125µm glass diameter single-mode fiber with A_{eff} of 155µm^2

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Abstract: A 125µm glass diameter trench-assisted single-mode fiber with a record A_{eff} of 155µm^2 and attenuation of 0.183dB/km at 1550nm is reported. This fiber shows acceptable micro-bend losses compared to those of a SSMF.

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1. Introduction

In long-haul transmissions, dispersion issues are now dealt with advanced coherent detection and digital signal processing techniques [1-4]. This new landscape has fostered innovation in low-attenuation, large effective-area (A_{eff}) fibers. During the past 2 years, demonstrations of fibers with attenuations below 0.185dB/km and A_{eff} larger than 110µm^2 at 1550nm (that has been the typical value for more than a decade) have been reported [5-8].

To design such fibers, step-index profiles only offer limited possibilities: low index differences and large core diameters are required to enlarge the A_{eff}, which inevitably deteriorates bending and cutoff behaviors. Adding a slightly depressed-index cladding next to the step-index core helps to reduce the macro-bending and cutoff degradations [6]. But, the main limitation to further enlarge the A_{eff} is the micro-bending sensitivity that greatly increases. An alternative to these structures consists in placing a largely depressed-index region in the cladding, i.e. a trench, slightly apart from the step-index core. These trench-assisted profiles not only provide improved macro-bending and cutoff performances, but also brings significant advantage in term of micro-bending behavior [9].

In this paper, we show how such structures can efficiently be used to design 125µm glass diameter single-mode fibers with A_{eff} larger than 150µm^2 at 1550nm and with acceptable micro-bending sensitivity.

2. Fiber design

In 2008, we reported a trench-assisted fiber with A_{eff} of 120µm^2, attenuation of 0.183dB/km at 1550nm, cable cutoff wavelength <1480nm and macro- and micro-bend losses lower than those of a Standard Single-Mode Fiber (SSMF) [5]. To further improve the performance of such a fiber, one can lower the attenuation and/or enlarge the A_{eff}. Keeping the same index profile and using a pure-silica-core structure, we have fabricated a fiber with A_{eff} of 121µm^2 and attenuation of 0.171dB/km at 1550nm, and same other characteristics as those of Ref.[5]. But further enlarging the A_{eff} requires to adjust the index profile and to carefully investigate the impact of micro-bend losses.

In that purpose, we have calculated the micro-bend losses of step-index profiles and of trench-assisted profiles as a function of A_{eff} at 1550nm (see Fig.1), using the formalism developed in [9] and experimental data for the SSMF and for Ref.[5] (collected using the Method B of the IEC TR-62221 document).

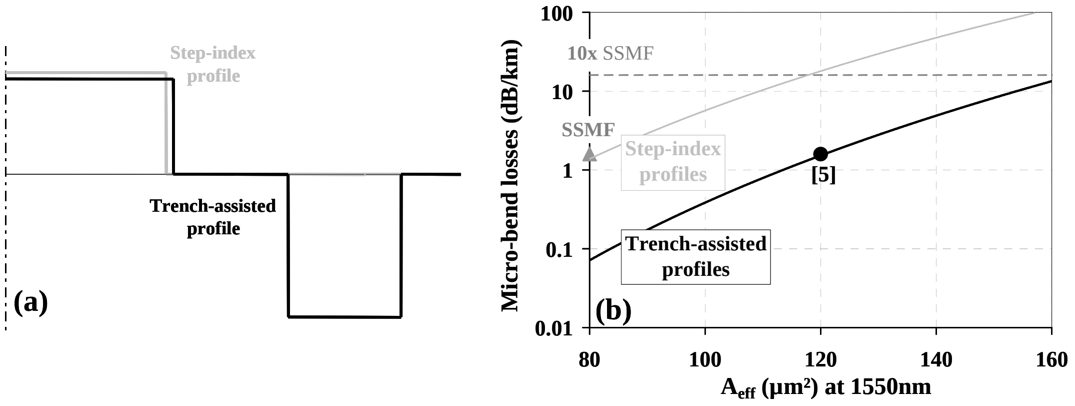

Fig.1: Comparison of step-index fibers (gray) and trench-assisted fibers (black) with same glass diameter of 125µm and same dual-coating properties and outside diameter of 245µm: index profiles (a), theoretical (lines) and experimental (symbols) micro-bend losses at 1550nm (b)

