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Simple Multi-Core Fiber Fabrication Method

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Abstract *We report a simple multi-core fiber fabrication method that uses standard manufacturing processes except for a stacking step, made with a limited number of adjusting rods. A 4-core fiber with 125µm-cladding and 200µm-coating diameters, and good optical and mechanical properties is fabricated using this method. ©2022 The Authors*

Introduction

Multi-Core Fibers (MCFs) with a standard cladding diameter of 125µm [1-6] offer advantages over larger-diameter MCFs in terms of long-term mechanical reliability and compatibility with standard connectivity solutions and cabling technology.

The standard cladding diameter of 125µm also improves fiber productivity because, for a given preform size, fiber length is proportional to the inverse of the square of the cladding diameter. But it is not sufficient to allow for mass production because MCFs fabrications are still complex and not always scalable (preforms, made by drilling [7], stacking [8], over-cladding bundled rods [9], slurry casting method [10] or modified cylinder method [11], are drawn in pressure-controlled conditions).

Ref.[12] reported an alternative method that consisted of collapsing a stacked primary preform (4 core-rods and 1 central adjusting rod), that was then over-cladded (off-line sleeving or rod-in-tube techniques) and drawn without specific pressure control. The fabricated 4-core fiber, however, was not homogeneous along the length and was not circular with cladding diameters ranging from 131 to 152µm. In this paper, we improve this method by adding a limited number of adjusting rods to the stack and, more importantly, by perfecting the over-cladding step using a specific cycle of silica-grain deposition and evaporation with a plasma torch [13]. This allows to obtain primary preforms with well-controlled geometrical properties along their lengths (internal cores dimensions/positions and outer diameter). A 4-core fiber with a standard cladding diameter of 125µm ±0.3µm and good optical and mechanical properties is obtained. This MCF fabrication method, that uses standard manufacturing processes, except for the stacking step, is scalable to large preform sizes and might open the door to mass production.

Fabrication

The fabrication of the primary preform is illustrated in Fig.1 for a 4-core fiber with a standard cladding diameter of 125µm. We chose a non-trench step-index profile that offers simplicity in terms of design and fabrication and that can be compliant with both ITU-T recommendations G.652.D and G.657.A1. 4 core-rods with such a simple profile, 9 adjusting silica rods and 1 rod for the marker were assembled before being put in a tube (Fig.1(a)).

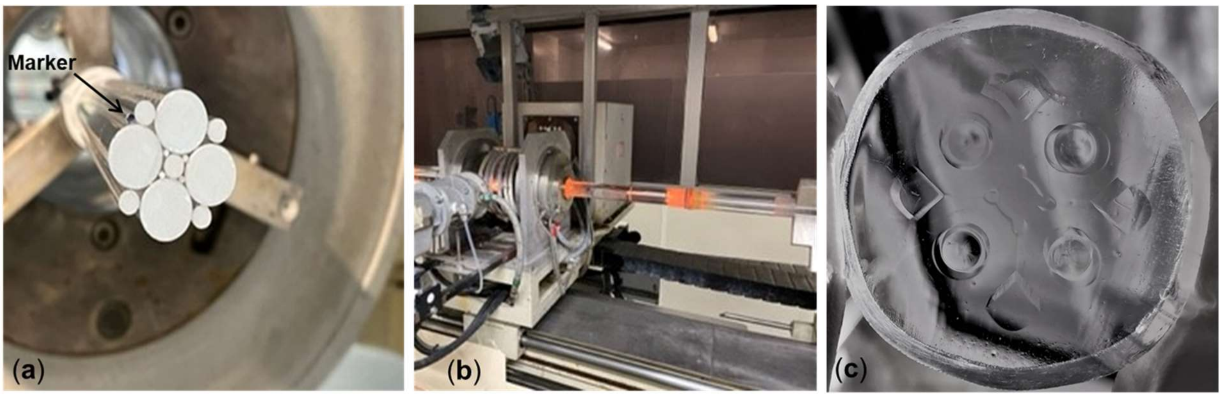

Fig. 1: Assembly of core-rods, adjusting rods and marker to make the stacked primary prefrom (a); bench on which the stacked primary preform is collapsed (b); cross-section of the collapsed primary preform (c).

