180µm-Coated Bend-Insensitive Fiber and Micro-Duct Cable

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Abstract *We report the design and fabrication of a 180µm-coated bend-insensitive fiber with standard 125µm cladding. This fiber shows excellent optical and mechanical properties and is fully compatible with legacy 245µm- and 200µm-coated fibers. A 288-fiber micro-duct cable with a record fiber density is also fabricated.*

Introduction

High-density cables have recently received considerable attention because of their ability to meet capacity demand and to make installation faster, more cost effective and environmentally friendly.

There are 3 well-known ways to increase cable density with fibers. The 1st one consists of using space-division-multiplexed fibers with standard 125µm cladding diameter[1],[2]. This is a promising solution, but there are important challenges ahead before making these solutions practical, namely cost and connectivity. The 2nd one consists of reducing the cladding diameter to 80µm with coating diameters around 160µm[3]-[5]. These fibers suffer from increased micro-bending sensitivity (factor of ~10 compared to standard 125µm-cladding fibers with same other properties) and still face connectivity and handling challenges. This leaves the 3rd option which consists of keeping a standard 125µm cladding diameter and of reducing the standard 245µm coating diameter. 200µm-coated fibers, introduced more than a decade ago[6], have recently allowed for impressive cable demonstrations with 6,912 fibers in a diameter small enough to fit into a 50mm duct. Preliminary studies of <200µm-coated fibers have also been reported[7],[8], but further work on index-profile designs and coating materials is needed to optimize their optical and mechanical performance and make them suitable for cabling.

In this paper, we report the design and the fabrication of such an optimized fiber with 180µm coating diameter. This bend-insensitive fiber is fully compliant with ITU-T recommendations G.652.D and G.657.A2 and has similar or better micro-bending sensitivity than those of 245µm- and 200µm-coated fibers. It can be spliced with these legacy fibers using conventional tools and fusion splicers and it ensures excellent mechanical reliability. A 288-fiber micro-duct cable with a diameter of 6.5mm, yielding a record fiber density of 8.7fiber/mm² for such cables, is fabricated.

Optical Properties

We chose a trench-assisted step-index profile that had long proved to be effective in reducing bending sensitivities (factors of up to ~100 in macro-bending and up to ~10 in micro-bending compared to non-trench step-index profiles with same other properties)[9]. The fiber is designed to fully meet G.652.D and G.657.A2 specifications with 180µm reduced coating diameter (see Tab.1).

Tab. 1: Characteristics of the fabricated 180µm-coated bend-insensitive fiber

	λ (nm)	**180µm Fiber**	***ITU-T G.657.A2***
Mode Field Diameter (µm)	1310	**8.8**	*8.6-9.2*
Cladding diameter (µm)	-	**125**	*125±0.7*
Primary Coating diameter (µm)	-	**150**	-
Secondary Coating diameter (µm)	-	**180**	-
Cable Cutoff Wavelength (nm)	-	**1190**	*≤1260*
Bend Loss at 15mm bend radius (dB/10turn)	1550	**0.007**	*≤0.03*
	1625	**0.027**	*≤0.1*
Bend Loss at 10mm bend radius (dB/turn)	1550	**0.015**	*≤0.1*
	1625	**0.036**	*≤0.2*
Bend Loss at 7.5mm bend radius (dB/turn)	1550	**0.156**	*≤0.5*
	1625	**0.306**	*≤1*
Zero-Dispersion Wavelength (nm)	-	**1318**	*1300-1324*
Zero-Dispersion Slope (ps/nm²/km)	-	**0.089**	*≤0.092*
Attenuation (dB/km)	1310	**0.338**	*≤0.40*
	1383	**0.306**	*≤0.40*
	1550	**0.189**	*≤0.30*
	1625	**0.198**	*≤0.40*
$\text{PMD}_{(Q)}$ (ps/√km)	1550	**0.028**	*≤0.20*

When moving from 200µm (primary diameter of 157µm and Young's modulus of 0.35MPa) to 180µm, the challenge is to maintain a significant buffer layer of soft primary coating for protection against micro-bending while at the same time preserve an adequate secondary coating thickness for handling robustness and mechanical protection.

We investigated the dependence of micro-bending sensitivity on the primary Young's modulus for several 200µm-coated fibers, all

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other properties being equal. The micro-bending sensitivity was normalized to that obtained with a primary Young's modulus of 0.35MPa (see Fig.1). Theoretical results[10] agree well with our experimental data. Moving from 0.35 to 0.15MPa reduces the micro-bending sensitivity by a factor of ~2 and can thus compensate for a reduction of the primary coating diameter. We finally reduced this primary diameter to 150µm and decreased the thickness of the colored secondary coating (that was kept with a very high Young's modulus to protect the fiber) to 15µm to reach a dual-coated diameter of 180µm.

