Single-Mode Multi-Optical-Fiber Lensed Connector Enabling Dust Insensitive and Low Mating Force

Osamu SHIMAKAWA*, Hajime ARAO, Naoki MATSUSHITA, Yuichi MITOSE, Dai SASAKI and Masaki OHMURA

We have developed single-mode-fiber (SMF) lensed connectors operable with small mating force and insensitive fine dust on their end faces. 24 SMF lensed connectors utilizing an MT connector technology have been successfully fabricated. The beam is expanded by a graded-index (GI) fiber lens array with a waist diameter of 52 µm, and the spring force in the mating condition can be reduced to 3.3 N, which is about one sixth of that for a 24-MPO connector. The optical fibers and lenses are precisely aligned with a pair of guide pins and holes made by high precision molding technologies. Their average and maximum insertion losses (ILs) are less than 0.7 dB and 1.6 dB, respectively. These have been the best results for single-mode multi-optical-fiber lensed connectors reported so far.

Keywords: multi-fiber connector, lens, expanded beam, single-mode

1. Introduction

The internet data center has grown to a larger scale in accordance with the explosion of data traffic recently. The optical fiber cables installed in data centers are required to meet the demand for higher-speed, larger capacity and longer transmission distance.

The most popular multi-fiber connector used in a data center is an Multi-fiber Push-On (MPO) connector.[*1] The connectors are designed based on physical-contact (PC) technologies to make fibers firmly connected to each other by applying certain pressing force.[(1)] Fiber count increase in MPO connectors is required in order to meet data traffic increase in recent years. As the fiber count increases, pressing force also needs to be increased in order for all fibers to maintain PC with each other.[(2)] Furthermore, single-mode PC connectors require careful end face cleaning before mating because the beam as small as 10 µm in diameter at the fiber end face is easily scattered by fine dust.

Lensed connectors using convex lenses have been proposed in order to cope with the issues for mating force and dust. As for multi-mode optical fiber (MMF) connection, a connector with less than 1.2 dB in splice loss was reported.[(3)] However, as for SMF, splice loss with practical use level has not been reported so far,[(4)] whereas SM fibers could play an important role in achieving higher bandwidth and longer distance.[(5),(6)]

Although alignment accuracy demanded between an optical fiber and a lens is less than 1 µm, it has been difficult to achieve. Therefore, a single-mode-fiber (SMF) lensed connector with low splice loss has not been reported so far.

We have developed SM multi-optical-fiber lensed connector technologies by utilizing a precision plastic molding technique for mechanically transferable[*2] (MT)/MPO connectors, a positioning technique between connectors and a graded-index (GI) fiber[*3] lens technique.[(7),(8)]

2. Structure

The proposed structure of a 24-fiber connector is shown in **Figure 1**. GI silica fibers are inserted into 24 holes in a plastic molded array plate. The GI fibers could work as lenses by optimizing the thickness.

SM fibers are also inserted into a 24-MT ferrule, and the ferrule end face is polished, too. The lens array plate and the MT ferrule have guide-holes and they are aligned with each other by guide-pin fit. Then, they are fixed with an adhesive. As the plate is made of the same material and has the same process as those of the MT ferrule, they have identical fiber hole positions. Therefore, precise position matching between SMF and GI lenses are passively accomplished by the use of two guide pins and holes. As shown in **Figure 2**, the beam from the SMF is expanded by the GI lens and transmits through free space, which is then coupled with another connector. These two connectors are intervened by a spacer. A constant distance is maintained between the two connectors by the spacer. The X and Y axes positions between mated connectors are aligned with two guide pins and fitting holes, and the tilt angles are aligned by the spacer faces fit. The assembled connector in an MPO connector housing is shown in **Photo 1**. Anti-reflection (AR) coating is applied on the connector end faces.

