Reduced Coating Diameter Fibers for High Density Cables

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Abstract: We review recent progress on reduced coating diameter fibers for increasing core density for optical interconnect applications. We discuss design considerations on microbending and mechanical reliability and present new experimental results. © 2022 The Author(s)

1. Introduction

High bandwidth and dense optical interconnects have attracted a lot of attention to accommodate the exponential growth of data center traffic. To increase the bandwidth of optical transmission links, systems with higher data rates [1] and more wavelengths [2] are being developed. Another dimension for increasing the bandwidth is to increase the core density in fiber and cables. Space division multiplexing (SDM) has been proposed using new types of multicores fibers or few modes fibers [3,4]. However, a new ecosystem needs to be developed for deploying these new SDM fibers including low-cost fiber manufacturing, fan-in/out or mode mux/demux devices, splicing and connector technologies. The core density can also be increased by reducing the fiber diameter. The fiber diameter can be reduced by decreasing the coating thickness and/or glass diameter. Fibers with the standard 125 µm glass diameter and reduced coating diameters of 190 µm and 200 µm have been commercially available for the past few years. Further reducing the coating diameter to below 190 µm with the standard glass diameter has been proposed [5,6]. In parallel, reduced cladding fibers with a glass diameter of 80 µm and a coating diameter around 165 µm have also been proposed beyond specialty applications [7-9].

In this paper, we review reduced diameter fiber technologies and discuss tradeoffs of different approaches. We focus on reducing coating diameters and present new experimental results.

2. Approaches for reducing fiber diameter

There are two approaches for reducing the fiber diameter as shown in Fig. 1. One approach is the reduced clad fiber (RCF) in which the clad diameter is reduced to less than 125 µm, for example 80 µm. The coating thickness can be kept the same as the standard diameter fiber or can be reduced too. The other approach is the reduced coating diameter fiber (RCDF) in which only the coating diameter is reduced while keeping the clad diameter of 125 µm. Both approaches offer smaller fiber diameters that can increase the core density in fiber cables, and each has its own advantages and challenges.

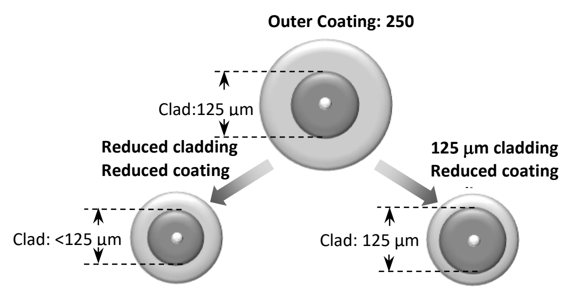

Fig. 1 Two approaches for reducing fiber diameter.

For the RCDF, one key advantage is the compatibility with the existing ecosystem for standard single-mode fibers with 125 µm glass diameter and the fiber can be handled with standard field equipment and installation procedures for splicing and connectorization. RCF can offer better bending reliability and packing density for component applications but requires new connectivity solutions.

For both the RCF and RCDF, two key design challenges are microbending sensitivity and mechanical reliability, which we will discuss more in detail in the next two sections.

3. Micro-bending sensitivity

For microbending sensitivity, both the glass diameter and coating thickness play important roles. Fiber microbending can be classified into two categories. One category is the intrinsic microbending caused by fiber buckling due to stresses produced by differential thermal expansion coefficients of glass and coating materials without external mechanical perturbations. A theoretical model has been proposed to analyze fiber buckling effects [10]. The minimum buckling strain threshold depends on the Young's moduli and dimensions of glass, primary and secondary coating materials. We use the curvature of bend due to fiber buckling [11] normalized to that of the fiber with standard 125 µm glass, 190 µm primary and 242 µm secondary coating diameters to describe the fiber intrinsic microbending sensitivity. Fig. 2(a) shows the effect of glass diameter on the intrinsic microbending sensitivity for different coating diameters. The ratio of the primary to the secondary coating diameters is kept constant at 1.25 for the three different coating diameters. It can be seen that both the glass diameter and the coating diameter have a large impact on the fiber intrinsic microbending. Smaller glass diameters and thicker coating diameters increase the intrinsic microbending sensitivity due to fiber buckling. For RCF with 80 μm glass diameter and 165 μm coating diameter, the intrinsic microbending sensitivity is about 6 times higher than the standard cladding fiber. This explains why the attenuation of the step-index core RCF with 80 μm glass diameter is about 0.5 dB/km, which is much higher than the standard single-mode fiber [7]. The microbending of RCF can be improved by putting a deep index trench in the clad, reducing the fiber MFD [7-9], or by further optimizing the extend of cladding reduction. On the other hand, the intrinsic microbending sensitivity of RCDF is reduced and the MFD can be kept around 9.1 μm, which is suitable for low loss connectors and splices. We made RCDF with different core profiles and different coating diameters ranging from 140 to 175 μm. Table 1 shows the measured cable cutoff, MFD and attenuation. These fibers have an MFD at 1310 nm around 9.1 μm but show no attenuation penalty on a standard shipping spool with 70 g winding tension compared to similar fibers with a standard 250 μm coating diameters. The fiber with a fluorine (F) trench also meets the ITU-T G.657.A1 and A2 bending requirements. The silica (Si) core fiber shows an attenuation of 0.160 dB/km which is of interest for applications relying on low loss.

