitch four-core fan-out with square-lattice structure. Since the MFD at the HΔ-4CF was 4.5 μm (@1550 nm), the MFD was expanded to 10 μm by TEC technique at the fiber end face. MFD mismatch loss at the connecting point between fanout and HΔ-4CF were reduced. SC connectors were attached to 80 mm fiber used for FB-FIFO on the opposite side of the bundle. Average insertion loss of the narrow pitch conversion device, which consists of the fanout and a tapered HΔ-4CF, was less than 0.6 dB, and a low loss narrow pitch fanout was realized.

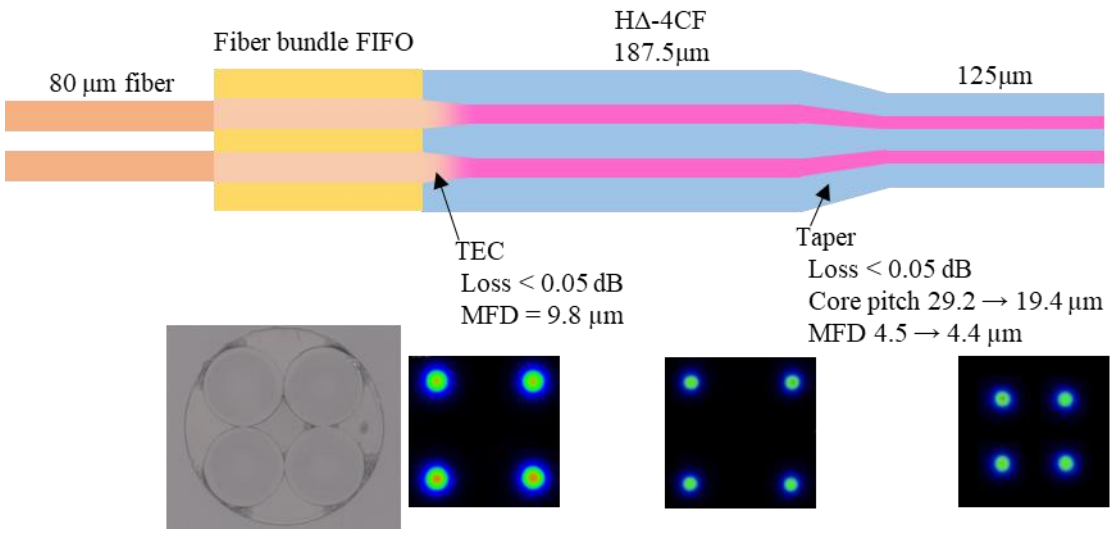

Fig.3 Configuration of the narrow pitch FIFO device

Table 1. Characteristics of High-Δ 4-Core Fiber

	Cladding diameter	Core pitch	MFD	TEC loss	Taper loss
Before stretching	187.5 μm	29.2 μm	4.5 μm	< 0.05 dB	-
After stretching	125.1 μm	19.4 μm	4.4 μm	-	< 0.05 dB

4. Conclusion

We have developed 19.4 μm pitch all fiber base fanout. HΔ-4CF with a cladding diameter of 187.5 μm and a core pitch of 29.2 μm was stretched to 125.1 μm, and core pitch was converted to 19.4 μm without changing MFD. Excess loss of HΔ-4CF pitch converter was less than 0.05 dB. A narrow pitch fanout with core pitch of 19.4 μm was realized by connecting a fiber bundle fanout to the HΔ-4CF pitch converter. Average insertion loss of the narrow pitch fanout was less than 0.6 dB, and all fiber based narrow pitch fanout is realized.

5. Acknowledgements

These research results were supported in part from the commissioned research (No.01001) by National Institute of Information and Communications Technology (NICT), Japan under “Research and Development of Spatial-Mode-Controllable Optical Transmission System”.

