Physical-contact 256-core MPO Connector with Flat Polished Multi-core Fibers

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Abstract: Physical contact of all the cores of ultra-high-density 256-core MPO connectors with 32 strands of 8-core fibers was achieved with a 22-N mating force by polishing method realizing flat fiber facets and small fiber-protrusion difference.
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1. Introduction

Over the last decade, optical interconnect technologies have been deployed in data centers and high-performance computing systems to address strong demands for high-bandwidth (BW) and high-density interconnects [1,2]. In order to improve the BW density on a front panel, the multi-core fiber (MCF) connector technology is one of the prospective candidates in space-division multiplexing (SDM) technology. However, rotational MCF alignments and physical contact (PC) connections including outer cores are significant challenges for realizing the MCF connectors. The PC connection is essential to realize a low coupling loss and high signal quality, however MCF connectors need larger mating forces for the PC, compared with conventional single-core fiber (SCF) connectors [3]. In the case of SCF connectors, fiber facets are polished to be a spherical-convex shape because a central core can contact each other by a small mating force. In contrast, in the case of MCF connectors, the spherical-convex facets rather increase the mating force because full end faces including all the cores have to contact [3]. Further higher mating force is required for multi-MCF connectors, because the cumulative difference of fiber protrusions—i.e., the fiber heights from a MT-ferrule surface—increases [4]. In our previous study, to investigate the channel scalability of high-density MCF connectors, we demonstrated 96-core (8-core×12-MCF) and 256-core (8-core×32-MCF) MPO connectors with low insertion losses (ILs) of < 1 dB at 1.31 µm using 125-µm-cladding 8-core fibers [5] and MT-insertable V-groove arrays for rotational fiber alignments [6]. We also achieved the PC of all the cores of the 96-core MPO connectors with a 22-N mating force by a polishing method that can align the heights of the slightly protruded fibers and flatten the fiber end faces, but had not applied the flat polishing method to the 256-core connector yet.

In this study, we numerically investigated the requirements on the end shapes of the fiber facets of the 256-core (8-core×32-MCF) MPO connectors for realizing the PC connection of all 256 cores with the mating force of 22 N. After that, we experimentally demonstrated PC connectable 256-core MPO connectors with return losses (RLs) of > 40 dB by a polishing method realizing flat fiber-facet curvature radii more than 23 mm and a small fiber-protrusion difference less than 0.3 µm.

2. Simulation

To achieve the physical contact of all the 256 cores in 32-MCF MPO connectors with a 22-N mating force, we numerically investigated the relationship between the elastic deformation of MT connectors (including fibers and adhesive) and fiber-shape parameters on the connector end face using a finite element method [7]. In the simulation, we assumed parabolic envelopes of the fiber protrusions from empirical profiles, as shown in Fig. 1(a). We chose two fiber-shape parameters as variables: the maximum difference between the fiber protrusions (δh: shown in Fig. 1(a)) and the curvature radius of fiber-facet (R_{FF}: shown in Fig. 1(b)). These two parameters influence the minimum mating

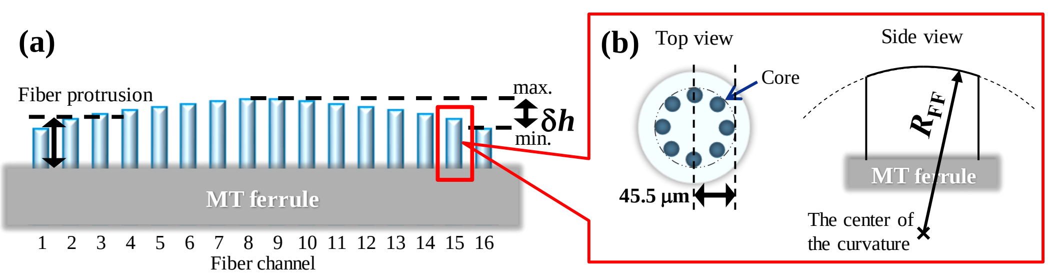

Fig. 1. Schematics showing the definitions of the fiber-shape parameters:
(a) the maximum fiber-protrusion difference δh, and (b) the curvature radius R_{FF} of the facet of a fiber tip.

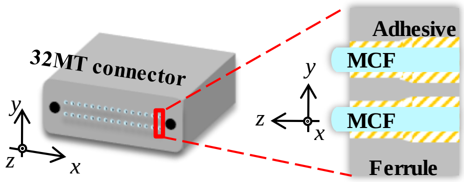

Fig. 2. Schematic of a 32MT ferrule.