For fair comparison, all fibers have macro-bend losses <10dB/m at 10mm bend radius at 1625nm, cable cutoff wavelengths <1530nm, same glass diameter of 125µm, and same dual-coating properties and outside diameter of

245µm. Trench-assisted profiles allow to gain a factor of ~10 in micro-bending sensitivity compared to step-index profiles. This is due to a specific mechanism that limits the coupling between the fundamental mode and the radiation modes that are confined by the trench [9]. This allows to target an A_{eff} of 160µm² at 1550nm with micro-bend losses less than 10 times higher than those of a SSMF.

To get a better picture of the advantages brought by the enlargement of A_{eff}, we have used an analytical expression that gives the achievable distance of transmission systems [10]. For all calculations, we have considered realistic non-linear-index (n_2) and splice-loss values (2 splices with SSMF per span), span length of 50km, discrete amplification and no optical dispersion compensation. Fig.2 shows the achievable distance as a function of A_{eff} for different attenuations compared to a standard undersea fiber (n_2=2.6×10^{-20}m²/W, attenuation=0.185dB/km, A_{eff}=110µm²). For same attenuation, enlarging the A_{eff} from 110 to 160µm² allows to gain ~20% in distance; and for same A_{eff}, reducing the attenuation from 0.185 to 0.165dB/km allows to gain ~10% (note that for longer span lengths, the gain would be higher [4]).

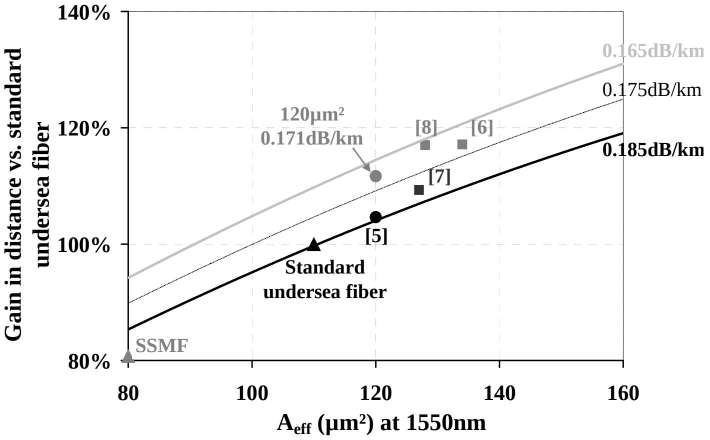

Fig.2: Achievable distance of a 50km-span transmission system as a function of A_{eff} for different attenuations at 1550nm compared to a standard undersea fiber with A_{eff}=110µm² and attenuation of 0.185dB/km

3. Experimental results

Based on these considerations, we have designed and fabricated a 125µm glass diameter trench-assisted single-mode fiber with A_{eff} of 155µm² and attenuation of 0.183dB/km (germanium-doped-core structure) at 1550nm, using our standard PCVD and drawing processes. Main characteristics are given in Table 1.

