Ultra-High-Density MCF Connector Technology

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Abstract: This talk will present our single-/multi-fiber multi-core fiber (MCF) connectors with the insertion loss of less than 1 dB and physical contact achieved by rotational fiber alignment mechanism and MCF-optimized end face polishing method, respectively.
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1. Introduction

High bandwidth (BW) optical interconnects, such as 100G MSA transceivers [1,2], are being rapidly deployed in large-scale data centers for improving the BW density on switch front panels. The BW density can be further improved by replacing pluggable transceivers with on-board optics [3], and ASIC integrated optics are being intensively studied. In on-board optics configurations, optical connectors are equipped on switch front panels instead of pluggable transceivers, and the total channel number of the optical connectors is a limiting factor for achievable BW per front panel. In addition, Si-photonics is widely used for short reach transceivers today and this technology is expected as a strong candidate for enabling ASIC integrated optics which are expected to support more than 100-channel optical I/O interfaces per switch to meet the future demand of the switching BW [4]. In order to address these future requirements for the high channel count optical connectivity, multi-core fibers (MCFs) can play an important role, since it offers a large scalability of the channel count. However, since the MCF has outer cores located in non-center part of the cladding, there are two major challenges for realizing MCF optical connectors, which are 1) rotational fiber alignment for low insertion loss (IL) and 2) suppression of mating force for physical-contact (PC) for achieving low reflection.

In this report, we present our recent work on high density optical connectors with MCFs, which overcomes the above mentioned challenges. Especially, we report our single-MCF connectors such as SC/MU/LC type connectors with low IL of less than 0.5 dB, and review multi-MCF connectors, such as MT/MPO type connectors with the MCF-optimized polishing technique for achieving PC [5].

2. Single MCF Connector

To realize an IL less than 0.5 dB in a single-MCF connector, the rotational misalignment less than ±1 degree and ferrule floating structure have to be simultaneously realized. Table 1 shows our design approaches for suppressing rotational misalignment for SC and MU/LC type single connectors. The conventional SC connector have clearance between flange and plug frame and this results in ±3 degree rotational misalignment at most. We optimized the clearance while keeping ferrule floating structure, thus rotational misalignment become less than ±0.5 degrees. On the other hand, the conventional MU/LC connector dimensions have a larger misalignment of ±10 degree at most, because MU/LC's flange outer diameter is about two-third of SC's, and the clearance causes larger rotational misalignment. Suppressing the misalignment by clearance optimization cannot achieve ferrule floating structure, therefore we employed an Oldham coupling mechanism to MU/LC connectors [6], as shown in Fig. 1. The Oldham structure enables the vertical and horizontal floating movement of ferrules with less than ±0.5 degree misalignment.

The PC is achieved by the deformation of fiber end faces caused by compressive force. Hence, the shape of the connector end face is important. If an MCF connector end face is polished in spherical shape as well as the conventional single-core fiber connectors, the glass deformation required to achieve the PC of outer cores becomes very large, and very high mating force would be necessary. To reduce the mating force to the IEC standard—7.8 to

Table 1. Rotational misalignment suppression between a flange and plug frame.

	Conventional	Our work
SC	±3° Plug frame Flange	±0.5° Clearance Clearance optimization
MU/LC	±10° Plug frame Flange	±0.5° Oldham coupling

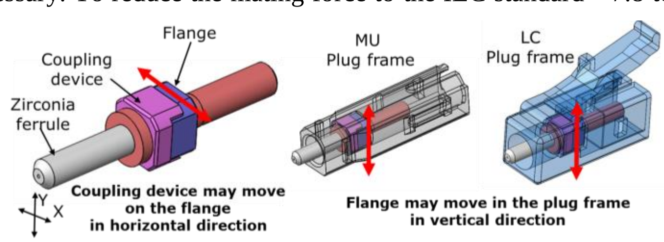

Fig. 1. Oldham coupling mechanism in MU/LC connectors.

12.8 N (SC type) or 5 to 6 N (MU/LC type), we numerically investigated the PC conditions for the 150-µm-cladding 7-core fiber with 45-µm core pitch [7] using a finite element method (FEM). In this calculation, we modeled the ferrule end shape with the following parameters: fiber withdrawal *U*, mating force *F*, curvature radius *R*, apex offset of MCF end faces *d*, as shown in Fig. 2. We assumed that the parameters basically take the typical values in the standard SMF connectors, and investigated the requirements on *R* and *d*. The results are summarized in Table 2.

We fabricated SC/MU/LC type MCF connector using the 7-core fiber. To realize the above conditions for PC, we optimized the ferrule polishing conditions, and achieved flatten connector end face and small apex offset. Connector spring force were the same as the IEC standard. Figure 3 shows the IL measured at the wavelength (λ) of 1.55 µm. Thanks to the reduced rotational misalignment realized by the clearance optimization and/or the Oldham coupling mechanism, we achieved the low ILs of less than 0.5 dB even in outer cores of all connectors. We also confirmed that the return losses were less than −40dB, and PC was achieved in all cores.