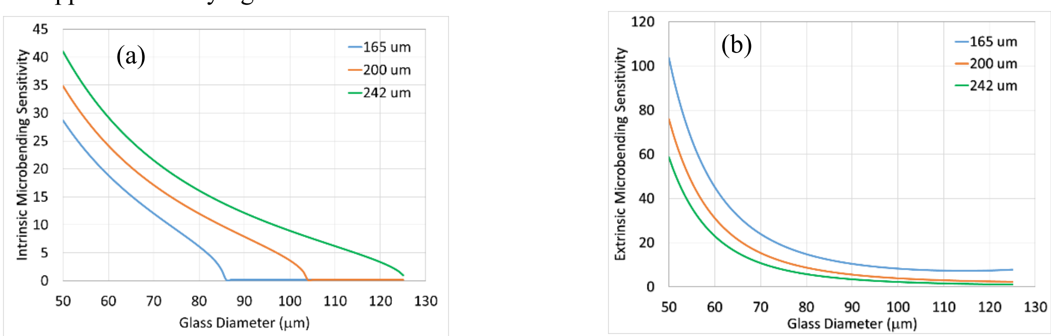

Fig. 2 Calculated microbending sensitivity (a) intrinsic (b) extrinsic.

Table 1. Measured cable cutoff wavelengths, MFD and attenuation of fibers with different coating diameters.

Core profile	Primary Coating Diameter (μm)	Secondary Coating Diameter (μm)	Cable Cutoff (nm)	1310 nm MFD (μm)	1550 nm MFD (μm)	1310 nm Attenuation (dB/km)	1550 nm Attenuation (dB/km)
Ge core, matched clad	133	142	1160	9.2	10.4	0.324	0.183
Ge core, matched clad	140	160	1220	9.1	10.2	0.333	0.187
Ge core, dual clad	145	170	1210	9.0	10.3	0.334	0.188
Ge core, F trench	145	170	1260	9.1	10.3	0.330	0.190
Si core, F dual clad	145	175	1222	9.3	10.5	0.276	0.160

Another category of microbending is the extrinsic microbending due to stresses or deformations by external perturbations. To analyze this type of microbending sensitivity, we use the microbending model in Ref. [12] that includes the mechanical properties of both glass and coating layers. The extrinsic microbending sensitivity is defined as the power bending spectrum normalized to that of the fiber with standard fiber with 125 μm glass, 190 μm primary and 242 μm secondary coating diameters. Fig. 2(b) shows the extrinsic microbending sensitivity as a function of glass diameter for different coating diameters. Smaller glass diameters and thinner coating diameters increase the extrinsic microbending sensitivity. However, the loss increase due to the extrinsic microbending depends on external perturbations. To improve the extrinsic microbending performance, it is important to minimize the external force applied to the fiber in the cable designs. We measured RCDF attenuation changes while the temperature was cycled from -60 to 100°C with the fibers deployed in a loose coil configuration (Fig. 3). The performance for the 165 and 175 μm fibers are very similar to the 200 μm fiber in the loose coil configuration, however, additional rigorous testing, including that in cables, is warranted. The microbending sensitivity can also be improved by using fiber designs with a low index trench. The analysis and experimental results suggest that with optimized fiber designs to reduce microbending and optimized cable designs to minimize external perturbations, it is possible to use reduced diameter fibers for high density cables.

4. Mechanical reliability

Fiber mechanical reliability is another factor to consider for reduced diameter fibers. In fiber handling and cabling processes, fibers can experience high stress events and can break if flaws are weaker than a stress level. Proof testing is used to ensure that the fiber strength distribution has a minimum strength level [13]. For terrestrial applications, the proof test stress is 700 MPa (100 kpsi), which is required for reduced diameter fibers.

To study the effects of thinner coating on fiber strength, we made fibers with the standard 125 μm glass diameter and different coating diameters and tested them by running them through the proof test under the 100 kpsi. Table 2 shows the break rate per km in the proof test. For the 170 and 160 μm coating diameters, the break rate increases slightly to between 0.06 and 0.08 breaks/km compared to 0.04 breaks/km for the standard 242 μm coated fiber. However, the break rate of the 140 μm coated fiber is much higher. We note that the fibers were made in the R&D lab environment, potentially resulting in large variances in break rates between different fiber conditions. It should also be noted that the proof test primarily measures the glass strength, and only indirectly provides information on the damage resistance of the coating and as such is not a substitute for puncture resistance measurements (Fig. 4). The preliminary proof test results suggest that the RCDF of 140 μm does not provide sufficient protection to prevent damage during the 100 kpsi proof tests. The proof test results the RCDF of 160 and170 μm look much better; however, a much larger sample size, more direct damage/puncture resistance measurements, and a rigorous analysis are needed to further understand the strength of RCDF.

