Multi-Fiber Cylindrical Ferrule for Remote Rotary Optical Fiber Switching

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Abstract: We devise a multi-fiber cylindrical ferrule for a rotary optical switch. We design the ferrule to achieve the equivalent loss to a conventional optical connector, and show the optical switching properties of the fabricated ferrule.

1. Introduction

It is important for 5G and Beyond 5G to construct a truly flexible optical fiber network. In order to allocate routes flexibly to meet optical fiber demands, we proposed an optical access network configuration with a concatenated loop topology and a remote operated optical fiber switching nodes [1,2]. Each node is equipped with optical cross-connect function, port monitoring function, and remote control function. The nodes will be installed outdoors and be driven by what optical energy can be transmitted from the central office. Therefore, the switch needs to be highly power efficient and reliable, and must provide efficient switching operation with extremely low standby power.

It is important that the switch not only save power during operation, but also to consume no power when not in operation. In addition, it is also important not to use spatial optical systems such as mirrors or collimators, as they can readily fall out of alignment due to vibration. The switch should also be immune to environmental changes such as humidity or temperature. An opto-mechanical switch satisfies those requirements. The switch created by rotating a circular array of fiber cores is expected to offer significant power savings because of its very small mechanical movement. Accordingly, we fabricated a prototype opto-mechanical switch based on multi-core fiber rotation switching, and reported 6-core switching performance at a wavelength of 1550 nm [3].

In this paper, we propose an opto-mechanical switch that rotates a multi-fiber cylindrical ferrule holding six equally-spaced conventional single-mode fibers against a ferrule holding one fiber. The multi-fiber ferrule is polished by a combination of spherical polishing and flat polishing to reduce return and gap losses in the O-L band. We measured the optical properties in the fabricated multi-fiber cylindrical ferrule.

2. Ferrule rotated optical switch mechanism and multi-fiber cylindrical ferrule requirement

Figure 1(a) shows an example of the optical switching system configuration. The N × N switch is configured as a matrix of 1 × N switches. Figures 1(b) and (c) show the basic arrangement of the optical switching mechanism for a 1 × N switch and the cross-sectional views of each ferrule. Our proposed optical switch has a multi-fiber ferrule (MFF) in which some single-mode fiber (SMF) are uniformly spaced along a circle centered on the ferrule's center. The switch also has a single fiber ferrule (SFF) whose fiber center matches the circumference on which the fibers of the MFF are set. Optical signal switching is achieved by rotating one of the opposing ferrules.

Figure 2(a) shows a cross-sectional view of the ferrules inside the sleeve. In the proposed switch, fiber endfaces must have some gap, D_G, to avoid damage to the fiber endfaces due to rotation. In conventional optical connectors polished for physical contact, large return loss occurs due to the difference in refractive index between silica glass

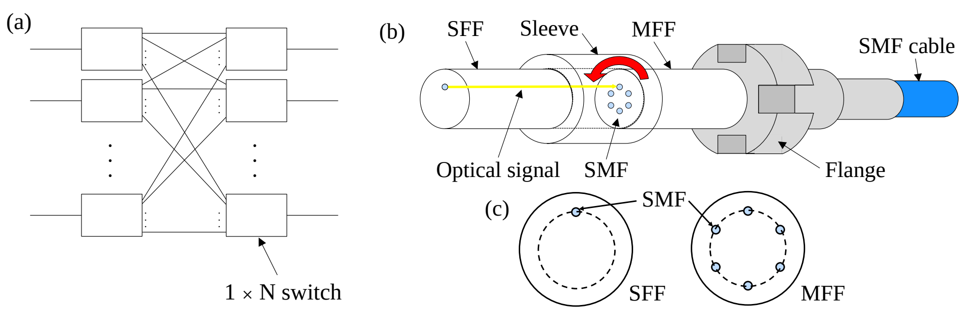

Fig. 1. (a) Optical switch system configuration. (b) Basic arrangement of ferrule rotated optical switching mechanism. (c) Cross-sectional views of SFF and MFF.

