Trench-Assisted Profiles for Large-Effective-Area Single-Mode Fibers

Marianne Bigot-Astruc (1), Frans Gooijer (2), Nelly Montaigne (3), Pierre Sillard (1)
1 : Draka, route de Nozay, 91460 Marcoussis, France, email: marianne.astruc@draka.com
2 : Draka, Zwaanstraat 1, 5651 CA Eindhoven, The Netherlands
3 : Draka, Billy-Berclau, 62092 Haisnes cedex, France

Abstract

Trench-assisted profiles allow reaching larger effective areas than conventional profiles. A 120µm² fiber with diameter of 125µm and lower bend losses than those of SSMF is fabricated.

Introduction

Transmission linearity remains the ultimate goal in order to meet the long-term needs of light-wave systems [1]. From a fiber point of view, this means larger effective areas (A_{eff}) and lower attenuations [2]. In the late '90s and in the beginning of the '00s, fibers with A_{eff} ~110µm² were developed [3,4] and used, in association with their reverse-dispersion fibers (RDFs) [5], in both submarine and terrestrial transmissions [6-9]. Nowadays, these fibers are commercially available. Fibers with A_{eff} ≥160µm² have also been reported [10,11], but they had diameters ≥160µm in order to compensate for the severe micro-bend-loss degradation. All these fibers have step-index profiles with depressed claddings.

In this paper, we study the use of trench-assisted step-index profiles to design large-A_{eff} fibers (LAFs). Such profiles, compatible with large-volume and cost-effective productions, allow to reach larger A_{eff} than those of depressed-cladding profiles, while keeping excellent bending performances.

A 125µm-diameter fiber with A_{eff} of 120µm² and attenuation below 0.185dB/km at 1550nm has been designed and fabricated with standard Draka's processes. This fiber exhibits lower macro- and micro-bend losses than those of G.652 standard single-mode fibers (SSMFs). We also present results of its dispersion compensation and its impacts on transmission system performances.

Fiber design and fabrication

The trench [12] has already been used to decrease the macro- and micro-bending sensitivities of fibers while keeping same A_{eff} and same cable cutoff wavelength (λ_{cc}) as those of a SSMF [13]. Here, we take a different approach and use the trench to enlarge the A_{eff} and to control the λ_{cc} while keeping same bending performances as those of a SSMF. Fig.1 compares the fundamental mode shape of a trench-assisted profile with A_{eff}=130µm² (black lines) with that of a depressed-cladding profile with A_{eff}=110µm² (gray lines). The trench is able to confine the mode tail (<1% of the mode power) so that bend losses equivalent to those of the depressed-cladding profile are obtained with a much larger A_{eff}. The trench also allows to manage the higher-order modes so that best compromise between cut-off and bending behaviors is reached. Extensive simulations have shown that, for equivalent bending sensitivities and λ_{cc}, A_{eff} can be enlarged by more than 10µm² compared to depressed-cladding profiles.

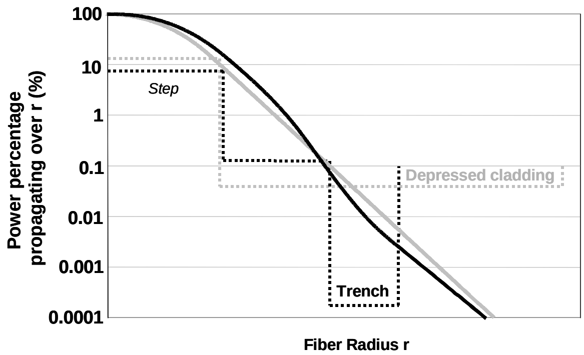

Figure 1: Profiles (dotted lines) and percentage of mode power propagating over radius r (full lines) for trench-assisted (black) and depressed-cladding (gray) step-index profiles

Based on this trench-assisted concept, a 125µm-diameter LAF with A_{eff} of 120µm² at 1550nm, and very low bend losses up to 1625nm, has been designed and fabricated with standard Draka's deposition and drawing processes. For this type of profile, the versatile PCVD process demonstrated its high efficiency.

Fiber characteristics

Table 1 gives the characteristics of a several-hundred-km fabrication of LAFs. The λ_{cc} is kept below 1480nm. Very low attenuation of 0.183dB/km is obtained at 1550nm for a Germanium-doped step-index profile. This is due to the low index-difference of the step and to the resulting low Rayleigh-scattering coefficient, but also to the trench that has a protective effect. The macro-bend losses are exceptionally low for this very large A_{eff} of 120µm²: 3.1dB/m for 10mm radius have been measured at 1625nm, which is ~5 times less than for a SSMF with A_{eff} of 80µm². Micro-bend losses have also been characterized using the fixed-diameter-drum method of the IEC TR 62221. 400m of fibers are wound with a tension of 3.5N around a 500mm-diameter drum with sandpaper (grade 40µm). The 125µm-diameter LAF experienced a loss increase of 0.9dB/km at 1625nm, which is

~twice as less as for a SSMF (with same coating). These excellent bending performances show the potentiality of the trench-assisted step-index profiles to reach larger A_{eff} than 120µm².