Table 1. Physical properties of the connector materials

Material	Young's modulus [GPa]	Poisson's ratio
MT Ferrule: PPS	14	0.4
MCF: SiO_2 glass	74	0.17
Adhesive: Epoxy resin	6.2	0.3

force to achieve the PC of all the cores, because all these *unflatness* of the fiber end faces on the connector faces have to be flattened by the glass deformation due to the compressive mating force, such that all the cores can be physically contacted. The relationship between the minimum mating force and the above two parameters can be roughly estimated by considering Hertz's formula and cumulative fiber-protrusion compression [4]. However, to obtain a more accurate estimation, we have to take account of the deformations of the connector ferrule and the adhesive between the ferrule and the fibers (see Fig. 2 for how the fibers are fixed to the ferrule). Thus, elastic deformations of three different materials—silica glass fiber, polyphenylene sulfide (PPS) ferrule, and epoxy adhesive— must be considered in the simulation. The physical properties of the above materials used in the simulation are shown in Table 1. The MCF diameter was 125 µm, and vertical (*y*-direction) and horizontal (*x*-direction) fiber pitches were 500 and 250 µm, respectively.

We investigated the relationship between the physically-contacting fiber facet radius (r_{PC})—the minimum value of the physically contacting radii on the fiber facets among all the fibers—, R_{FF} (5–50 mm) and δh (0.3–0.5 µm) at the 22-N mating force, as shown in Fig. 3. As expected above, r_{PC} increases with increase in R_{FF}, as shown in Fig. 3. So, improving r_{PC}—or fiber-facet flatness— is effective to achieve the PC of outer cores. In addition, Fig. 3 shows that δh has a significant effect on r_{PC} for the 32MT compared with the 12MT, because the mating force for the PC connection depends on the cumulative difference of the fiber protrusions, which increases as the fiber count increases. Based on the results in Fig. 3, we calculated the minimum R_{FF} ($R_{FF,min}$) that achieves the PC of all the cores, as shown in Fig. 4. Here, we regarded the "PC" as the PC of the cores; therefore, $R_{FF,min}$ is the minimum R_{FF} that achieves $r_{PC} \geq$ 45.5 µm—the whole outer edges of the cores are completely contacted. According to Fig. 4, we confirmed that $R_{FF,min}$ increases as the fiber count increases. For example, the $R_{FF,min}$ of 32MT needs to be more than 23 and 38 mm when δh is 0.3 and 0.5 µm, respectively, which is much larger than 6-mm $R_{FF,min}$ of 12MT. Therefore, the fiber-facet flatness and fiber-protrusion alignment are especially important for the PC connection of high-fiber-count MCF connectors, such as the 256-core 32MT connectors.

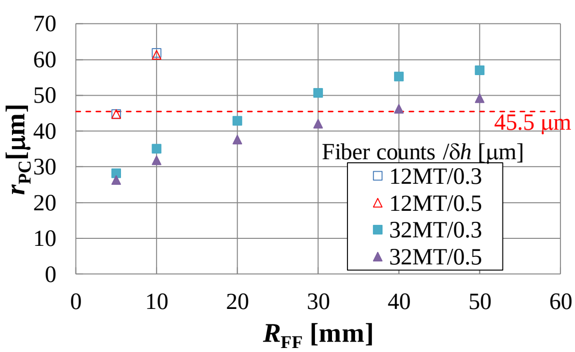

Fig. 3. Dependence of fiber counts on δh and r_{PC}

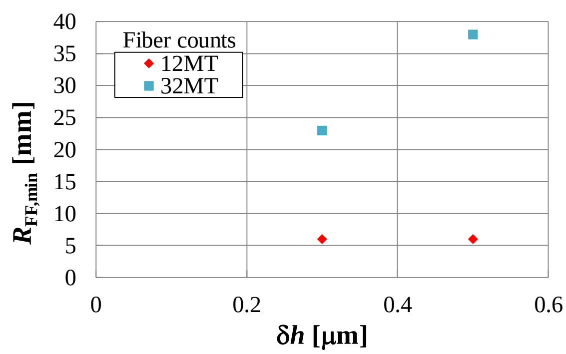

Fig. 4. Dependence of $R_{FF,min}$ for PC on δh and fiber counts

3. Fabrication and measurement

Based on the simulation results, we fabricated a pair of 256-core MPO connectors where 32 strands of 125-µm-cladding 8-core fibers [5] were inserted to a 32-hole MT ferrule by using MT-insertable V-groove arrays [6]. The MT end faces were polished such that fiber-tip facets and fiber protrusions can be flattened and aligned, respectively. The end face photo and three-dimensional geometric profile of a fiber tip on a polished MT ferrule are shown in Fig. 5. We used standard MPO housings and springs to achieve 22-N mating force. Table 2 shows the measured shape parameters of the fiber tips of two fabricated MPO connectors (MPO A and MPO B), which confirmed that the fiber-tip shapes achieved the PC condition obtained in the simulation: $R_{FF,min}$ > 23 mm and δh < 0.3 µm.