Table 2. Fiber proof test results at 100 kpsi

Coating diameter (μm)	Fiber length (km)	Breaks/km
140	15	0.7
160	200	0.08
170	200	0.06
242	100	0.04

For RCDF, another mechanical reliability factor to consider is coating damage resistance. One test method for coating damage resistance is the coating puncture test [14]. Using this method, we tested fibers with different coating diameters using typical coating materials used for standard single-mode fibers. Fig. 4 plots the puncture load at which the fiber fails as a function of secondary coating cross-sectional area of a commercial coating (blue dots). The puncture load increases linearly with the secondary coating cross-sectional area for the same coating material. A thinner secondary coating is more susceptible to damage. However, it is possible to use different coating designs to improve the puncture resistance. In Fig. 4, we show three data points with two new coating designs, which can help increasing the failure puncture load. New coating design 2 can increase the puncture load from 15 to 32 g for coating diameter around 165 μm, which is comparable to that for the coating diameter of 200 μm used in commercial products. By improving the puncture resistance of the coating via innovative compositions, we believe that it is possible to make RCDF with a diameter of around 165 μm to meet the mechanical protection requirements.

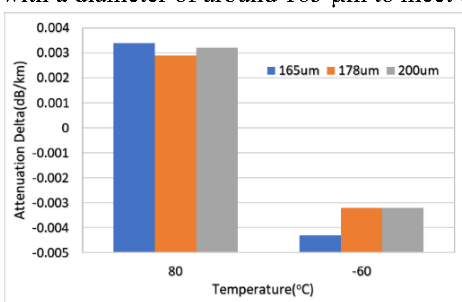

Fig. 3 Attenuation changes at two temperatures on loose coiled fibers.

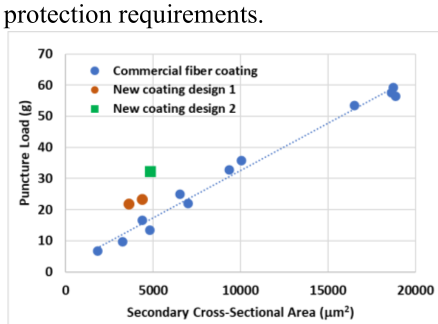

Fig. 4 Coating puncture resistance test results.

5. Conclusion

We have reviewed recent progress on RCDF and discussed key design considerations to improve fiber microbending and mechanical reliability. Our analysis and experimental results suggest that by optimizing both the fiber and coating designs, RCDF with coating diameter around 165 μm may be promising as one of the candidates including RCF and multicore fiber (MCF) for high density cable applications.

6. References

[1] IEEE P802.3bs 400 Gb/s Ethernet Task Force. Available online: www.ieee802.org/3/bs/.
[2] IEEE P802.3cw 400 Gb/s over DWDM Systems Task Force. Available online: www.ieee802.org/3/cw/.
[3] M. Li, "New Development Trends in Optical Fibers for Data Centers," ECOC2018, paper TH1.E5.
[4] D. L. Butler et al., "Space Division Multiplexing in Short Reach Optical Interconnects," J. Light. Tech. 35, pp. 677-682, 2017.
[5] W. Niu, et al.,"Thin-Coated Fibers for High-Density Optical Interconnects," OFC2021, paper M3C.2.
[6] P. Sillard et al., "180μm-Coated Bend-Insensitive Fiber and Micro-Duct Cable," ECOC2021, paper We1A.3.
[7] S. R. Bickham et al., "Reduced Cladding Diameter Fibers for High-Density Optical Interconnects," J. Light. Tech. 38, pp. 297-302, 2020.
[8] K. Mukasa et al., "Optimizations of thin cladding diameter fibers," OFC2021, paper M3C.1.
[9] S. Matsuo et al., "1,728-Fiber Cable with 12-Fiber Ribbons Comprising 160μm Coating Fiber with 80-μm Cladding," OFC2021, paper M3C.3.
[10] T. A. Lenahan, "Thermal buckling of dual-coated fiber," in AT&T Technical Journal, vol. 64, no. 7, pp. 1565-1584, Sept. 1985,
[11] M. H. Aly et al., "Excess loss due to thermal buckling in double coated single-mode optical fibers," CLEO1990, paper CTHI38.
[12] J. Baldauf, N. Okada and M. Miyamoto, "Relationship of Mechanical Characteristics of Dual Coated Single Mode Optical Fibers and Microbending Loss," IEICE Transactions on Communications Vol. E76-B, No.4, pp.352-357, 1993.
[13] TIA-455-31 FOTP-31 Proof Testing Optical Fibers by Tension.
[14] G. S. Glaesemann, D. A. Clark, "Quantifying the Puncture Resistance of Optical Fiber Coatings," Proc. 52nd IWCS, pp.237-245, 2003.