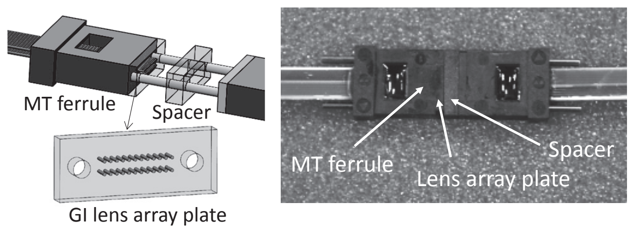

Fig. 1. Internal structure of 24-SMF lensed connector

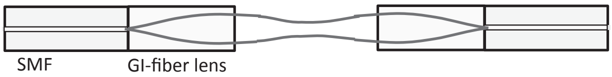

Fig. 2. Schematic of optical system

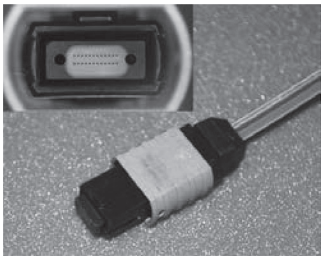

Photo 1. Assembled connector in MPO housing

A silica–glass–made–lens gives a lower change in optical focal length than a plastic-made-lens under a temperature changing environment, which results in stable optical coupling between SMFs. Additionally, the flat surface of a GI lens allows the connector to be more easily cleaned than a convex lens.

3. Optical Design

The output beam from an SMF is expanded and collimated by the GI lens. The expanded beam is less sensitive to dust at the connector end face than a beam from conventional PC connectors. It also has an advantage where the expanded beam is less sensitive to X and Y misalignment between mated connectors. On the other hand, as the beam diameter becomes larger, the beam becomes more sensitive to tilt misalignment. Therefore, the beam diameter has to be optimized. As the lens connector has an MT connector based structure, parts size accuracy and alignment accuracy can almost be the same as MT connectors. The beam waist diameter is designed to be 52 μm in achieving average insertion loss (IL) of less than 1 dB while taking into consideration the size variation and alignment accuracy of parts.

The IL distribution of a connector pair calculated by the Monte Carlo simulation*4 is shown in **Figure 3**. The major tolerance values used in the optical model are estimated based on the dimensional variation of typical MT/MPO connector parts. The average IL at the wavelength of 1.31 and 1.55 μm are 0.78 dB and 0.53 dB, respectively. The estimated probability for the loss of less than 2 dB is 98%. As the optical design is optimized for the wavelength of 1.55 μm, IL at 1.55 μm is better than that at 1.31 μm.

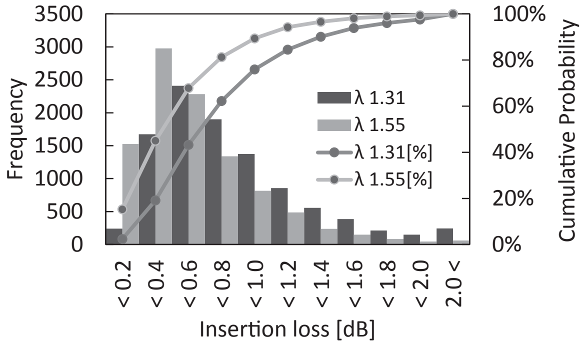

Fig. 3. Monte Carlo simulation results of connector IL

4. Optical Characteristics

SM 24-fiber (2-rows × 12-fibers) lensed connectors were fabricated. Inter-fiber pitch of 0.25 × 0.5 mm was the same as that of a standard 24-fiber MPO connector. Each lens surface has an AR coating for the wavelength of 1.31 and 1.55 μm. The spring force in the mating condition is 3.3 N. It is only about one sixth of that for a 24-MPO connector.

4-1 IL

The measured IL results for five mated connector pairs (5 connector pair × 24 fibers = 120 fibers) are shown in **Figure 4**. The bar graphs show experimental results and the curved line plots indicate simulation results in **Fig. 3**. The average IL at the wavelength of 1.31 and 1.55 μm are 0.67 and 0.54 dB, respectively. They are close to simulated results. The maximum IL at both

