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Single-Mode Fibers with Reduced Cladding and/or Coating Diameters

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Abstract *A review of single-mode fibers with reduced cladding and/or coating diameters is presented. Different options are compared, and the associated cable miniaturizations and densities are discussed.*

Introduction

Single-mode fibers with reduced cladding and/or coating diameters [1-3] have recently attracted considerable attention [4-10] because they are elegant and mature solutions to increase densities in cables. This allows to keep up with traffic demand in limited spaces and makes cable installations faster, more cost-effective, and eco-friendlier [7].

Reducing the legacy 245µm coating diameter to 200µm while keeping a standard 125µm cladding diameter was introduced more than a decade ago [2]. It is now a well-established technology that has allowed for recent impressive cable demonstrations [11]. Reports on <200µm-coated fibers with standard 125µm cladding diameter [4-7] or with reduced 80µm cladding diameter [8-10] have also recently shown the potential of this reduced-size approach.

In this paper, we review and compare different options that allow to reduce the coating diameter of single-mode fibers below 200µm (see Fig.1), and we discuss the associated cable miniaturizations and densities.

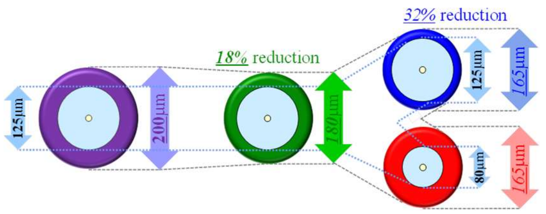

Fig. 1: Cross-section schemes of reduced-size fibers compared to 200µm-coated fibers (to scale).

Optical Properties

Throughout the paper, we consider single-mode fibers with trench-assisted step-index profiles that allow to reduce, ceteris paribus, bending sensitivities by factors of up to ~100 in macro-bending and up to ~10 in micro-bending compared to non-trench step-index profiles [12]. All fibers are compliant with ITU-T recommendations G.652.D and G.657.A2, except for the cladding diameter that can be reduced to 80µm. Note that almost all recent <200µm-coated fibers [5-7;8-10] have G.657.A2 trench designs. Finally, we take a 200µm-coated fiber with primary coating diameter of 157µm and Young's modulus of 0.35MPa, and standard 125µm cladding diameter (200µm/157µm(0.35MPa)/125µm) as a reference. All secondary moduli are ~1000MPa.

Last year, we introduced a colored 180µm/150µm(0.15MPa)/125µm fiber (cross-section area 18% smaller than that of 200µm-coated fibers, see Fig.1). This fiber has shown excellent optical performance [5]. To further reduce the coating diameter to 165µm (cross-section area 32% smaller than that of 200µm-coated fibers, see Fig.1), we consider 2 options: keep a standard 125µm cladding (165µm/145µm/125µm) or decrease it to 80µm (165µm/135µm/80µm). For both options, the primary concern is the increase of the micro-bending sensitivity that leads to cable-induced loss effects and ultimately prevents from increasing cable densities.

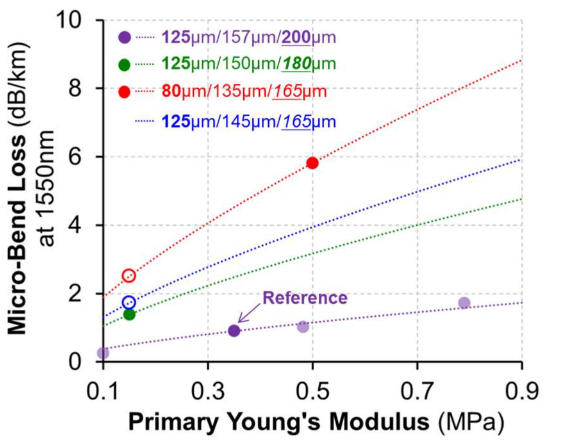

Fig. 2: Theoretical (lines and open circles) and experimental (solid circles) micro-bend loss at 1550nm of fibers with different dimensions vs. primary Young's modulus, all other properties being equal.

We investigated the dependence of the micro-bend loss at 1550nm on the primary modulus, that is known to have a significant impact on the performance (see Fig.2). Theoretical results, calculated with the model of [13] (lines and open circles), agree well with experimental data, obtained using the fixed diameter drum Method B of the IEC-62221 document (solid circles). As expected, the 80µm cladding option is more micro-bending sensitive than the 125µm options despite thicker coatings. But in all cases, reducing the primary modulus is an effective way to improve performance: moving from 0.50 to 0.15MPa reduces the micro-bend losses by a factor of ~2.3 for all fibers. As a result, the 180µm/150µm(0.15MPa)/125µm fiber (solid green circle in Fig.2) has a small micro-bending sensitivity (×1.5 that of our reference (solid dark purple circle in Fig.2)) that allows for excellent performance in micro-duct cables [7]. 0.15MPa is an acceptable lower limit for this parameter. Going to lower values might indeed cause cohesion issues.