Table 1. Characteristics of the 125µm glass diameter fiber

Chromatic Dispersion	1550nm	ps/nm-km	21.7
Dispersion Slope		ps/nm²-km	0.064
Cable Cutoff Wavelength		**nm**	**1550**
Effective Area	**1550nm**	**µm²**	**155**
	1530nm		0.189
Attenuation	**1550nm**	**dB/km**	**0.183**
	1570nm		0.181
Macro-Bend Loss at 10mm bend radius	**1550nm**	**dB/m**	**0.4**
	1625nm		**0.5**
Micro-Bend Loss (IEC TR 62221, method B): **245µm coating diameter**	**1550nm**	**dB/km**	**14.7**
Micro-Bend Loss (IEC TR 62221, method B): **320µm coating diameter**	**1550nm**	**dB/km**	**1.3**
Polarization Mode Dispersion	1550nm	ps/√km	0.05

Because trench-assisted profiles allow for much better light confinement than step-index profiles, very low macro-bend losses of 0.4 and 0.5dB/m at 10mm bend radius have been obtained at 1550 and 1625nm, respectively, which is 10 to 20 times less than those of a SSMF.

Micro-bend losses have been carefully investigated using the Method B of the IEC-62221 document (spectral losses are recorded in standard temperature and humidity conditions before and after winding 400m of a fiber with a tension of 3N around a 320mm-diameter drum coated with a 40µm-grade sandpaper, the difference giving the micro-bend-loss spectrum of the fiber). Fig.3 summarizes our findings. Experimental results are in good agreement with the theory. The fiber with glass diameter of 125µm and dual-coating diameter of 245µm experiences a loss increase of 14.7dB/km at 1550nm. This is indeed less than ten times higher than what is obtained for a SSMF (1.6dB/km at 1550nm) with same coating properties and dimensions, which is remarkable given the very large A_{eff} of the fiber. We have then investigated the impact of the dual-coating diameter. Keeping same 125µm glass diameter and increasing the dual-coating diameter from 245 to 320µm, the micro-bending sensitivity can be decreased by a tenfold factor, bringing the micro-bend losses (1.3dB/km at 1550nm) to the level of the SSMF. Finally, we have also measured the trench-assisted pure-silica-core fiber with A_{eff} of 121µm^2 and attenuation of 0.171dB/km at 1550nm. As expected, this fiber has similar micro-bend losses as those of Ref.[5].

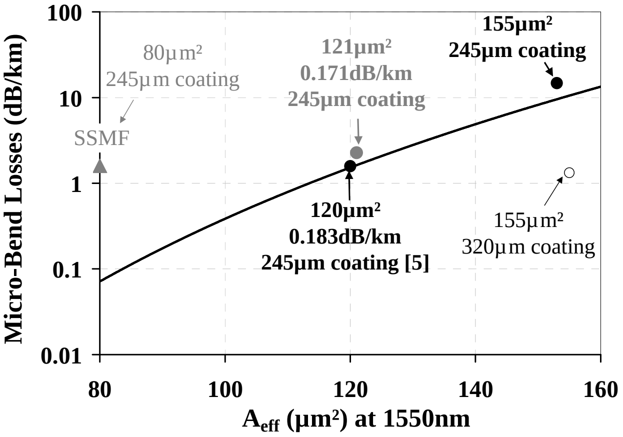

Fig.3: Theoretical (line) and experimental (circles) micro-bend losses at 1550nm of different 125µm glass diameter trench-assisted fibers; the experimental SSMF value (gray triangle) is given for comparison

At last, average splice losses of 0.03dB have been obtained between two 155µm^2 fibers, while splicing to a SSMF resulted in losses of 0.13dB using an appropriate bridge fiber.

4. Conclusion

Micro-bend loss is the main limitation of A_{eff} enlargement when one wants to keep a standard 125µm glass diameter. In addition to optimizing coating properties, trench-assisted profiles bring significant advantages because the trench reduces the coupling between the fundamental mode and the radiation modes, providing an intrinsically lower micro-bending sensitivity than that of step-index profiles.

Taking these considerations into account, we have designed and fabricated a 125µm glass diameter trench-assisted single-mode fiber with a record A_{eff} of 155µm^2 and attenuation of 0.183dB/km at 1550nm. This fiber exhibits acceptable micro-bend losses compared to those of a SSMF, even though the A_{eff} is ~twice as large.

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