The optical return losses (RLs) of MPO A and MPO B were measured using an optical backreflection meter (OBM) at the wavelength of 1.31 µm. The measurement setup is shown in Fig. 6. The output light from the OBM was coupled into a core of an MCF pigtail of MPO A, through a fan-in (FI) device. The OBM and the FI were connected with the standard single-mode fibers via FC/PC connectors, and the FI and MPO A were connected with SC ferrules and a split sleeve with index matching oil. The MCFs in the SC ferrules were actively aligned in the rotational direction. MPO A was connected to MPO B using a standard MPO adapter. The other ends of the MCFs from MPO B were terminated by an MPO with 8° angle polish. Therefore, the background RL should be well suppressed. Figure 7 shows the measured RL histogram of the 256 cores. The RLs were achieved to be more than 40 dB for all the 256 cores. Thus, we confirmed the PC of all the cores in the high-density 256-core (8-core×32-MCF) MPO connectors.

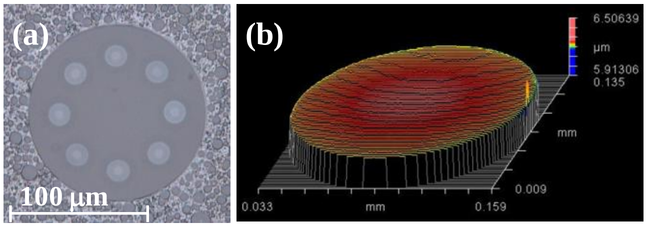

Fig. 5. A polished fiber facet: (a) end face photo and (b) 3D profile.

Table 2. The shape parameters of the fiber tips on the fabricated 32-MCF MPO connectors

Sample	MPO A	MPO B
Ave. R_{FF} [mm]	48	51
Min. R_{FF} [mm]	41	43
δh [µm]	0.20	0.17

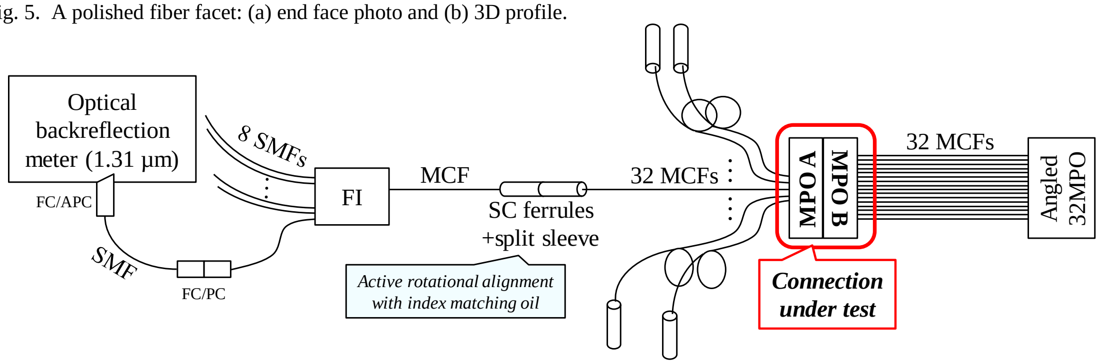

Fig. 6. The RL measurement setup

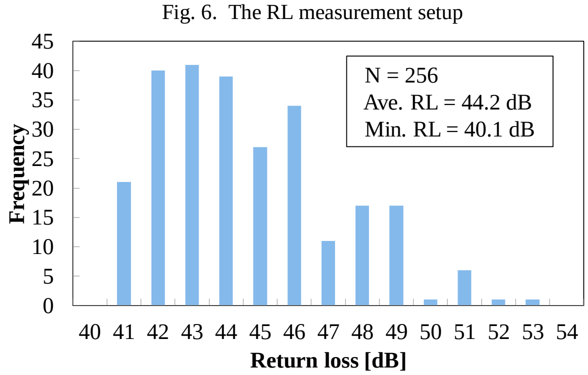

Fig. 7. The histogram of the RLs of the 256-core MPO connectors

4. Conclusion

The high-density 256-core PC MPO connectors were experimentally demonstrated based on the simulation results. The fiber-shape conditions for achieving the PC connection with the 22-N mating force was calculated by a numerical simulation at the fiber counts of 12 and 32, and we found that the fiber-shape requirements of a 32-MCF MT are much severer than those of a 12-MCF MT—$R_{FF,min}$ needs to be larger than 23 mm with δh of < 0.3 µm in the case of the 32-MCF MT. Based on the simulation, we fabricated 256-core (32-MCF) MPO connectors satisfying the PC-condition fiber shapes by using a new polishing method. Finally, the PC connection of the 256-core connectors with the practical 22-N mating force was confirmed by measuring the RLs of > 40 dB. The results demonstrate that the high-density MCF MPO connector is an attractive technology to support the data-traffic growth.

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