Keeping a 125µm cladding diameter and going to 165µm coating diameter with a 0.15MPa primary modulus (165µm/145µm(0.15MPa)/125µm fiber, open blue circle in Fig.2) is then expected to result in low micro-bending sensitivity (×1.9 that of our reference), very close to that of the 180µm/150µm(0.15MPa)/125µm fiber. With 80µm cladding diameter and 165µm coating diameter, 0.50MPa does not seem to be an option. The 165µm/135µm(0.50MPa)/80µm fiber (solid red circle in Fig.2) that we fabricated shows a high micro-bending sensitivity (×6.5 that of our reference) that already induces an attenuation increase from 0.20dB/km at 1550nm on a tension-less spool to 0.25dB/km on a 30g-tension spool. With a primary modulus of 0.15MPa (open red circle in Fig.2), however, the micro-bending sensitivity can be reduced to ×2.8 that of our reference, which should be acceptable.

Micro-bending performance is not the only concern for reduced-size fibers. Compatibility and connectivity aspects should also be addressed. 180µm/150µm(0.15MPa)/125µm and 165µm/145µm(0.15MPa)/125µm fibers have the advantage of being compatible with legacy 125µm-cladding fibers and with standard field equipment and procedures for splicing and connectorizing. 165µm/135µm(0.15MPa)/80µm fibers, on the contrary, are not fully backward compatible, and require specific tools and new connectivity solutions [9,10].

Mechanical Properties

In addition to micro-bending and compatibility/connectivity aspects, the reduced-size fibers must meet the industry requirements for fatigue properties, tensile strength, and coating strip force (in accordance with IEC 60793-2-50). The 180µm/150µm(0.15MPa)/125µm fiber has already proved to fulfill these requirements [5].

The 165µm/135µm(0.50MPa)/80µm fiber that we fabricated passed the dynamic fatigue stress corrosion test with n-value ≥25 (exceeding the minimum specified value of 18). The strength at 50% probability of breakage was also always above the 550kpsi lower limit specified by the Standard. Typical Weibull plot of the 10m tensile strength distribution is shown in Fig.3, together with those of the 180µm/150µm(0.15MPa)/125µm fiber and of our reference (200µm/157µm(0.35MPa)/125µm) for comparison. We could not perform the strip force test because of the design of the tool required for the test (paired blades close around and cut the coatings were not effective because of the too small cladding diameter). It is worth mentioning that there should not be difficulty in stripping this fiber using adapted blades or other tools (scissor-like action to close a set of V-grooves around the coating) that are commonly found in the field.

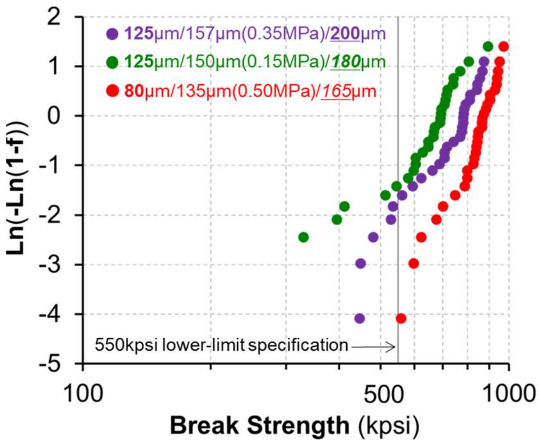

Fig. 3: Typical tensile strength Weibull distributions of fibers with different dimensions.

The 165µm/145µm(0.15MPa)/125µm fiber should also perform well in term of fatigue properties, tensile strength, and required strip force given the margins that exist for the 180µm/150µm(0.15MPa)/125µm fiber.Increasing the secondary modulus could also help.

Finally, we proof-tested several 1000s of km of the 180µm/150µm(0.15MPa)/125µm fiber at 100kpsi. The break rate was ≤4breaks/100km, slightly higher than that of our reference (200µm/157µm(0.35MPa)/125µm) which was ~2breaks/100km. 165µm-coated fibers are not expected to show much higher breaks [6,8]. This shows that mechanical reliability should not be problematic.

High Density Cables

Few fiber ribbons and/or cables using <200µm-coated fibers have been reported so far [1,5,10].

