Recent Trends and Future Challenges concerning Research on Multi-core-Fiber Connection and Optical Cable

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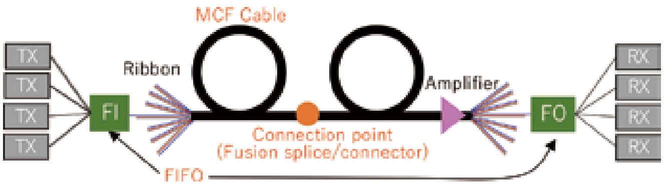
1. Background

The "single-mode fiber" (SMF) currently used in optical communications has only one core, which provides the pathway for transmission of light, and its communication capacity is said to be approaching the limit[1]. To address the growing need for enhanced communication capacity, "multi-core fiber" (MCF) has become the focus of significant attention. Recently, several connection technologies and cable technologies necessary for the practical application of MCF have been reported. The latest trends and future challenges concerning these technologies are introduced in this article.

2. Multi-core-fiber connection technology

A schematic diagram of a transmission system using MCF cables is shown in Figure 1. Firstly, the fusion-splicing technology and connector-connection technology for connecting the MCFs are introduced. Secondly, the SMF-MCF conversion technology required to connect MCF cables to existing SMFs is then introduced. Finally, the challenges associated with these technologies are described.

■ Figure 1: Schematic diagram of MCF transmission system

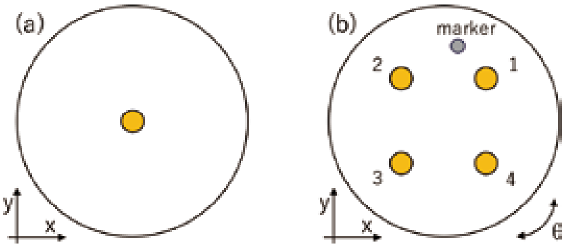


2.1 Fusion-splicing technology

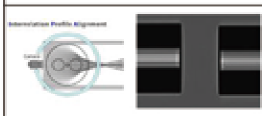
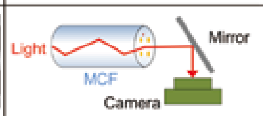
Fusion splicing is a method of joining optical fibers by heating and melting the tips of the optical fibers. It is widely used as a general-purpose method of connecting SMF (with one core in the center of the cladding); however, MCFs (with multiple cores located away from the center of the cladding) must be rotationally aligned around the axis of the MCF (see Figure 2). The two main methods for observing and aligning the cores of MCFs are shown schematically in Figure 3. The "side-view" and "end-view" methods are ways of aligning the cores of MCF in reference to side and cross-sectional images of the MCF, respectively. Compared to the end-view method, the side-view method allows for a simpler equipment configuration and is advantageous in terms of size and cost.

In recent years, many studies have used the side-view method, and it has been reported that the average splice loss and alignment time for 4-core MCF are 0.1 dB and 90 seconds, respectively[2, 3]. The challenge facing MCF fusion-splicing technology is how it can achieve similar splice loss and splicing time as those achieved by SMF splicing technology, and, at present, splice loss and splicing time must be further reduced.

■ Figure 2: Cross-section and alignment direction of optical fiber: (a) SMF and (b) MCF



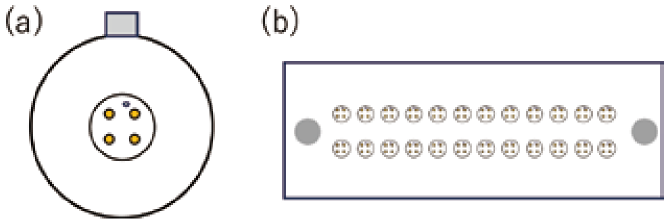
■ Figure 3: Observation methods and features of fusion splicing

	Side-view method	End-view method
Observation methods		
Observation mechanism	Simple (Rotation-alignment mechanism is required)	Complicated
Alignment time	Middle	Long
Detection of markers	Possible (simple structure)	Possible (complicated structure)

2.2 Connector technologies for single fiber and multiple fibers

"Connector connection technology" is a kind of a detachable connection method. As with fusion splicing, after rotationally aligning each MCF core with respect to the axis of the optical fiber, it is necessary to fix the cores to the connector key. To date, as well as single-MCF connectors, multiple-MCF connectors have been reported (see Figure 4). As for single-MCF connectors average loss of less than 0.1 dB has been reported[4], and as for multiple-MCF connectors average loss of less than 0.2 dB has been reported[5, 6].

