No-polish Air-gap Single-mode Low-loss Multi-fiber Anti-reflection Coated Connector

K. K. Wojewoda, I. A. Radice, M. O. D. Kearney, U. Thapa, and I. J. Murgatroyd
Oxford Fiber Ltd, Sir Frank Whittle Business Centre, Gt. Central Way, Rugby, CV21 3XH, UK
kaz.wojewoda@oxfordfiber.com

Abstract: We developed a multi-fiber air-gap optical connector which does not require polishing or physical contact between fibers. The developed single-mode connector has an average IL of 0.36dB and RL of 59.3dB with anti-reflective coating.
OCIS codes: (060.1155) All optical networks; (060.2340) Fiber optics components; (060.0060) Fiber optics and optical communications; (200.4650) Optical interconnects.

1. Introduction

Optical fibers are of great importance in the maintenance and growth of internet communication including the expected growth in 5G mobile networks [1,2]. Crucial to the performance of the wider optical network is the need to connectorise the optical fibers so that light can be injected into or extracted from the optical fiber. Optical fiber jumpers terminated with connectors are used to link the components and equipment in the fiber optics network. To meet the increase of data traffic, multi-fiber push-on (MPO) connectors using angled physical contact (APC) mating have been developed [3]. To ensure low insertion loss (IL) and return loss (RL), all the optical fibers of an APC-MPO/APC-MPO connection must stay in physical contact. A great challenge is to clean APC-MPO connectors in use as dust can interfere with the light and stop fibers' faces from physical contact causing air gaps. In the presence of air gaps, optical interference between input and reflected beams will occur causing IL to vary with gap thickness and wavelength [4]. Another challenge for MPO connector is the manufacturing process, which requires several polishing steps of the MT-ferrule end-face, is complex and time consuming [5].

To overcome the drawbacks of the APC-MPO connectors, new types of non-physical-contact connectors have been developed. The most common non-contact connectors are lensed connectors, which expand the light beam making the connection less sensitive to dust [5, 6] but these have high IL. The second type of non-physical contact connectors are air-gap connectors which apply micron level gaps between the fiber faces of mated connectors. Air-gap connectors are more sensitive to dust than lensed connectors, but cleaning of the end face is easier than APC-MPO connectors due to non-physical contact mating. When the air-gap is micron level, the optical interference between input and reflected beams will cause the IL to vary with gap size or wavelength. This optical interference can be suppressed by anti-reflection (AR) coating [7].

In this paper we present a new type of air-gap multi-fiber connector. This connector does not require polishing of the end face, which lowers the cost of manufacturing. The manufacturing process of this connector uses an 8° pre-angled MT ferrule, with an angle cleaved multi-fiber ribbon precisely glued into the ferrule. The fiber end-faces are recessed below the end face of the ferrule, which creates an air-gap when this connector is mated with a connector of the same type, or mated with a standard APC-MPO ferrule. AR coating is applied on the ferrule end-face to improve IL and RL and to suppress optical interference.

2. Structure and optical design

The proposed design of the angled no-polish connector (ANP-MPO) with an air-gap is shown in Fig. 1 and it is compatible with the standard APC-MPO connector. The manufacturing process of ANP-MPO starts by preparing a 12-fiber stop ferrule using conventional polishing to produce fibers protruding by several microns. The stop ferrule is mated with an MT ferrule so that the protruding fibers enter the fiber channels of the MT ferrule. A ribbon of 12 fibers is cleaved at an 8° angle, using the Ox-RAC-08 angled ribbon cleaver from Oxford Fiber Ltd., and inserted into the 12-channel MT-ferrule. The cleaved fiber ribbon is pushed up against the protruding fibers of the stop ferrule so that the cleaved fibers are stopped a few microns sub-flush from the end of the MT ferrule. The cleaved fibers are glued into place and the stop ferrule is removed. This creates an MT ferrule with an air-gap. The cleaved fiber end faces are controllably recessed from the end-face of the MT-ferrule with a variation in fiber positioning across the 12 fibers of less than 3 microns. The average recess is controlled in the range of 2.5-10 microns. The manufacturing process is finalized by applying an AR coating layer. To maximize the number of connectors coated at once in a vacuum chamber, only a short portion of fiber is cleaved and glued into an MT-ferrule. After the AR coating process is completed, the connector is fusion spliced to a long length of optical fiber ribbon as shown in Fig. 1. An ANP-MPO to standard APC-MPO connection is presented in Fig. 2. The ANP-MPO can be connected to ANP-MPO, and such a connection is shown in Fig. 3.

