Ultra-compact Multi-fiber Connector with Magnetic Physical Contact

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Abstract: An ultra-compact multi-fiber connector features a novel magnetic attraction structure for high-density on-board connector. The fabricated connectors show low-insertion losses comparable to those of conventional MPO connectors while achieving space-saving connection with an angled physical-contact.

1. Introduction

With the rapid increase in data traffic in the transmission links of data center networks, high-bandwidth optical interconnects based on single-mode fiber transmission have been attracting attention, which include those with pluggable transceivers, on-board optics, and co-packaged optics (CPO) [1]. With such optical interconnects, a high-density on-board connector is strongly required as the number of connected fibers increases. For example, when we consider CPO applications in which multiple photonic integrated circuits (PIC) modules with fiber pigtails are placed on all sides of an LSI chip on a board, the several dozen fiber pigtails should be connected efficiently to other single-mode fibers in a limited space at the module edge or on the board [2]. The conventional high-density multi-fiber connector known as the MPO connector [3] can yield good optical characteristics with a push-pull connection but seems not to be ideal for such applications because it is too large for module-edge or on-board connections. Besides, further size reduction of MPO connectors is limited because they need a mechanical spring and related housing parts, which are essential for applying the compression force of about 10 N needed for angled physical-contact (PC) connection [3]. An alternative approach is to use MT connectors with a clip [4] at the edge of the fiber pigtails. Although they are small enough, their operability is not good, and they need extra operation space when we attach the clip with a large tool, which seems to be an obstacle for achieving multiple high-density connections or module-edge pluggable connections.

In light of the above background, we have developed an ultra-compact multi-fiber connector featuring a novel magnetic attraction structure that is suitable for high-density optical interconnects such as CPO. With its miniaturized size due eliminating the spring and other extra mechanical parts, our magnetic multi-fiber connector can achieve space-saving connection, while delivering enough magnetic force for angled PC. In addition, we designed a new magnetic connection structure based on a detachable-magnet scheme, which allows us to achieve pluggable connection at the module edge or on the board with high operability. On the basis of a detailed simulation, we devised a magnetic PC connector with a compact connection size of about $9.3 \times 5 \times 16$ mm^3. The fabricated connectors in randomly mated pairs achieved good optical characteristics comparable to those of conventional MPO connectors with low insertion losses of less than 0.6 dB and high return losses of more than 65 dB.

2. Basic concept and structure

Our basic concept is to use magnetic attraction force as compression force applied between mated connector facets for PC connection, while following the conventional fiber alignment mechanism with high-precision ferrules. The magnetic force enables us to eliminate the spring/clip and related housing parts, and thus, the connector size can be miniaturized while achieving both precise alignment and PC connection. We have already presented this concept in a simplex connector [5], and demonstrated a miniature simplex connector with magnetic PC, where magnetic force was set to 3 N. On the other hand, the required force for multi-fiber PC connection is larger than that required for a simplex one, and the conventional MPO connector actually uses a spring with about 10-N force. If we apply our concept to multi-fiber connectors in the same way we did for the simplex one, the large magnetic force required would make it difficult to easily connect/disconnect the connectors and also cause some operation failures such as the chipping or deformation of components. Here, we propose a new magnetic connector structure and scheme that can address the above concerns.

Figure 1(a), (b), and (c) respectively show the basic structure of the proposed multi-fiber connector with magnetic PC in the connected state, its cross-sectional diagrams, and its connection procedure. At one connector on the receptacle side, a square magnetic-metal part with a square socket is fixed around the ferrule. At the other side, two square U-shaped magnetic-metal plates are fixed around the other ferrule, behind which are placed two square U-shaped magnets and magnetic-metal parts that serve as magnetic yokes. The two magnets have opposite magnetization directions, both of which are parallel to the lengthwise fiber direction. In addition, each facet of the components is angled to be parallel to the ferrules as shown in Fig. 1(b). In this configuration, the attraction force between the two ferrules is applied vertically to their angled facet through the magnetic force between the square-socket part and magnetic-metal plates with the two magnets. The connection procedure is shown in Fig. 1(c). The magnets are not attached when the two ferrules are mated via guide pins, which enables us to connect them without magnetic force. After that, the two square U-shaped magnets are attached respectively by sliding them along both sides of the ferrule, and then the magnetic force is applied. Finally, the yokes are attached from two sides of the ferrule in the same way to enhance the magnetic force. The magnets and yokes can be removed in reverse order when we disconnect the connectors. Here, the force required for sliding the magnets is relatively small compared to the force for pulling them because of the magnetism principle. Thus, by separating the steps of ferrule-mating and magnet-attachment, our magnetic connector can be easily connected/disconnected even with large applied force of more than 10 N.