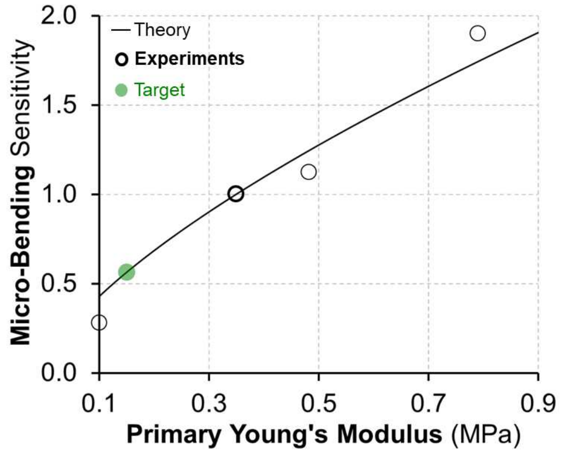

Fig. 1: Theoretical (line) and experimental (open circles) micro-bending sensitivity at 1550nm of 200µm-coated fibers as a function of primary Young's modulus, all other properties being equal.

We experimentally evaluated and compared the resulting micro-bending sensitivity of the 180µm-coated G.657.A2 trench fiber to those of other 200µm- and 245µm-coated fibers (all with same primary Young's modulus of 0.35MPa) using the fixed diameter drum Method B of the IEC-62221 document (see Fig.2).

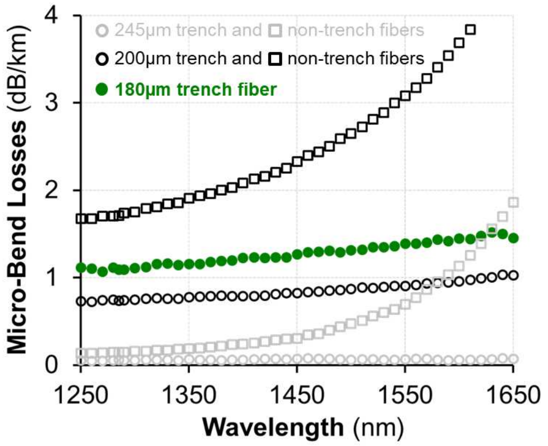

Fig. 2: Experimental micro-bend-loss spectra of 245µm- (gray symbols), 200µm- (black symbols), and 180µm- (green circles) coated fibers G.657.A2 trench (circles) and G.652.D non-trench (squares) fibers.

The flat spectra of trench fibers, due to the specific coupling between the fundamental mode and the radiation modes confined by the trench[9], are recognizable and the improvement factors compared to non-trench fibers are confirmed (13 for 245µm-coated fibers and 3.5 for 200µm-coated fibers at 1550nm). More importantly, as expected, thanks to its reduced primary Young's modulus, the 180µm-coated G.657.A2 trench fiber is almost not degraded compared to the 200µm-coated G.657.A2 trench fiber and performs better than the 200µm-coated G.652.D non-trench fiber.

We then conducted fusion splicing tests to ensure no problems exist with the 180µm-coated G.657.A2 trench fiber and that it is backward compatible with 245µm- and 200µm-coated fibers. More than 150 splices were made with conventional instruments (core-alignment mode and standard recipes) after which bi-directional OTDR measurements were made to evaluate the quality of the splices. Mean losses were ≤0.008dB/km for the 180µm/180µm-coated fiber splices, and ≤0.016dB/km for the 180µm/200µm and 180µm/245µm-coated (trench and non-trench) fiber splices at 1310, 1550, and 1625nm (see Tab.2).

Tab. 2: Splice losses of 180µm-coated bend-insensitive fiber

λ (nm)	1310	1550	1625
	With Itself		
Number of splices	**15**		
Mean loss (dB)	**0.007**	**0.007**	**0.008**
Standard deviation (dB)	**0.003**	**0.003**	**0.006**
Maximum loss (dB)	**0.013**	**0.014**	**0.027**
	With 200µm-coated fibers		
Number of splices	**36**		
Mean loss (dB)	**0.014**	**0.013**	**0.012**
Standard deviation (dB)	**0.009**	**0.007**	**0.006**
Maximum loss (dB)	**0.035**	**0.027**	**0.028**
	With 245µm-coated fibers		
Number of splices	**108**		
Mean loss (dB)	**0.016**	**0.014**	**0.014**
Standard deviation (dB)	**0.009**	**0.008**	**0.008**
Maximum Loss (dB)	**0.043**	**0.039**	**0.038**

Note that no special measures were required for handling the 180µm-coated fibers. The usual care was taken to maintain instruments and tools in proper condition.

Mechanical Properties

In addition to the physical attributes that impact optical characteristics, the 180µm-coated G.657.A2 trench fiber must meet existing requirements for stripping, tensile strength, and fatigue properties (in accordance with IEC 60793-2-50 for type B fibers).

Fibers were tested to measure the coating strip force. There was no difficulty in cleanly stripping the 180µm coatings with commonly used tools. The measured coating strip force required to mechanically remove the coating along the longitudinal axis was 0.7N, above the Standard that specifies >0.4N.