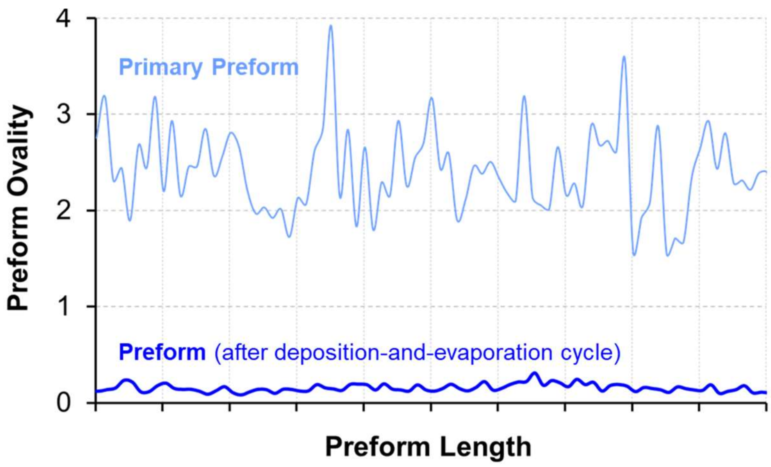

Fig. 2: Ovality of the primary preform and of the preform (after the deposition-and-evaporation cycle at the over-cladding step).

The resulting stacked primary preform was then collapsed under vacuum on a standard bench (Fig.1(b)). During this step, all gaps between the rods were closed. The collapsed primary preform without holes or bubbles is shown in Fig.1(c). This technique allows for good control of the geometry and avoids defects.

This primary perform was then over-cladded using a specific cycle of layer-by-layer silica grain deposition and evaporation with a plasma torch. This is a very effective technique that has two main advantages. Firstly, it allows to control the geometrical properties of the preform, and particularly the core-to-core distance because the preform outer diameter can be adjusted to any desired value after the stacking and collapsing steps, without being constrained by the tube thickness (that can be evaporated). Secondly, it allows to obtain multi-core preforms with outer diameters with accuracy of ± 0.1mm all along the length and ovalities below 0.2, which are typical values for standard single-mode preforms (see Fig.2). In comparison, the average ovality of the multi-core primary preform (measured before the deposition-and-evaporation cycle) is higher than 2. The final 4-core preform had a diameter of 42mm and a length of ~1m (~110km fiber capacity). The preform diameter was only limited by the size of our collapsing furnace, but it can be enlarged to more than 100mm using bigger furnaces. All other fabrication steps are already adapted to larger and longer preforms.

Finally, the preform was drawn on standard equipment without the need for pressure control. Drawing speed and tension were similar to those used to fabricate G.652.D single-mode fibers. The cladding diameter was 125 ±0.3µm. We applied a dual-layer acrylate coating to reach a colored diameter of 200µm. A 4-core fiber with a standard cladding diameter of 125µm and a coating diameter of 200µm has recently been reported and is promising for high-density-cable applications [14]. When moving from the standard diameter of 245µm to the reduced diameter of 200µm, care was taken to maintain a significant buffer layer of soft primary coating for protection against micro-bending (thickness of 16µm and Young's modulus of 0.35MPa) while at the same time preserve an adequate secondary coating thickness for handling robustness and mechanical protection (thickness of 21.5µm and Young's modulus of 1200MPa) [15].

Characterization

Fig.3 shows the cross section of the fabricated 4-core fiber with a standard 125µm cladding diameter and a 200µm coating diameter. The average core pitch is 39.4µm. Table 1 summarizes the measured optical properties. The mode-field diameters are compliant with ITU-T recommendation G.652.D (nominal values

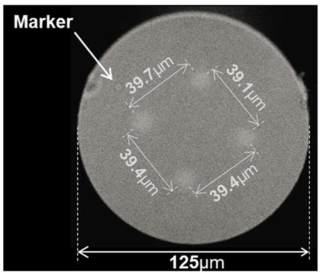

Fig. 3: Cross section of the fabricated 4-core fiber.

Tab. 1: Optical properties of the fabricated 4-core fiber.