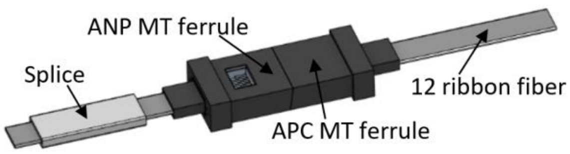

Fig. 1. ANP-MPO with a fusion splice connected to a standard APC-MPO (connector housing not shown).

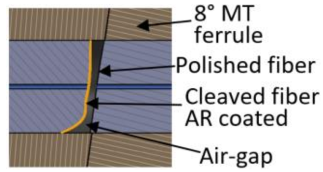

Fig. 2. ANP to APC connection (fiber end-face separation is exaggerated).

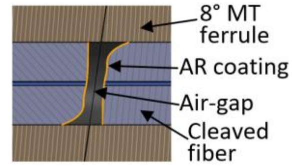

Fig. 3. ANP to ANP connection (fiber end-face separation is exaggerated).

3. Evaluation of optical characteristics

We fabricated 12-fiber, air-gap, AR coated, SM connectors (ANP-MPO*)* and measured their optical properties. Fig. 4 summarizes the IL of 26 female connectors (N=312 channels) mated with a standard (not AR coated) male APC-MPO reference jumper (the type of connection shown in Fig. 2). As shown in Table 1, the IL at the wavelength (WL) of 1310 nm is less than 0.66 dB and at the WL of 1550 nm is less than 0.63 dB with a probability of 97%. As shown in Table 2, the RL at the wavelength (WL) of 1310 nm is less than -49.6 dB and at the WL of 1550 nm is less than -49.5 dB with a probability of 97%. The ANP-MPO was fusion spliced to an APC-MPO pigtail and the splice losses are included in the measurements.

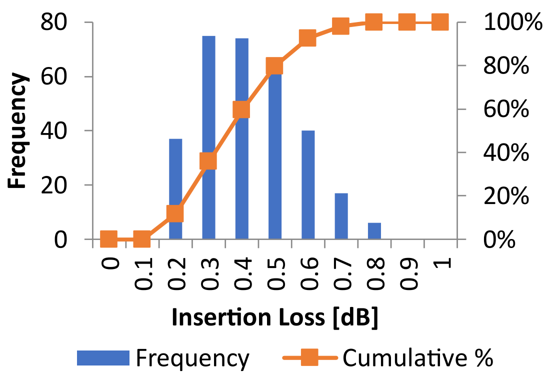

Fig. 4. Measured IL distribution at 1310 nm for ANP-MPO to APC-MPO connections.

Table 1. Measured IL for ANP-MPO to APC-MPO connection.

WL	1310nm	1550nm
Ave.	0.38 dB	0.35 dB
SD	0.14 dB	0.12 dB
97%	0.66 dB	0.63 dB

Table 2. Measured RL for ANP-MPO to APC-MPO connection.

WL	1310nm	1550nm
Ave.	61.4 dB	59.2 dB
SD	5.6 dB	4.7 dB
97%	49.6 dB	49.5 dB

We observed that APC-MPO to APC-MPO connection is more sensitive to dust than ANP-MPO to APC-MPO. Fig. 5 and Fig. 6 present measured IL for 12 fibers for APC-MPO to APC-MPO and ANP-MPO to APC-MPO respectively. For both connections (Fig. 5 and 6), the connectors were cleaned with a Cletop™ tape before the test and then cleaned with an ionizing air-gun every 10 connect/disconnect cycles.

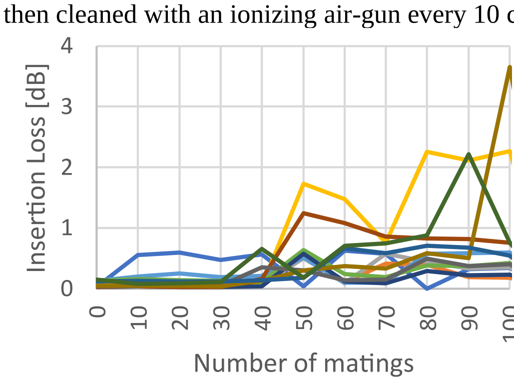

Fig. 5. Measured IL for 100 of APC-MPO to APC-MPO connect and disconnect cycles (12 channels).

