Miniature Optical Connector with Magnetic Physical Contact

Kota Shikama, Norio Sato, Atsushi Aratake, Satoshi Shigematsu, and Takeshi Sakamoto
NTT Device Technology Labs., NTT Corporation, 3-1 Morinosato Wakamiya, Atsugi-city, Kanagawa, 243–198 Japan
kouta.shikama.bc@hco.ntt.co.jp

Abstract: We present a miniature physical-contact optical connector featuring a novel magnetic attraction structure. The magnetic optical connectors we designed and fabricated yield low insertion and high return losses comparable to those of a conventional connector.

1. Introduction

Optical connectors with a physical-contact (PC) connection such as SC/LC connectors are essential components for constructing modern optical communication systems that include high-bandwidth optical interconnects for data center networks. Recently, as the optical transceiver package size has become smaller in conjunction with increased bandwidth density [1, 2], a denser optical interface with a smaller optical connector to replace the conventional duplex LC interface is required. A smaller optical connector is also strongly required to achieve more compact board-to-board/on-board optical fiber connection for use as the breakout cable connection for rewiring transmission links. The connector for on-board application is especially important for on-board optics [3] and co-packaged optics, as they feature a large number of fibers in a limited board space. Another application that uses smaller connectors is the in-package connection instead of fusion splicing in transceiver assembly. Here, conventional PC optical connectors are limited in terms of their size, for two reasons. The first is the necessity of a mechanical spring and related holding parts, which are essential to apply enough compression force for achieving PC connection [4]. The second is the housing parts that are required for achieving the push-pull connection and assuring mechanical-force resistance while taking the application of large external force into consideration [5]. Although conventional standardized PC optical connectors yield excellent optical performance and mechanical reliability with sophisticated structures, they seem to be over-engineered and are too large if we use them for these new applications such as on-board/in-package connection described above.

In light of the above background, we have developed a miniature optical connector with a PC connection enabled by a novel magnetic attraction structure. Our magnetic optical connector can achieve precise fiber alignment and yield enough compression force without a spring or other mechanical parts. We have devised a new coupling mechanism between a ferrule with a magnetic metal flange and a magnet adapter with a split-sleeve, in which the magnetic attraction between the adapter and each mated flange is applied. On the basis of a redesign of the compression force for achieving stable PC connection and a detailed calculation of the magnetic force, we fabricated a simplex magnetic optical connector with a connection size of about 3 × 3 × 9 mm^3. The fabricated connectors in the randomly mated pairs achieved comparable characteristics to conventional connectors with low insertion and high return losses of less than 0.4 dB and more than 45 dB, respectively. The fabricated connectors also maintained the PC connection throughout online measurement during temperature changes from –20 to 85°C after short-term reliability tests, which demonstrates the high environmental durability of our proposed magnetic connector.

2. Basic structure

Figures 1(a) and (b) respectively show the basic structure of the proposed magnetic optical connector and its cross-sectional diagram. The magnetic connector consists of a short 1.25-mmϕ ferrule with a magnet/magnetic-metal flange, a split-sleeve, and a magnet adapter. The fiber alignment is achieved by mating two ferrules in the sleeve, which is the same mechanism as the conventional connector. The difference is that a compression force for PC

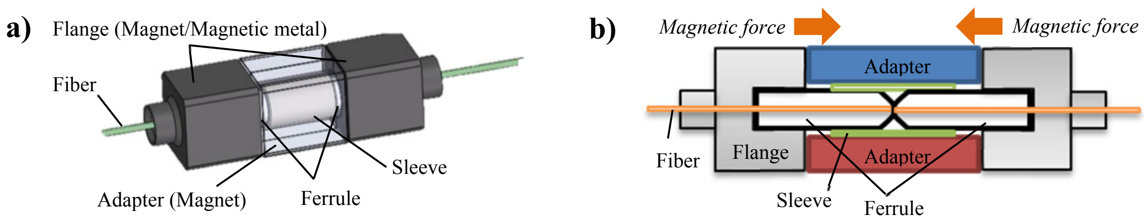

Fig. 1. (a) Basic structure of proposed magnetic optical connector and (b) its cross-sectional diagram.

connection is provided by the magnetic attraction between the flange and the adapter. This magnetic attraction structure enables us to eliminate the conventional spring/clip and related mechanical holding parts. Moreover, the magnetic force helps achieve the self-mating connection and holds the connectors in the mated state, which eliminates the need for other mechanical housing parts such as a locking structure. Thus, the connector size can be miniaturized while achieving both precise fiber alignment and the PC connection, which are key enablers for devising a good optical connector. In addition, the magnetic connector can easily stick to another magnetic connector, which means we can fabricate a multiplex connector without any jointing part. The proposed optical connection technology based on the magnetic attraction can be applied to multi-fiber connectors such as the MT/MPO connector, and the clip and spring can be eliminated in the same manner.