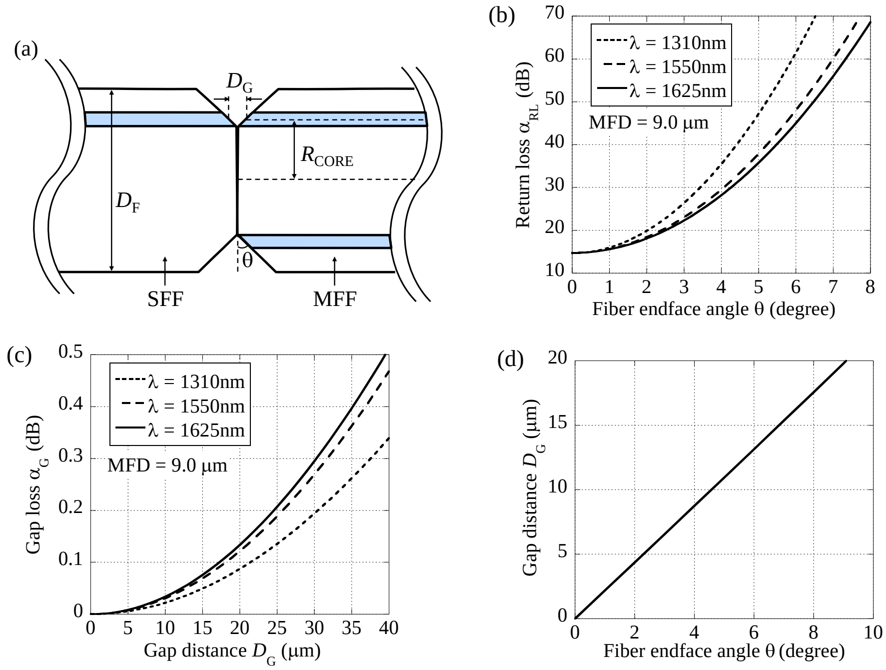

Fig. 2(a) Cross-sectional view of the ferrule aspect inside the sleeve. (b) Relationship between the fiber endface angle and the return loss. (c) Relationship between the gap distance and gap loss. (d) Relationship between the fiber endface angle and gap distance.

and air created by the gap. This degrades transmission performance. Therefore, we polished the fiber endface of MFF at the angle of θ in order to achieve good transmission performance. Figure 2(b) shows the numerical relationship between fiber endface angle θ and return loss α_{RL}. In general, as θ is increased, α_{RL} is increased, and it is possible to reduce the influence of reflection on transmission performance. The standard value of the α_{RL} in a conventional optical connector is 40 dB or more, making it necessary to set θ to 5.5 degrees or more in order to obtain good reflection characteristics in O to L bands. Figure 2(c) shows the numerical relationship between D_G and gap loss α_G. If the mode field diameter is 9.0 μm and α_G is set to 0.1 dB or less, D_G must be suppressed to 18 μm or less. Figure 2(d) shows the relationship between θ and D_G when the ferrule endface is given an oblique profile as shown in Fig. 2(a). Here, the outer diameter of the fiber is 125 μm. θ for realizing the gap of 18 μm or less is 8.2 degrees. Therefore, the allowable angle for achieving a α_{RL} of 40 dB or more and a α_G of 0.1 dB or less is 5.5 to 8.2 degrees.

3. Prototype of optical switch and switching performance

We realized an optical switch that employs the switching mechanism shown in Fig. 1 (b). Figures 3(a) and (b) show, respectively, an endface image observed by microscope and a cross-sectional view of a ferrule during polishing process. We used a zirconia ferrule with 2.5-mm outer diameter D_F as well as a conventional SC connector ferrule. Seven fiber holes including the center were arranged in a hexagonal structure in which the fiber distance R_{CORE} was constant. Conventional single mode fibers were inserted and bonded into each fiber hole. In order to realize the ferrule endface shown in Fig. 2(a), a new polishing process combining spherical polishing and flat polishing was performed. In spherical polishing, the relationship between θ at R_{CORE} and curvature radius R_{CR} is given by equation (1).

$$\sin\theta = \frac{R_{CORE}}{R_{CR}} \qquad (1)$$

Figure 3(c) shows the numerical relationship between θ and R_{CR} at the fiber endface. When R_{CR} is 6.0 to 8.9 mm, it is possible to achieve α_{RL} of more than 40 dB and a θ of 5.5 to 8.2 degrees which realizes a α_G of less than 0.1 dB. Figures 3(d) and (e) show the measured return loss values of the fabricated MFF. A α_{RL} of 50 dB or more was achieved at wavelengths of 1.31 and 1.55 μm. The θ observed by using a laser microscope was 6.0 to 6.5 degrees. The fabricated MFF was rotated in 60 degree increments in the solid sleeve for switching. Figure 3(f) plots the loss