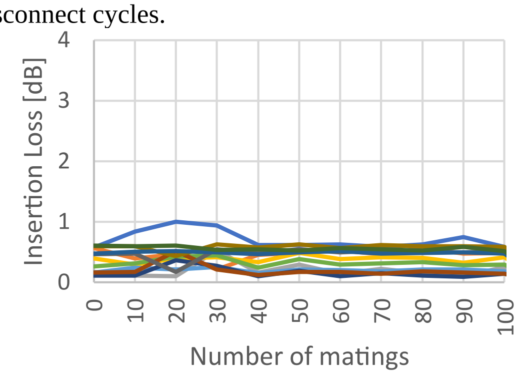

Fig. 6. Measured IL for 100 of ANP-MPO to APC-MPO connect and disconnect cycles (12 channels).

The APC-MPO/APC-MPO connector is seen to have unstable IL for increasing numbers of matings, across many of the 12 channels. This is presumably due to the presence of dust. In contrast, the ANP-MPO/APC-MPO connector shows little evidence for an increase of IL over a similar number of mating cycles. This demonstrates the superiority of an air gap connector in real life networks which may suffer multiple disconnections and which may be difficult to clean adequately.

26 pairs of ANP-MPO/APC-MPO connectors were thermally aged at 60°C for 3 days, humidity aged (95%) at 40°C for 3 days and dried-out at 60°C for 1 day. Two pairs of ANP-MPO/APC-MPO were vibration tested from 10 Hz to 55 Hz in 3 axes for 2 hours each. Three pairs of ANP-MPO/APC-MPO connectors were successfully tested under tension (2.2 N), 1.5 m drop tested and 50 connect/disconnect cycles tested. A pair of ANP-MPO/APC-MPO was thermal cycled from -40°C to 75°C. Maximum observed IL change at 1310nm was 0.26dB (recorded during thermal cycle test). The ANP-MPO connectors are seen to be robust.

Fig. 7 summarizes the IL of 25 female, SM, ANP-MPO connectors (N=300 channels) mated with a male ANP-MPO reference jumper (as shown in Fig. 3). The measured raw IL results for ANP-MPO/ANP-MPO are reduced by 0.15 dB to account for lack of reflection at the reference point for the IL measurement [8]. As shown in Table 3, the IL at the wavelength (WL) of 1310 nm is less than 0.73 dB and at the WL of 1550 nm is less than 0.68 dB with a probability of 97%. As shown in Table 3, the RL at the wavelength (WL) of 1310 nm is less than -48.6 dB and at the WL of 1550 nm is less than -47.1 dB with a probability of 97%. The ANP-MPO was fusion spliced to an APC-MPO pigtail and the splice losses are included in the measurements.

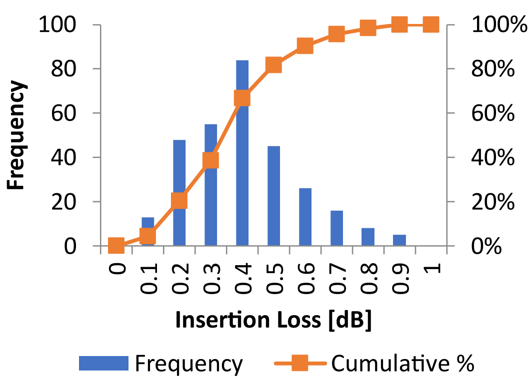

Fig. 7. Measured IL distribution at 1310 nm for ANP-MPO to ANP-MPO connection.

Table 3. Measured IL for ANP-MPO to ANP-MPO connection.

WL	1310nm	1550nm
Ave.	0.36 dB	0.31 dB
SD	0.17 dB	0.16 dB
97%	0.73 dB	0.68 dB

Table 4. Measured RL for ANP-MPO to ANP-MPO connection.

WL	1310nm	1550nm
Ave.	59.3 dB	62.1 dB
SD	6.2 dB	7.4 dB
97%	48.6 dB	47.1 dB

4. Conclusions

We have demonstrated a new type of multi-fiber connector, ANP-MPO, which does not require a polishing process. Instead, the proposed connector utilizes 8° angle cleaved fibers, which are fixed in a standard 8° pre-angled ferrule. The fiber end-faces are intentionally recessed from the MT ferrule end-face to create air-gaps. To suppress optical interference and improve IL and RL the end-face of the connector is AR coated. The ANP-MPO can be connected to a second ANP-MPO, as well as to a standard APC-MPO, which means the ANP-MPO is compatible with the existing connector architecture. The average IL at 1310 nm for the ANP-MPO/APC-MPO and the ANP-MPO/ANP-MPO connections was 0.38 dB and 0.36 dB respectively, and RL was more than 59dB. Environmental testing shows that the connector is robust for field use and stable over many connect/disconnect cycles. This new connector is suitable for use in fiber networks with its advantage of dust-insensitivity and simpler manufacturing.

5. References

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