A typical Weibull plot of the 10m tensile strength distribution is shown in Fig.3, together with those of 245µm- and 200µm-coated G.657.A2 trench fibers for comparison. The strength at 50% probability of breakage of the 180µm-coated fibers was always above the 550kpsi lower limit specified by the Standard, before and after the aging treatments.

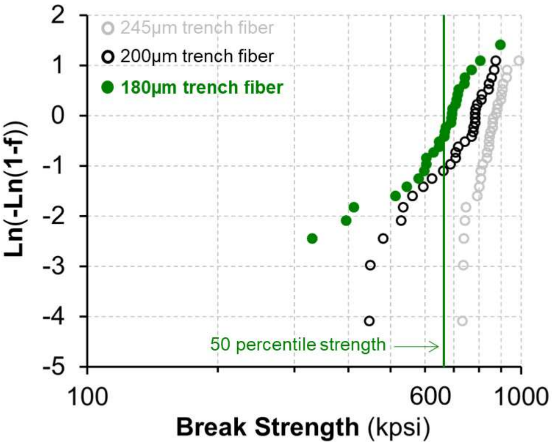

Fig. 3: Typical tensile strength Weibull distributions of 245µm- (gray circles), 200µm- (black circles), and 180µm- (green circles) coated trench fibers.

Finally, we performed the dynamic fatigue stress corrosion test and data consistently yielded n-value ≥20 for both unaged and aged samples, exceeding the minimum specified value of 18.

High Density Micro-Duct Cable

Given the excellent optical and mechanical performance of the 180µm-coated bend-insensitive fiber, we fabricated a micro-duct cable with 288 of such fibers. The cable has a standard structure composed of 12 loose tubes with reduced sizes (diameter of 1.2mm) containing 24 fibers each and disposed around a central strength member (see Fig.4). The cable diameter is 6.5mm, yielding a record fiber density of 8.7fiber/mm² for such cables, and a weight of only 43kg/km. It is compliant with the optical and mechanical specifications of IEC 60794-1-21 (loss variations ≤0.05dB or ≤0.1dB for all tests). The results of a critical temperature cycling test (from -40 to +70°C, 2 cycles, no ageing) are also shown in Fig.5. The attenuation variations at 1310 and 1550nm are far below the 0.05dB/km target for maximum change, confirming the practical use of the cable.

It is possible to install this cable into an 8mm inner diameter duct where previously it was only possible to install 192 fibers with 200µm coating diameter (<6.5fiber/mm²) or 144 fibers with 245µm coating diameter (<5fiber/mm²). With the 180µm-coated bend-insensitive fibers, up to 50% smaller micro-ducts can be used to deploy the same number of fibers. These smaller ducts offer other significant advantages, to wit: up to 50% less polyethylene material used for fabrication, faster installation (laying them straight is easier than larger ducts), and longer lengths (~70%) on a drum which reduces the numbers of drums needed for a project.

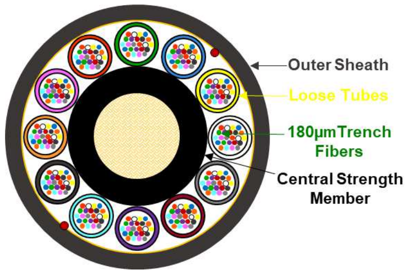

Fig. 4: 288-fiber micro-duct cable design.

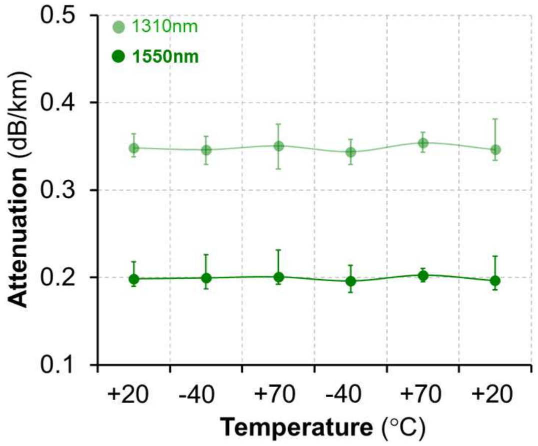

Fig. 5: Thermal cycling results (average and variations) on the 288-fiber micro-duct cable at 1310 and 1550nm (all 180µm-coated bend-insensitive fibers monitored).

Conclusion

A new 180µm-coated bend-insensitive fiber with standard 125µm cladding diameter was designed and fabricated. This fiber is fully compliant with ITU-T recommendations G.652.D and G.657.A2. It has similar or better micro-bending sensitivity than those of legacy 245µm- and 200µm-coated fibers thanks to the combination of a trench design with a low primary coating Young's modulus. Fusion splicing tests proved the full backward compatibility with legacy fibers, and all mechanical requirements for stripping, tensile strength, and fatigue properties were met.

The smallest 180µm diameter provides a cross-section area about half of that of 245µm-coated fibers, and thus allows for tighter fiber packing densities and cable miniaturization. A 288-fiber micro-duct cable with a diameter of 6.5mm, yielding a record fiber density of 8.7fiber/mm² for such cables, was fabricated.

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