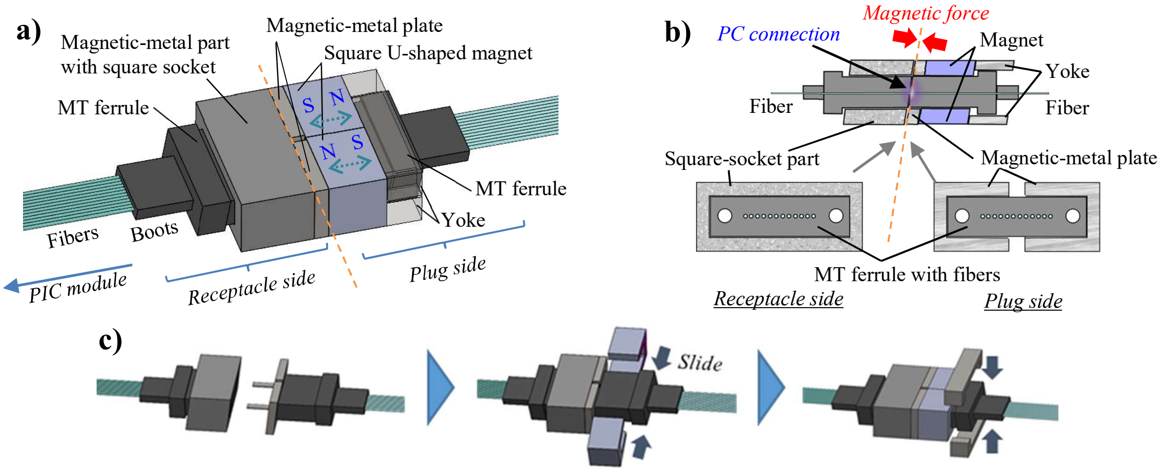

Fig. 1. (a) Basic structure of proposed magnetic connector, (b) its cross-sectional diagrams, and (c) its connection procedure.

3. Magnetic simulation for stable angled PC

We then calculated the magnetic force in detail by changing geometries of the magnets and magnetic-metals to determine how to provide enough force for multi-fiber PC (i.e., about 10 N) while making the connector size as small as possible. The MT ferrule we considered is a standard one 6.4 mm in width and 2.5 mm in height. We used neodymium-based magnets (B_r = 1.35 T; H_{cb} = 880 kA/m) and SUS430 as a magnetic-metal material since it has good workability and its cost is low. Here, we made a space between the two magnetic-metal plates in the proposed structure as shown in Fig. 1(a). In addition, it should be noted that the ferrules should slightly protrude from each facet of the square-socket part and magnetic-metal plates, respectively, to ensure that the ferrule ends touch each other. For this purpose, there should be a gap between the square-socket part and the magnetic-metal plates.

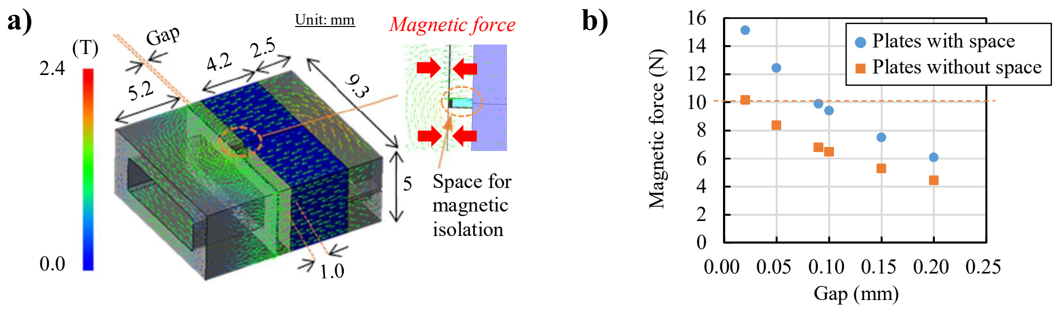

Fig. 2. (a) Simulated magnetic flux density and (b) calculated magnetic force versus gap.

Figure 2(a) shows an example of the simulated magnetic flux density line; and Fig. 2(b) shows the simulation results for the magnetic force as a function of the gap, in which dimension parameters we were set as shown in Fig.

2(a). As shown in Fig. 2, we confirmed that the space between two magnetic-metal plates prevents the magnetic circuit from closing through the boundary of the two facing plates, which makes it possible to maintain magnetic force between the square-socket part and the magnets even through the magnetic-metal plate. We also confirmed that the magnetic yokes help enhance the magnetic force by closing the magnetic circuit effectively. As shown in Fig.2 (b), we found that the ideal gap should be less than about 0.09 mm if we set the target magnet force to more than 10 N under the dimensions shown in Fig. 2(a).