■ **Figure 4: Schematic diagrams of MCF connectors: (a) single MCF and (b) multi MCF**



The challenge facing MCF connector-connection technology is how it can achieve similar connection loss and alignment time as those achieved by SMF connector-connection technology while minimizing associated costs. Currently, it is necessary to further reduce connection loss and alignment time.

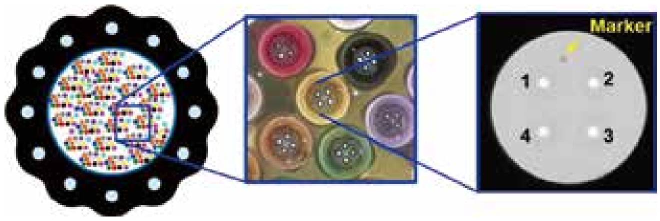
2.3 SMF-MCF conversion technology

Connecting existing SMFs and devices to MCF necessitates a fan-in/fan-out (FIFO) configuration to multiplex and demultiplex each core of the MCF. The four types of FIFO configurations—with the associated insertion loss and cost—are shown schematically in Figure 5. As shown in the figure, the bundle type[7, 8, 9], which achieves low loss and low cost, and the fused type[10], which achieve low loss and high reliability, are attracting attention. Insertion losses averaging 0.4 dB and 0.2 dB have been reported for the bundle and fused types, respectively. The SMF-MCF conversion technology (FIFO configuration) is implemented as a device that is not found in normal SMF systems, and it is hoped that the device will be further reduced in terms of loss, cost, and crosstalk in the future.

3. Multi-core-fiber cable technology

To enable the practical application of MCF, it is necessary to install it in the field as cables. To date, MCF cables consisting of several to several hundred 2- to 12-core MCFs have been reported[11-15]. It has also been reported that these MCF cables have loss increases and mechanical properties equivalent to those of SMF cables[11-14], and it has been confirmed that they do not pose any major problems when laid in the field[13]. A schematic cross-sectional view of a cable composed of 288 four-core MCF and a photo of a portion of the cable are shown in Figure 6. Since MCF cables can bundle a very large number of cores at high density, they are expected to be used in applications requiring high-density, high-capacity transmission, such as undersea cables and data centers. To enable the practical application of MCF, it is desirable to develop technology to reduce the connection time and inspection time for a large number of MCFs in a cable.

■ **Figure 6: Cross-sectional view of MCF cable and MCFs**



4. Conclusion

The latest trends concerning the connection technology and cable technology necessary for practical application of MCF—and future challenges facing each technology—were introduced.

References

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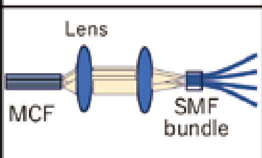
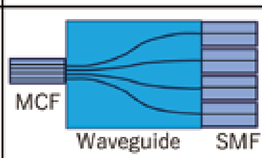
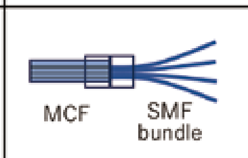
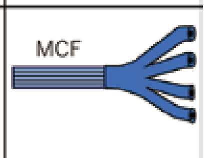
■ **Figure 5: Four types of FIFO configurations**

	Free space type	Waveguide type	Fiber bundle type	Fused type
Schematic diagram				
Loss	Low	Medium	Low	Low
Cost	Medium	Low	Low	Medium