Using this single-MCF connector technology, the end-to-end MCF transmission link with silicon photonics transceiver natively supporting an 8-core fiber was demonstrated, where we used one MCF LC connector pair to connect 8 cores at once, instead of multi-SMF connectors such as Q8MPO [8].

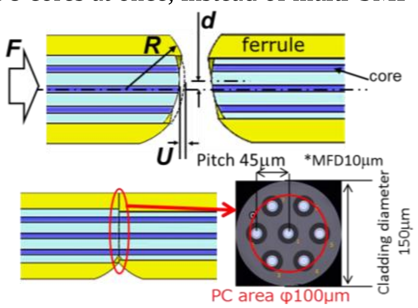

Fig. 2. Parameters relating to the single-MCF ferrule shape.

Table 2. Calculated PC conditions for the 7-core fiber and the standard SMF.

Parameter	SC		MU/LC	
	MCF	SSMF	MCF	SSMF
Fiber withdrawal *U*	≤ 0.05 µm		≤ 0.05 µm	
Mating force *F*	7.8 to 12.8 N		5 to 6 N	
Curvature radius *R*	10 to 25 mm		> 20 mm	7 to 25 mm
Apex offset *d*	< 25 µm	< 70 µm	< 15 µm	< 70 µm

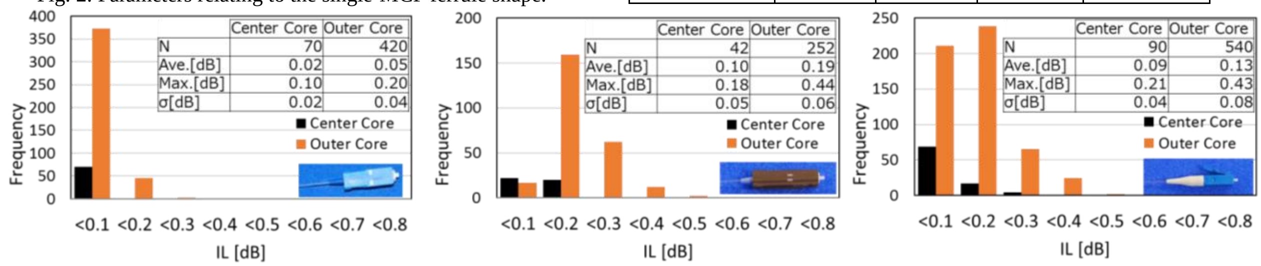

Fig. 3. Insertion loss histograms of (a) SC connector, (b) MU connector, and (c) LC connector.

3. Multi-MCF connector

Multi-MCF connectors have a strong potential for increasing spatial channel density. However, it is challenging to realize simultaneous precise rotational alignment of multiple MCFs in a standard MT ferrule. In earlier studies, MCFs were rotationally aligned and fixed to “alignment members” separated from a MT ferrule one by one [9]. In addition, the MCF cladding diameter was larger than the standard 125 µm, and thus the fiber pitch in the MT ferrule was larger than the standard pitch of 250 µm. In our study, we aligned 125-µm-cladding MCFs on a common V-groove, as shown in Fig. 4. The V-groove dimensions were designed to fit into the standard MT ferrule. The fiber pitch on the MT-insertable array is 250 µm and compatible to the hole pitch of the conventional MT ferrules. Because only V-groove is an additional material, our method has a potential to reduce the manufacturing cost of MCF connectors.

Because the amount of MCF deformation is larger than that of the single-MCF connector, realizing PC in a multi-MCF connector is more difficult. Conventional polishing technique is to make spherical fiber surface because

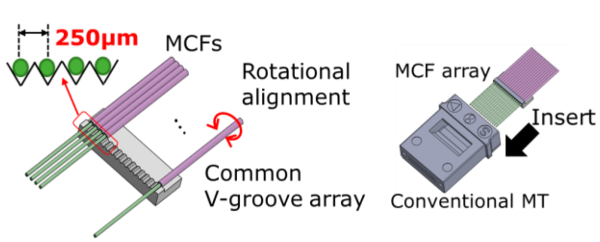

Fig. 4. MT-insertable V-groove array method for rotational MCF alignment [5].