4. Fabrication and results

We fabricated our magnetic PC connector with a standard 12-MT ferrule in which twelve single-mode fibers were fixed with an adhesive and the connector-end was appropriately polished to an angle of 8 degrees. The size of each part was set to be the same as the dimensions shown in Fig. 2(a). We then fixed the SUS430 square-socket part to one ferrule and the SUS430 plates to the other using a specialized jig in order to meet the gap value requirement described in the former section. Figure 3(a) shows photographs of the fabricated connector before and after connection, in which the neodymium-based magnets and the SUS430 yokes are depicted after connection. The attachment of the magnets and the yokes were conducted by hand easily, and confirmed high operability. The connected size is sufficiently small (about $9.3 \times 5 \times 16$ mm^3), which is about seven times smaller than MPO connectors in volume. Figure 3(b) shows a histogram of insertion losses of the randomly mated magnetic PC connector. The insertion losses were acceptably low, less than 0.6 dB, and the average loss was 0.16 dB, which are comparable to conventional MPO-connector characteristics. The return losses of the mated connectors were also acceptably high, more than 65 dB thanks to the angled facets. We also confirmed that the insertion losses did not change significantly when we filled the gap between the mated connectors with ethanol, which means that the angled PC connection was successfully achieved by magnetic force. Since the insertion-loss is mainly determined by alignment accuracy if the PC connection is achieved, these results indicate that our proposed magnetic structure does not have any negative effect on the fiber alignment.

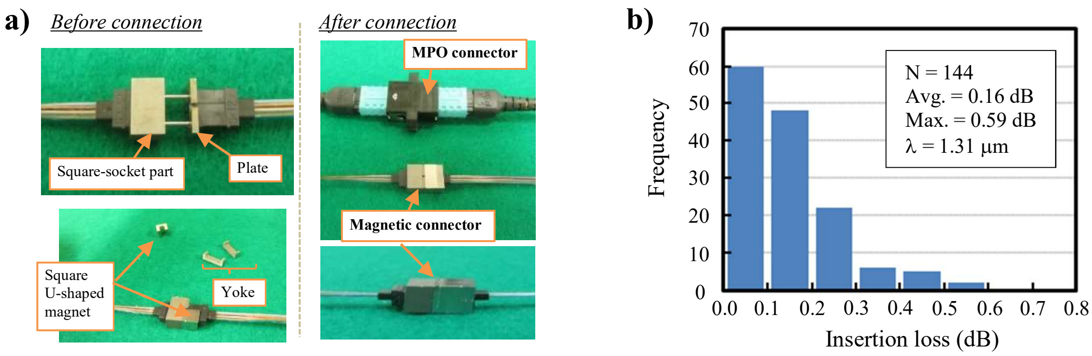

Fig. 3. (a) Photograph of fabricated magnetic connector and (b) histogram of insertion losses.

5. Conclusion

We presented and demonstrated an ultra-compact multi-fiber physical-contact (PC) connector with a novel magnetic attraction structure. Our design based on a detachable-magnet scheme and detailed simulation enables us to achieve angled PC with a pluggable connection. The fabricated connectors provided good optical performance comparable to that of conventional MPO connectors with a connection size of $9.3 \times 5 \times 16$ mm^3, which is about seven times smaller than the MPO connector in volume. Our proposed magnetic PC connector is poised to become a key solution for achieving high-density optical interconnects such as co-packaged optics.

6. References

[1] "Co-Packaged Optic Assembly Guidance" retrieved 11 Oct. 2021 from http://www.copackagedoptics.com.
[2] S. Fathololoumi et al., "1.6 Tbps Silicon Photonics Integrated Circuit and 800 Gbps Photonic Engine for Switch Co-Packaging Demonstration," *J. Light. Technol.*, vol. 39, no. 4, pp. 1155-1161, (2021).
[3] S. Nagasawa et al., "A high-performance single-mode multifiber connector using oblique and direct contact between multiple fibers arranged in plastic ferrule," *Photon. Techno. Lett.*, vol. 3, no. 10, pp. 937-939 (1991).
[4] T. Satake et al., "A new type of demountable plastic-molded single-mode multifiber connector," *J. Light. Technol.*, vol. 4, no. 8, pp. 1232-1236 (1986).
[5] K. Shikama et al., "Miniature optical connector with magnetic physical contact," *Proc. OFC*, paper W2A.14 (2020).