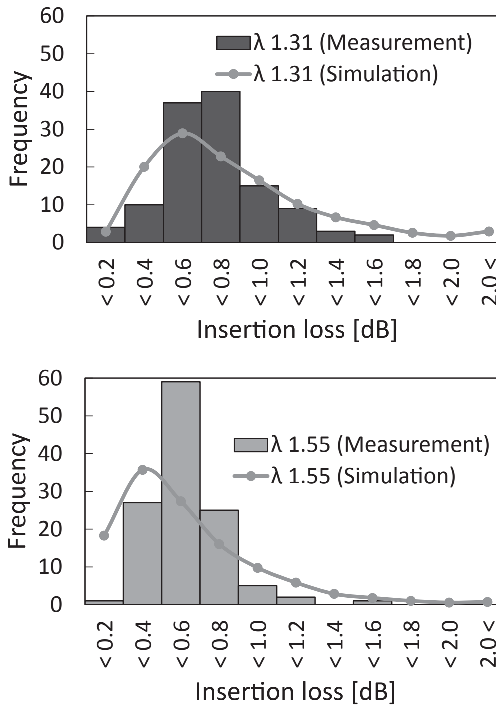

Fig. 4. Measured and simulated IL

wavelengths is less than 1.6 dB. It is better than any of the other results that have ever been reported.

4-2 Crosstalk

Unlike PC connectors, a part of scattered light from the lensed connector might be coupled with other fibers, since a beam from a fiber in the lensed connector transmits through a free space. Therefore the optical channel crosstalk*5 was measured. The input fiber is No. 6. The result is shown in **Figure 5**. Although neighboring fibers in the same row are Nos. 5 and 7, their crosstalk is only less than -70 dB.

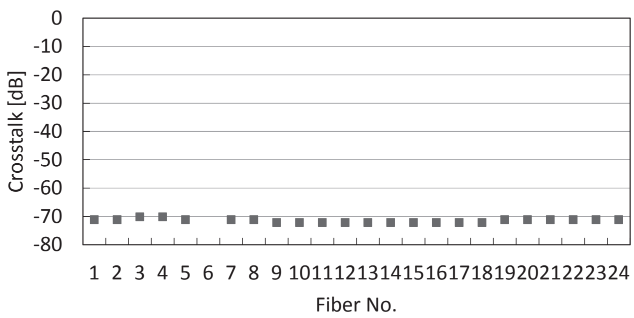

Fig. 5. Measured crosstalk

4-3 Wavelength dependent IL

The wavelength dependence of the IL was measured by an optical spectrum analyzer. Although the characteristics of expanded beam connectors are affected by lens chromatic aberration and AR coating characteristics, IL variation from the wavelength of 1.28 to 1.625 µm is as small as 0.2 dB as shown in **Figure 6**.

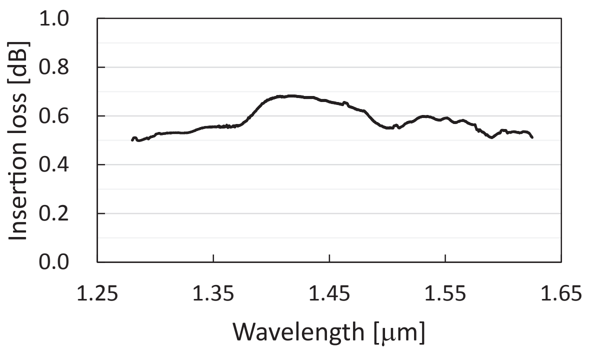

Fig. 6. Measured wavelength dependent IL

4-4 Thermal dependent IL

IL changes at the wavelength of 1.55 µm at temperature in the range of -10 to 60°C were measured. **Figure 7** shows the results of eight channels in one connector pair. The eight channels consist of two channels in both the left and right sides and four channels in the center of one row of the connector. The changes through 15 cycles are less than 0.08 dB. The inserted MT ferrule SMFs and plate GI fiber lenses are made of the same material, therefore misalignment between SMF and GI lenses due to thermal expansion or shrinkage is sufficiently small.

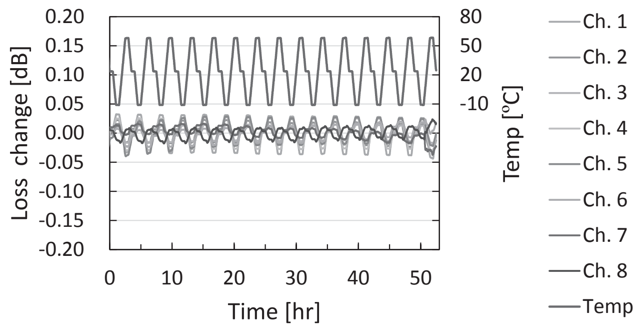

Fig. 7. Measured thermal dependent IL

4-5 Return loss

Measured return loss at the wavelength of 1.31 and 1.55 µm is shown in **Figure 8**. All 24 fibers showed return loss of more than 33 dB.

