Stripping-Free Direct Fiber Insertion Connectors Using Thin-Coated Optical Fibers

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Abstract: Single-mode fiber connectors are demonstrated with 125 µm diameter thin-coated fibers directly inserted into connector ferrules. Low insertion loss of less than 0.3 dB is achieved due to the high concentricity of the coating. © 2022 The Author(s)

1. Introduction

Optical connectors are a fundamental building block of optical fiber communication networks, which have been experiencing exponential growth driven by hyperscale datacenters and 5G wireless deployment [1]. For making optical connectors, the termination process always starts with stripping the coating of the fiber and exposing a section of cladding to insert into and bond with the micro holes of the connector ferrule. This connector making process has been largely based on manual processing, which is labor intensive and time consuming. Process automation has been making progress in recently years to improve production efficiency and product yields. In both the manual and automated processes, coating stripping is a critical step. In the fiber stripping process, the coating is carefully removed to avoid damage to the glass cladding. However, when bare fiber is inserted into the ceramic ferrule, any mechanical contact can still result in flaws that can cause immediate fiber breaks, which are particularly a problem for automated processes. In addition, the flaws on glass cladding can cause long term connector reliability issues.

To avoid fiber break and connector reliability issues, it is desirable to leave a coating layer on fiber cladding to protect the glass. For the standard single-mode fiber with a coating diameter of about 250 µm, the variations of coating diameter and concentricity are in the range of a few microns. These large geometry coating variations make it very difficult to achieve required low connector loss. Recently, thin-coated fiber with 125 µm coating diameter has been demonstrated [2], which is attractive for connector applications.

In this paper, we propose stripping-free connectors by direct insertion of an optical fiber with a thin precise polymer hard coating into a connector ferrule and demonstrate feasibility of low connector insertion loss.

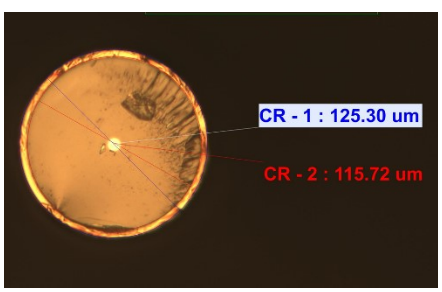

Fig. 1. Cross section of a 125 µm diameter thin-coated fiber. CR-1: Coating diameter. CR2: Cladding diameter.

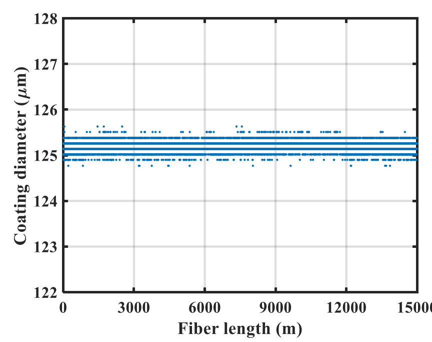

Fig. 2. Measured coating diameter along the fiber length.

2. Precision Thin-coated Fiber

The refractive profile used in our thin-coated fibers is a step-index design used in standard single-mode fibers. The glass diameter is reduced to around 115 µm to allow a thin coating with 125 µm diameter, which enables us to use the standard ceramic ferrules without stripping the coating layer for connector applications.

To place a uniform thin coating on fiber with a uniform diameter and good concentricity, the coating process parameters such as diameter of glass fiber, diameter of sizing die, draw speed, material properties of the coating fluid and delivery pressure are controlled carefully. Through precise process control and optimization, we can put a thin coating on fiber with excellent uniformity and concentricity.

For connector applications with thin-coated fiber directly inserted into a connector ferrule, good coating adhesion to glass and coating stability that can survive the connector polishing process are essential. To meet these requirements, a commercially available acrylate hard coating was selected, that has a Young's modulus of larger than 2 GPa and a pencil hardness of greater than 6H. Fig. 1 shows a micrograph of the cross section of a thin-coated fiber. The fiber cladding diameter is about 115 µm, and the coating dimeter is 125 µm. The fiber shows excellent coating concentricity. The fiber has also very small coating diameter variations. Fig. 2 plots the measured coating diameter during fiber draw over a length of 1.5 km. The coating diameter has a standard deviation of 0.14 µm, which is comparable to that of the glass cladding.