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In [5], we reported a 288-fiber micro-duct cable that combined 180µm/150µm(0.15MPa)/ 125µm fibers and small-outer-diameter loose tubes (1.2mm outer diameter for 24 fibers). This cable (12×24-fiber loose tubes, diameter of 6.5mm, density of 8.7fiber/mm²) was also successfully installed for a public utility supplier in Germany end of last year. It fitted into an 8mm inner diameter duct where previously it was only possible to install 192×200µm-coated fibers. Note that the minimum inner diameters of the ducts are defined so that the duct fill ratios are below the 70% limit required for efficient blowing installations.

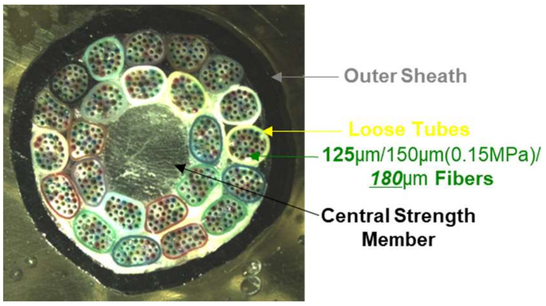

Fig. 4: 576-fiber micro-duct cable.

In [7], we described the feasibility of a micro-duct cable with up to 576 fibers. This cable has been fabricated and qualified since then. It is shown in Fig.4 (24×24-180µm/ 150µm(0.15MPa)/125µm-fiber loose tubes, disposed around a central strength member). Its diameter is 8.2mm, yielding a record fiber density of 10.9fiber/mm² for such cables. It is compliant with the optical and mechanical specifications of IEC 60794-1-21. The results of a temperature cycling test (from -40 to +70°C, 2 cycles, no ageing) are shown in Fig.5. The attenuation variations at 1310 and 1550nm are below the 0.05dB/km target for maximum change. This cable can be blown into a 10mm

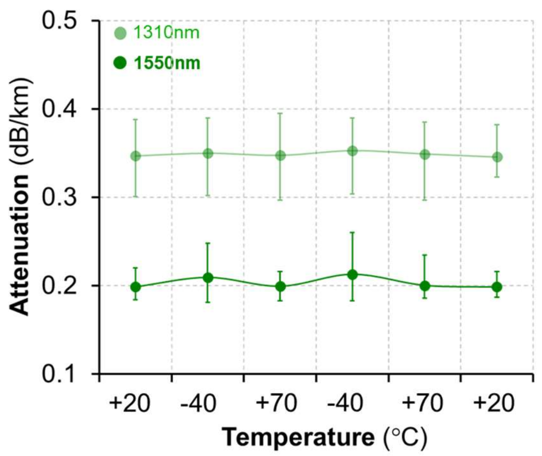

Fig. 5: Thermal cycling results (average and variations) of the 576-fiber micro-duct cable at 1310 and 1550nm (all 180µm/150µm(0.15MPa)/125µm fibers monitored).

inner diameter duct where it is currently only possible to install 432×200µm-coated fibers.

165µm-coated fibers could allow to reach even higher densities (>12fiber/mm²) provided the cables are compliant with the optical and mechanical specifications of IEC 60794-1-21.

The increase of cable densities brought by <200µm-coated fibers compared to ≥200µm-coated fibers not only makes possible to install more fibers into congested duct spaces, but also allows to use smaller micro-ducts for same number of deployed fibers. This makes the installation faster (smaller micro-ducts retain less shape memory and can thus be laid straight more easily than larger micro-ducts), and eco-friendlier (less polyethylene material used for fabrication and longer lengths on drums, which reduces the number of drums for a project, i.e., less truckloads to deliver the material at site and less waste of micro-ducts because scrap is ~proportional to the number of drums).

Conclusion

We reviewed and compared different options that allow to reduce the coating diameter of single-mode fibers below 200µm. Combining G.657.A2 trench design and low primary modulus has already allowed to develop a colored 180µm-coated fiber with a standard 125µm cladding diameter and good optical and mechanical performance, that is fully compatible with legacy 125µm-cladding fibers and with standard field equipment and procedures. Further reducing the coating diameter to 165µm either with standard 125µm cladding or with reduced 80µm cladding diameters seems possible in term of micro-bending performance. But further work is needed to fully address the compatibility/connectivity (especially for 80µm cladding diameter) and mechanical aspects.

These reduced-size fibers allow for tighter fiber packing densities and cable miniaturizations. Micro-duct cables with record densities were successfully fabricated using colored 180µm-coated fibers (up to 10.9fiber/mm² for a 576-fiber cable) and going to 165µm coating diameter should allow to reach densities above 12fiber/mm². These high-density cables enable the installation of more fibers into congested duct spaces and the use of smaller ducts for new installations, resulting in fast and low-cost deployments and reduced environmental footprints.

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