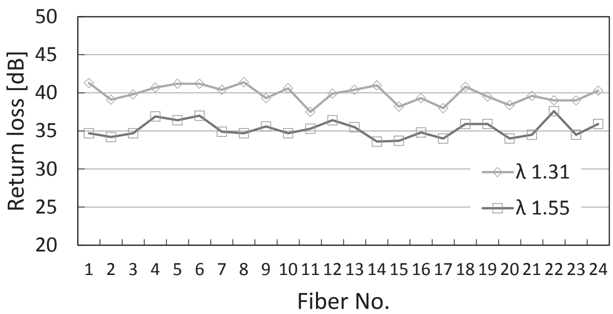

Fig. 8. Measured Return loss

5. Conclusion

24 SMF lensed connectors utilizing an MT connector technology were successfully fabricated. The spring force in the mating condition is only 3.3 N, which is about one sixth of that for a 24-MPO connector. Their average and maximum ILs are less than 0.7 dB and 1.6 dB, respectively, and the return losses are more than 33 dB. The results in this study are better than any other results for SM multi-optical-fiber lensed connectors ever reported.

Technical Terms

*1 Multi-fiber Push-on (MPO) connector: A multi-optical-fiber connector utilizing PC connection technology. It can be connected to an adapter with a one-touch operation.

*2 Mechanically transferable (MT) connector: A multi-optical- fiber connector. The MPO connector was designed based on an MT connector. Both MT and MPO connectors use the same plastic ferrule.

*3 Graded index fiber: A multi-mode fiber. It has a radially distributed refractive index profile. It works as an optical lens as well as a GRIN lens, although the manufacturing method is different from a GRIN lens.

*4 Monte Carlo simulation: A calculation method for an approximate solution using random sampling. In this paper, the insertion loss of the SM lensed connector was estimated by random sampling of connector parts and assembling accuracy.

*5 Crosstalk: A phenomenon where signals transmitted on one line leak into other lines. In this paper, we define it as leakage from one fiber to other fibers.

References

(1) S. Nagasawa et al., "A high-performance single-mode multi-fiber connector using oblique and direct endface contact between multiple fibers arranged in a plastic ferrule," IEEE Photonics Technol Letters, vol. 3, no. 10, pp. 937–939 (1991)

(2) S. Kato et al., "Condition for making physical contact of multi mode 2D MPO connector," Proc. IWCS2010, P. 16

(3) D. Childers et al., "High density, low cost, no-polish optical ferrule," IEEE Optical interconnects conference2013, MD4

(4) D. Childers et al., "New, single-mode, multi-fiber, expanded beam, passive optical interconnect," Proc. SPIE, vol. 8991, 89910J-1 (2014)

(5) C. DeCusatis, "Optical interconnect networks for data communications," J. Lightwave Technol., vol. 32, no. 4, pp. 544–552 (2014)

(6) C. Lam et al., "What devices do data centers need?," Proc. OFC2014, M2K.5

(7) W. Emkey et al., "Analysis and evaluation of graded-index fiber-lenses," J. Lightwave Technol., vol. LT-5, no. 9, pp. 1156–1164 (1987)

(8) O. Shimakawa et al., "Single-mode 24-fiber connector with GI fiber lens array," Proc. OFC2015, W4B.2

Contributors (The lead author is indicated by an asterisk (*).)

O. SHIMAKAWA*

• Assistant General Manager,
Optical Communications R&D Laboratories

H. ARAO

• Optical Communications R&D Laboratories

N. MATSUSHITA

• Information transmission R&D department,
Optical Communications R&D Laboratories

Y. MITOSE

• Optical Communications R&D Laboratories

D. SASAKI

• Assistant Manager, Optical Communications R&D Laboratories

M. OHMURA

• Assistant General Manager,
Optical Communications R&D Laboratories