3. Stripping-free Direct Fiber Insertion Connector Process

Thin-coated fiber is first inserted into a 1.0 mm diameter loose tube cable for ease of handling. The thin-coated fiber cable is terminated with LC connector components using a standard process except for skipping the fiber stripping step. Standard fiber bonding epoxy such as the EPO-TEK 353ND is dispensed at the back end of the ferrule. The un-stripped thin-coated fiber is then inserted into the ferrule micro hole with the epoxy wicking throughout the gap between the fiber coating and the inner surface of the micro hole.

LC ceramic ferrules with an average micro hole diameter of 125.5 µm were used to demonstrate close fit fiber insertion. The average diameter of the fiber coating is 125.2 µm. With such a close fit, insertion of the thin-coated fiber into the ferrule is still feasible. Because the fiber glass cladding is never exposed, there is no risk of flaw generation or fiber break even if there is friction during the fiber insertion into the ferrule.

The bonded fiber ferrule assembly is cured at 150 °C for 1 hour before going through standard denubbing and polishing process. Six LC connector jumpers using thin-coated fibers were fabricated.

4. Results and discussions

Microscope image of a polished connector end face is depicted in Fig. 3, where the thin-coating cross section along with a small epoxy bond line is shown. The coating thickness is highly uniform.

End-face geometry of the connector was measured using an interferometer (Sumix-Quantum), from which we could obtain connector geometric parameters such as fiber protrusion, radius of curvature, and apex offset. Fig. 4 plots fiber protrusion heights above the ferrule surface for 12 connector samples. It can be seen that all the fiber protrusion heights are between about 75 to 100 nm, which is within the IEC standardization on single-mode connectors [3]. Also, other parameters such as radius of curvature and apex offset all meet standard requirements.

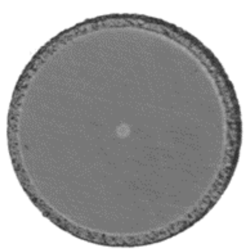

Fig. 3. Microscope image of the connector end face.

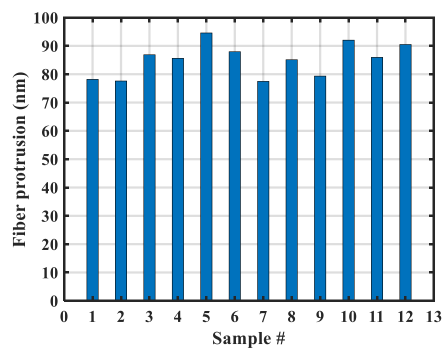

Fig. 4. Fiber protrusion at the connector end face measured by interferometry.

Fiber protrusion remained consistent after 10 mate-demate cycles. Mated connector pairs were further tested under temperature cycles from -10 °C to 60 °C over 8 hours for 21 cycles. The fiber protrusions were then re-tested. The difference in fiber height after thermo cycles was less than 50 nm, which is consistent with that of standard connectors. The bonding strength between the outer surface of the coating and the ceramic ferrule is therefore comparable with that of standard glass to ceramic interface.

Although the measured protrusion results are below the IEC requirement, they are on the high side of the 100 nm limit. To understand better fiber protrusion effects of thin-coated fiber, a numerical simulation was performed on thin-coated fiber and standard fiber connectors using a finite-element-analysis (FEA) approach similar to the one reported in Ref. [4-5]. Stress distribution induced by the end face geometry was modeled assuming the same spring load for both connector types. By analyzing the stress distribution under a radius of curvature (ROC) in the range of 5-30 mm in simulation, it was found that the smaller ROC caused larger compressive pressure due to smaller interactive area in the contact pair. FEA results of 5 mm ROC on standard fiber and thin-coated fiber PC type connectors are compared in Table 1. Fiber protrusions of standard fiber do not significantly change the stress distributions on the end face of fiber. If using the stress of standard fiber as a reference, thin-coated fiber can tolerate slightly higher fiber protrusion up to 230 nm. This is caused by the coating layer of the thin-coated fiber inside the connector ferrule. The coating layer combined with the epoxy layer absorb more pressure and bring more deformation compared with the standard fiber connector. It also results in larger displacement of ferrule in the thin-coated fiber connector.