Dispersion@1550nm (ps/nm/km)	20.3
Slope@1550nm (ps/nm²/km)	0.062
Dispersion/Slope@1550nm (nm)	328
λcc (nm)	1474
Aeff@1550nm (µm²)	120
Attenuation@1530nm (dB/km)	0.188
Attenuation@1550nm (dB/km)	0.183
Attenuation@1570nm (dB/km)	0.180
Macro-bend loss$_{\text{Radius 10mm}}$ @1550nm (dB/m)	1.2
Macro-bend loss$_{\text{Radius 10mm}}$ @1625nm (dB/m)	3.1
Micro-bend loss (IEC TR 62221)@1625nm (dB/km)	0.9
PMD@1550nm (ps/√km)	0.02

Table 1 : Characteristics of the LAF

At last, splice losses of 0.03dB have been obtained between two LAFs, while splicing LAF and SSMF resulted in losses of 0.1dB.

Dispersion compensation and system performances

The LAF has a dispersion-over-slope ratio at 1550nm similar to that of commercially-available fibers with A_{eff} between 100 and 110µm². Its dispersion and slope can thus easily be compensated for with cabled RDFs (dispersion ~-40ps/nm/km, slope ~-0.13ps/nm²/km, A_{eff} ~30µm², attenuation ~0.240dB/km) used in submarine transmissions. For these two-fiber cables, the equivalent A_{eff} is calculated as the A_{eff} of a one-fiber cable with same attenuation that gives the same non-linear phase shift for a constant output power. For a 50km LFA+RDF link, the equivalent A_{eff} is found to be ~90µm², which is significantly larger than the ~83µm² that corresponds to a link composed of a fiber with same characteristics but an A_{eff} of 105µm² and same RDF.

The dispersion-over-slope ratio of the LAF is also very close to that of a SSMF at 1550nm (~10% difference). As a consequence, dispersion compensating modules (DCMs) coming from standard productions of DCMs for SSMF can compensate for the dispersion and the slope of the LAF. Fig.2 shows the residual dispersion of a link composed of the LAF and of a dispersion compensating fiber (DCF) for SSMF, produced with the PCVD process (see characteristics in the inset of Fig.2). Maximal dispersion variations of ±0.04ps/nm/km in the extended C-band are obtained, which demonstrates the easiness of compensation of the LAF and its full compatibility with high-bit-rate, ultra-long-haul terrestrial transmissions.

All these findings enable us to use the analytical expression that gives the achievable distance of 40Gbps WDM terrestrial systems [14]. For 80km span length, we find that the LAF allows to gain 5% in distance compared to a fiber with same characteristics but an A_{eff} of 105µm², and 15% in distance compared to a SSMF with A_{eff} of 80µm² and attenuation of 0.190dB/km.

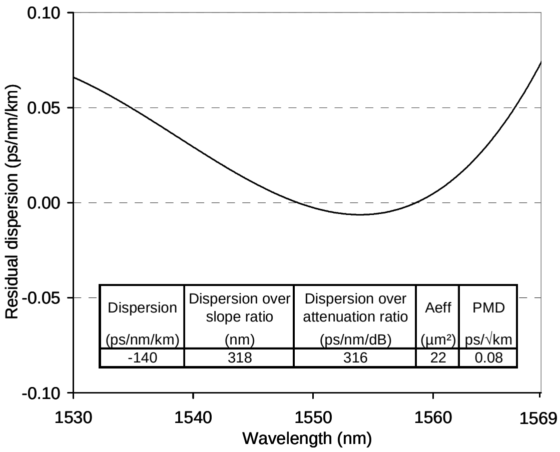

Figure 2: Residual dispersion of LAF+DCF link (inset: characteristics of the DCF at 1550nm)

Conclusion

Trench-assisted profiles are excellent candidates to design fibers with very large A_{eff} and low bending sensitivities. A 125µm-diameter fiber with A_{eff} of 120µm² and attenuation of 0.183dB/km at 1550nm, λ_{cc} <1480nm and macro- and micro-bend losses lower than those of a SSMF has been fabricated with standard Draka's processes. This fiber proved to be easy to compensate with usual cabled RDFs or with off-the-shelf DCMs and showed increased system performances in both submarine and terrestrial configurations.

Acknowledgments

The authors acknowledge fruitful discussions with G. Charlet, J.-C. Antona and S. Bigo from Alcatel-Lucent, Bell Labs, France

References

1. E.B. Desurvire, JLT (2006), p.4697
2. M.J. Li and G. Mohs, OFC'08, Workshop OSuA
3. T.Kato et al., Elec. Lett. (1999), p.1615
4. S. Knudsen et al., Elec. Lett. (2000), p.2067
5. K. Mukasa et al., ECOC'97, p.127
6. T. Naito et al., ECOC'99, PD2.1
7. M. Nissov et al., OFC'00, PD30
8. S. Knudsen et al., Elec. Lett. (2001), p.965
9. M. Vasilyev et al., OFC'02, ThQ4
10. M. Tsukitani et al., ECOC'02, Tu3.2.2
11. K. Mukasa et al., OFC'08, OThR1
12. W.A. Reed, US patent 4,852,968 (1989)
13. L.-A. de Montmorillon et al., ECOC'06, Mo.3.3.2
14. P. Sillard et al., OFC'08, JWA13