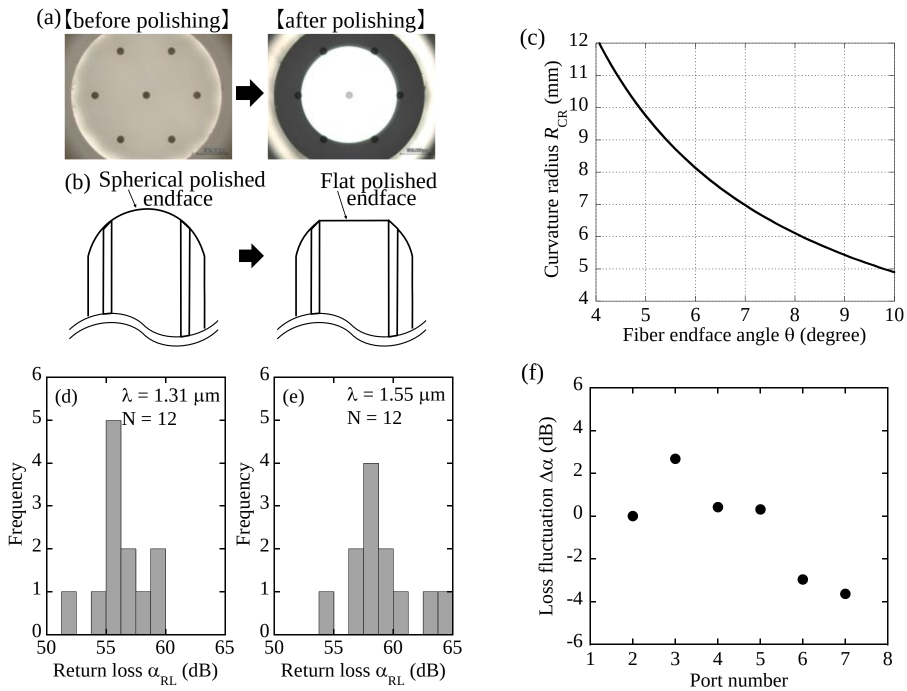

Fig. 3(a) Endface image by microscope observation. (b) Cross-sectional view of ferrule aspect during polishing process. (c) Relationship between fiber endface angle and curvature radius. (d) Return loss characteristics of fabricated MFF at 1.31 μm. (e) Return loss characteristics of fabricated MFF (d) at 1.55 μm. (f) Loss fluctuation by MFF rotated switching.

fluctuation, $\Delta\alpha$, at each port under switching. In this experiment, two MFFs were connected facing each other inside a solid sleeve and one MFF was switched using only one fiber. Here, port 1 located at the MFF center was not used in switching. We found that by switching yielded a $\Delta\alpha$ of -3.7 to + 2.7 dB. The R_{CORE} of the rotating MFF was 841.5 to 846.2 μm. Moreover, the fiber distance from the center fiber of the MFF used as the SFF dummy was 847.6 μm. Therefore, a maximum offset of about 6 μm occurs in the switching, and it is considered that the loss fluctuated due to the offset loss. The fiber hole misalignment in the ferrule for the conventional optical connector is specified to be 0.5 μm or less. Therefore, by limiting the variation of R_{CORE} to 0.5 μm or less, the offset loss is reduced to 0.2 dB or less [4], and good connection characteristics can be expected.

4. Conclusion

We proposed an optical switch that utilizes a multi-fiber cylindrical ferrule. Assuming communication in the O to L bands, we proposed an endface shape that realizes reflection characteristics equivalent to those of conventional optical connectors. A new polishing process that combines spherical polishing with flat polishing realizes an MFF with a return loss exceeding 50 dB. The fabricated MFF was rotated inside a solid sleeve to perform switching, and we confirmed that the optical signal passed through the fibers set in the MFF. It was clarified that connection characteristics equivalent to those of a conventional optical connector can be expected by suppressing the dispersion of the fiber hole position of the MFF to about 0.5 μm.

5. References

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