6. References

[1] P. J. Winzer, D. T. Neilson, A. R. Chraplyvy, “Fiber-optic transmission and networking: the previous 20 and the next 20 years,” Optics Express Vol. 26, No. 18, pp. 24190-24239 (2018).
[2] K. Nakajima, T. Matsui, K. Saito, T. Sakamoto, and N. Araki, “Multi-Core Fiber Technology: Next Generation Optical Communication Strategy,” IEEE Communications Standards Magzaine, Vol. 1, No. 3, pp. 38-45 (2017)
[3] T. Matsui, Y. Yamada, Y. Sagae, and K. Nakajima, “Standard cladding diameter multi-core fiber technology,” The Optical Networking and Communication Conference & Exhibition (OFC2021), San Diego (USA), Mar. 2021, Tu6B.4.
[4] T. Gonda, K. Imamura, M. Tsukamoto, K. Kawasaki, S. Arai, R. Sugizaki, S. Beppu, D. Soma, H. Takashi, and T. Tsuritani, “Design of multicore fiber having upgradability from standard single-mode fibers and its application,” IEEE Journal of Lightwave Technology, Vol. 37, No. 2, pp. 396-403, 2019.
[5] K. Kawasaki, T. Sugimori, K. Watanabe, T. Saito, R. Sugizaki, “Four-fiber Fan-out for MCF with Square Lattice Structure,” The Optical Networking and Communication Conference & Exhibition (OFC2017), San Diego (USA), Mar. 2017, W3H.4.
[6] K. Watanabe, T. Saito, K. Imamura, M. Shiino, “Development of Fiber Bundle Type Fan-out for Multicore Fiber,” Proc. Of 17th Opto-Electronics and Communications Conference (OECC2012), Busan (Korea), July. 2012, 5C1-2.
[7] K. Watanabe, and T. Saito, “Compact Fan-Out for 19-core Multicore Fiber, with High Manufacturability and Good Optical Properties,” Proc. Of 20th Opto-Electronics and Communications Conference (OECC2015), Shanghai (China), July. 2015, PWe.31.
[8] Y. Abe, K. Shikama, H. Ono, S. Yanagi, and T. Takahashi, “Fan-in/fan-out device employing v-groove substrate for multicore fibre,” Electronics Lett., Vol. 51, No. 17, pp. 1347-1348, August 2015.
[9] L. Gan, J. Zhou, L. Shen, X. Guo, Y. Wang, C. Yang, W. Tong, L. Xia, S. Fu, M. Tang, and D. Liu, “Ultra-Low Crosstalk Fused Taper Type Fan-in/Fan-out Devices for Multicore Fibers,” The Optical Networking and Communication Conference & Exhibition (OFC2019), San Diego (USA), Mar. 2019, Th3D.3.
[10] https://www.optoscribe.com/media/1105/508053-optoscribe-3d-optofan-data-sheet-v6-screen.pdf
[11] T. Watanabe, M. Hikita, and Y. Kokubun, “Laminated polymer waveguide fan-out device for uncoupled multi-core fibers,” Optics Express, Vol. 20, No. 24, pp. 26317-26325, September 2012.
[12] Y. Ding, F. Ye, C. Peucheret, H. Ou, Y. Miyamoto, and T. Morioka, “On-chip Grating Coupler Array on the SOI Platform for Fan-in/Fan-out f Multi-core Fibers with Low Insertion Loss and Crosstalk,” Proc. Of 40th European Conference and Exhibition on Optical Communications (ECOC2014), Cannes (France), Sep. 2014, We.1.1.3.
[13] H. Arao, O. Shimakawa, M. Harumoto, T. Sano, and A. Inoue, “Compact Multi-core Fiber Fan-in/out Using GRIN Lens and Microlens Array,” Proc. Of 19th Opto-Electronics and Communications Conference (OECC2014), Melbourne (Australia), July. 2014, Mo1.E1.
[14] T. Takahata, A. Kaya, Y. Ozawa, Y. Minagawa, and T. Kobayashi, “High Reliability Fan-in / Fan-out Device with Isolator for Multi-core fibre Based on Free Space Optics,” The Optical Networking and Communication Conference & Exhibition (OFC2021), San Diego (USA), Mar. 2021, We1A.5.0.
[15] T. Hayashi, Y. Tamura, T. Hasegawa, and T. Taru, “125-μm-cladding Coupled Multi-core Fiber with Ultra-low Loss of 0.158 dB/km and Record-low Spatial Mode Dispersion of 6.1 ps/km$^{1/2}$,” The Optical Networking and Communication Conference & Exhibition (OFC2016), Anaheim (USA), Mar. 2016, Th5A.1.
[16] K. Jedrzejewdki, “Biconical fused taper – a universal fibre devices technology,” Opto-Electronics Review, Vol. 8, No. 2, pp. 153-159 (2000).