Table 1. Stress distributions and deformation comparisons on standard and thin-coated fiber PC type connectors.

ROC = 5 mm	Fiber protrusion (nm)	Deformation of fiber core (nm)	Stress on fiber core region (MPa)	Deformation and displacement of inner diameter of ferrule (nm)
Standard fiber	100	4.68	-383.3	3093.5
Thin-coated fiber	100	4.48	-364.9	3296.7
	230	4.88	-383.0	3416.0

Measured core concentricity of the connectors using a Data Pixel Koncentrik-V2 system is illustrated in Fig. 5. Due to the close fit between the thin-coated fiber diameter and the ferrule inner diameter, the core-to-ferrule eccentricity is less than 500 nm, which also confirms the excellent thickness uniformity of the thin-coated fibers. Fig. 6 shows the insertion loss of 12 randomly selected connector pairs, which is less than 0.12 dB and is consistent with the measured core-to-ferrule eccentricity of the connectors. The connector pairs also exhibit low return loss. The measured return losses for all pairs are less than -50 dB.

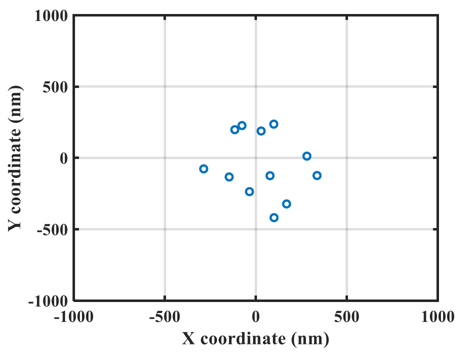

Fig. 5. Plot of core-to-ferrule concentricity.

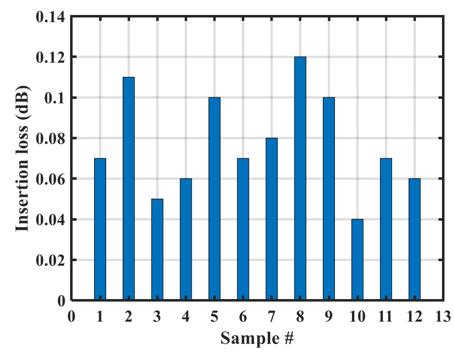

Fig. 6. Insertion loss of 12 randomly selected connector pairs.

5. Conclusions

Thin-coated fibers with a single layer of 125 µm diameter hard coating have been directly terminated in LC connectors without the need of stripping the coating. Polishing process and end face geometry of the connector are similar to those of standard connectors. Random mate insertion loss of less than 0.3 dB and return loss of less than -50 dB have been demonstrated due to the high core-to-ferrule concentricity. This simple termination process eliminates flaws due to mechanical coating stripping process, which reduces fiber breaks in connector process and can result in connectors with high reliability.

6. References

[1] Cisco Annual Internet Report (2018–2023) White Paper, https://www.cisco.com/c/en/us/solutions/collateral/service-provider/global-cloud-index-gci/white-paper-c11-738085.html.

[2] W. Niu, M. Drake, B. R. Knowlton, Y. Zhang, A. L. Wallace, J. S. Stone, Y. Gu, S. D. Hart, H. M. de Pedro, A. R. Zakharian, and M. Li, "Thin-Coated Fibers for High-Density Optical Interconnects," in Optical Fiber Communication Conference (OFC) 2021, P. Dong, J. Kani, C. Xie, R. Casellas, C. Cole, and M. Li, eds., OSA Technical Digest (Optical Society of America, 2021), paper M3C.2.

[3] IEC 61755-3-1, "Fiber optic connector optical interfaces – Part 3-1: optical interface, 2.5 mm and 1.2 mm diameter cylindrical full zirconia PC ferrule, single mode fiber" July 2006.

[4] Zhou, Xinlei & Yao, Qiang & Chen, Ke & Gong, Zhenfeng & Peng, Wei & Yu, Qingxu. (2016). Loss analysis of physical contact fiber-optic connector induced by the endface geometry and the contact force. Optical Engineering. 55. 046107. 10.1117/1.OE.55.4.046107.

[5] Robert Elkins et al, "Compensating for fiber undercut in physical contact optical connectors", IWCS, 2010.