3. Design for stable PC connection

To achieve stable PC connection with the proposed structure while making the connector size as small as possible, designing the magnetic force in detail is important, since the magnet size mostly determines the magnetic force applied to the connector. If we set the minimum magnetic force to the same value as the standardized spring (9.8N for SC [4], 6N for MU/LC [6]), the magnet adapter should be large. Here, the compression force provides sufficient pressure to the mated connector-end in order to absorb the fabrication error of the polished connector-end. Figure 2(a) schematically shows the mated connectors with spherically polished ends, which are represented as the endface radius of curvature *R*, the spherical radius apex offset Δ, and the spherical withdrawal of the fiber from the virtual sphere on the ferrule endface *U*. Figure 2(b) shows the calculated results of allowable withdrawal for PC connection versus radius of curvature using the finite-element method simulation, where the simulation condition was the same as the one reported [7] in the case of an yttria-stabilized zirconia ferrule. As shown in (b), we found that the standardized spring force allows very large withdrawal margins for PC connection. We also found that there are still some margins when we set the compression force to 3N: for example, 185-nm withdrawal for 20-mm *R* pairs. We can easily suppress the withdrawals below the allowable curve for 3N by taking the current mass-producible polishing technique and long-term withdrawal deformation [8] into consideration. Thus, we redesigned and set the minimum force to 3N in this study.

We then designed the magnet adapter as follows. As the adapter material, we used a neodymium-based magnet (NEOREC 50BF, TDK Corporation) that has large residual magnetic flux density over a wide temperature range. As the flange material, we used a common stainless steel, SUS430, since it has good workability and its cost is low. We also devised a special adapter structure assembled with cylinder-magnet halves to enlarge the magnetic force compared to a one-magnet cylinder. The length of the adapter was set to slightly less than the sum of the protrusion length of each mated ferrule from the flange to ensure that the ferrule ends touched each other. Figures 3(a) and (b) show the simulation results of the magnet field lines and magnet force as a function of the gap between the flange

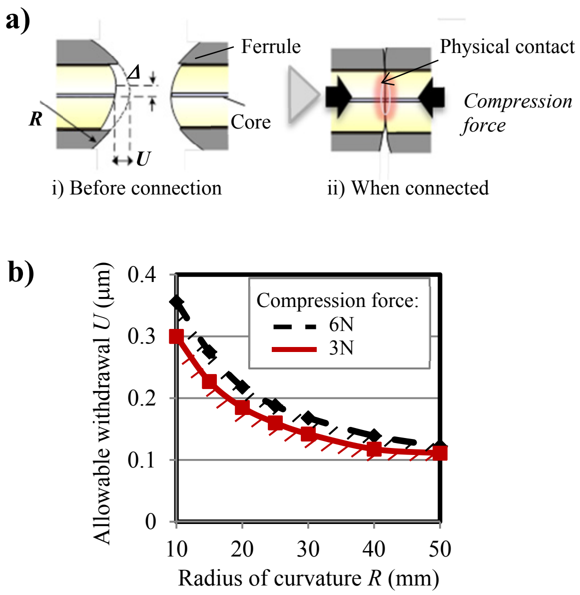

Fig. 2. (a) PC image of connectors with polished ends and (b) calculated allowable withdrawal for PC with various *R*.