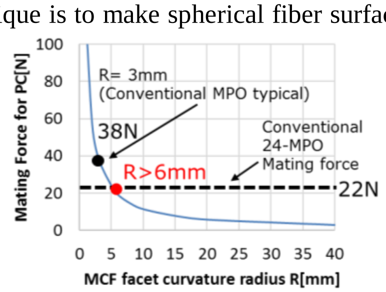

Fig. 5. Mating force vs. MCF facet curvature radius for the 96-core MPO connector.

the technique is optimized for single core fibers which have a core at the cladding center, so it is not suitable to MCFs because MCF end faces should be flatten for the PC of outer cores. Assuming the 8-core fiber having cores located at 40.5μm from the center of the 125-μm cladding [10], we calculated the relationship between the curvature radius of the MCF facets and the required mating force for 96-channel (8-core × 12-fiber) MPO connector based on Hertz formula, as shown in Fig. 5. According to the result, an MCF facet curvature radius of more than 6 mm is required for PC when the mating force is 22 N, i.e., the maximum in the MPO standard. Therefore, we developed an MCF-optimized polishing method which can flatten MCF facets to achieve the curvature radius of larger than 6 mm.

Using the above-described MT-insertable V-groove array method, facet polishing methods, and the 125-μm-cladding 8-core MCF, we fabricated 96-channel MPO connector with conventional 12-MT ferrules and MPO housings with 22-N mating force, as shown in Figs. 6(a,b). The connector end faces were polished with the angle of 8 degrees. The ILs of all the cores of the connectors measured 0.29 dB in average and 0.57 dB at maximum at λ of 1.31 μm, as shown in Fig. 6(c). We confirmed the PC of all the cores by measuring the ILs with/without index matching liquid, as shown in Fig. 6(d). Here, the ILs for the conventional polish condition showed large variations caused by the index matching liquid, which means that there were air gaps, or Fresnel reflections, between the MCF facets. On the other hand, in the MCF optimized polish condition, the IL did not change (marks on the “y = x” line) regardless of existence/absence of index matching liquid, which indicates no air gap or no Fresnel reflections.

To demonstrate the spatial channel scalability of our MT-insertable V-groove array method, we also fabricated 256-core MT connector with a highly-precise 32-MT ferrule with 2×16 hole layout. Two V-groove arrays were inserted into the MT ferrule and MCFs were rotationally aligned, as shown in Fig. 7(a,b). We measured the ILs of all the cores of the connectors using index matching liquid, and their average was 0.26 dB and the maximum was 0.93 dB at λ of 1.31 μm, as shown in Fig. 7(c).

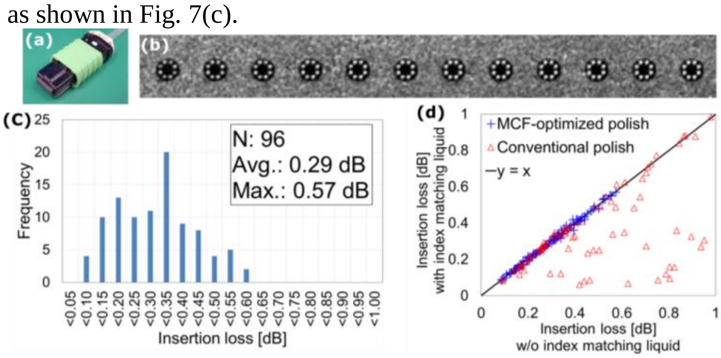

Fig. 6. 96-core MPO connector: (a) outlook, (b) end face, (c) IL histogram, and (d) ILs with/without index matching liquid [5].

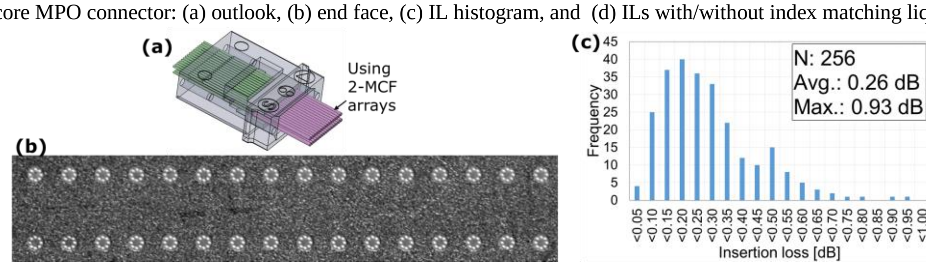

Fig. 7. 256-core MT connector: (a) 3D design, (b) end face, and (c) IL histogram [5].

4. Conclusion

High-density MCF connectors can be realized with low IL and physical contact by the simple rotational alignment methods and the MCF-optimized polishing method. The MCF connectors can contribute to the drastic improvements of future switch I/O BW and front panel BW. The 125-μm-cladding 8-core MCF and the MCF connector technologies can increase the front panel BW by eight times. For example, the number of spatial channels in a typical 1U size front panel with 12MPO interfaces can be increased from 384 channels to 3072 channels by the MCF connector technology.

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