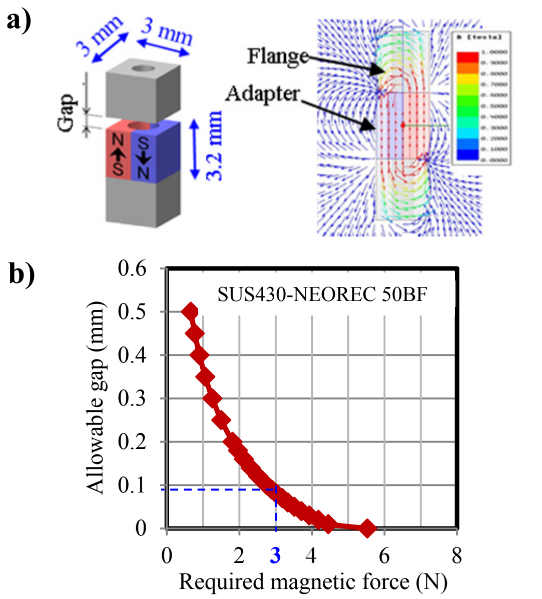

Fig. 3. (a) Simulation results of magnetic force lines and (b) allowable gap vs. magnetic force.

and the adapter, respectively, when the adapter size was set to 3.0 × 3.0 × 3.2 mm^3. We confirmed that the magnetic force was about 5.5N when the gap was about zero, which is almost the same value as the conventional LC spring. We also found that the ideal gap should be less than 0.08 mm so that the magnetic force exceeds the designed minimum force of 3N. Thus, we designed the dimensional tolerances of the ferrule with the flange and the magnet adapter to meet the above gap value, which is easily achieved using current machining technology.

4. Fabrication and results

We fabricated our magnetic optical connector with a 1.25-mmϕ zirconia ferrule in which a standard single-mode fiber was fixed with an epoxy adhesive and the connector-end was appropriately polished. Figure 4(a) shows a photograph of the fabricated connector, whose connection size is sufficiently small (about 3 × 3 × 9 mm^3), along with a conventional SC-connector for comparison. Also shown is a SUS430-based plate that can cover the connector during actual use. This cover plate reduces magnetic flux leakage that may have an impact on other electric components. It can also enlarge the magnetic force and prevent the rotation of the flange, which makes it possible to achieve stable optical connection. Figures 4(b) and (c) show the histogram of insertion and return losses of the randomly mated magnetic connector, respectively. The insertion losses were acceptably low, less than 0.4 dB, which are comparable to the mated conventional connector characteristics. This result indicates that our magnetic attraction structure and ferrule miniaturization do not have any negative effect on the fiber alignment. The return losses were also acceptably high, more than 45 dB, which indicates that all the connectors achieved PC connection thanks to our magnetic attraction structure. We confirmed that the maximum gap of ten measured pairs was 65 μm, which was within our designed range. Our magnetic connector achieved PC connection after a 100-hour damp-heat test (85°C, 85% R.H.). The connector also maintained the PC connection in online measurement with temperatures ranging from –20 to 85°C, even after the above short-term reliability test, which demonstrates the high environmental durability of our connector.

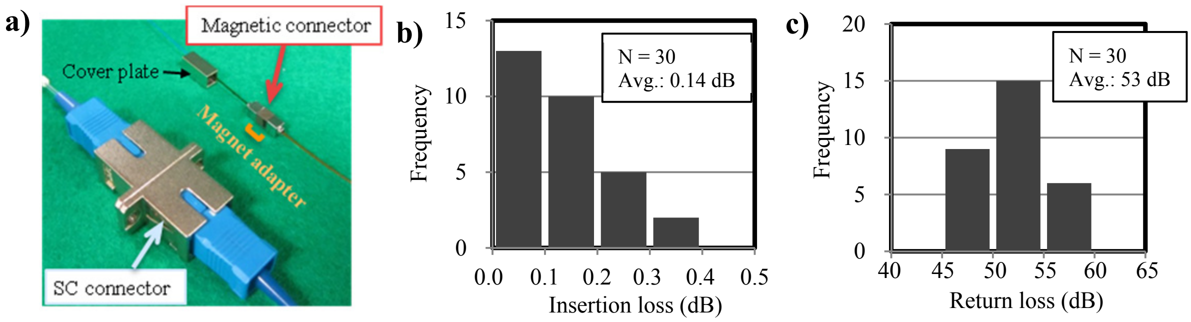

Fig. 4. (a) Photograph of fabricated magnetic optical connector. Histograms of (b) insertion losses and (c) return losses.

5. Conclusion

We presented and demonstrated a miniature optical connector with springless physical contact enabled by a novel magnetic attraction structure. The fabricated simplex connectors provided a good optical performance with PC connection and yielded sufficient environmental durability, and were miniaturized to about 3 × 3 × 9 mm^3. Our magnetic connector shows promise as a new optical connection technology and is poised to become a key engine for achieving future high-bandwidth optical interconnects such as co-packaged optics.

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6. References

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