	λ (nm)	Core 1	Core 2	Core 3	Core 4
Mode Field Diameter (µm)	1310	8.8	8.9	8.8	8.9
	1550	9.8	9.9	9.8	9.9
Cable Cutoff Wavelength (nm)	-	1289	1256	1232	1288
Attenuation (dB/km)	1310	0.347	0.345	0.346	0.348
	1550	0.215	0.215	0.215	0.225
	1625	0.241	0.239	0.238	0.243
Crosstalk (dB/km)	1550	<-30			

between 8.6 and 9.2µm at 1310nm), and so do the cable cutoff wavelengths of 2 cores out of 4 (maximum value below 1260nm). Slight process adjustments should allow to reach values <1260nm for all cores. The average attenuation was 0.217dB/km at 1550nm. There is room to reach the typical ~0.19dB/km of G.652.D single-mode fibers by improving the cleanliness of the stacking and collapsing steps. The crosstalk value was below -30dB/km at 1550nm, which is expected for a MCF with a cladding diameter of 125µm and 4 cores based on non-trench step-index profiles [5]. Note that using trench-assisted step-index profiles, that are compatible with our fabrication method, would lead to crosstalk values <-50dB/km [2].

The mechanical properties of MCFs have been little studied. This is, however, of major importance when fibers are to be deployed in the field. We thus investigated the stripping, fatigue and tensile strength properties of the 4-core fiber. The measured coating strip force required to mechanically remove the coating along the longitudinal axis was measured at 0.8N (above the Standard that specifies >0.4N). We then performed the dynamic fatigue stress corrosion test and consistently obtained n-value ≥24 (exceeding the minimum specified value of 18). Finally, a typical Weibull plot of the 10m tensile strength distribution is shown in Fig.4, together with that of a G.652.D/G.657.A2 single-mode fiber with a coating diameter of 200µm for comparison [15]. The strength at 50% probability of breakage of the 4-core fiber was 575kpsi (above the 550kpsi lower limit specified by the Standard).

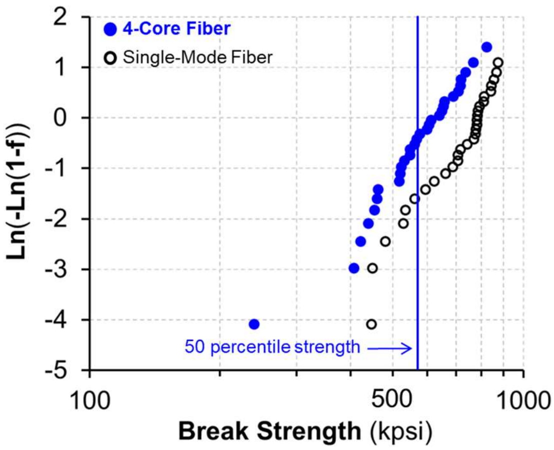

Fig. 4: Typical tensile strength Weibull distributions of fibers with cladding diameter of 125µm and coating diameter of 200µm: 4-core fiber (purple circles), single-mode fiber (black circles).

The 4-core fiber thus meets the requirements for stripping, fatigue properties, and tensile strength of IEC 60793-2-50 for type B fibers.

Conclusion

A simple MCF fabrication method was presented. This method uses standard manufacturing processes, except for the stacking step, and is scalable to larger preform sizes, which might open the door to low-cost and large-scale production.

A 4-core fiber with a standard cladding diameter of 125µm and a coating diameter of 200µm and good geometrical, optical and mechanical properties was fabricated using this method.

References

[1] G. Le Noane, D. Boscher, P. Grosso, J. C. Bizeul, C. Botton, "Ultra high-density cables using a new concept of bundled multicore monomode fibers: a key for the future FTTH networks," in Proceedings *International Wire and Cable Symposium (IWCS'94)*, pp. 203-209 (1994).

[2] T. Matsui, T. Sakamoto, Y. Goto, K. Saito, K. Nakajima, F. Yamamoto, T. Kurashima, "Design of multi-core fiber in 125µm cladding diameter with full compliance to conventional SMF," presented at *ECOC'15*, Valencia, Spain, paper We.4.3 (2015).

[3] T. Hayashi, Y. Tamura, T. Hasegawa and T. Taru, "125µm-cladding coupled multi-core fiber with ultra-low loss of 0.158dB/km and record-low spatial mode dispersion of 6.1ps/km$^{1/2}$," presented at *OFC'16*, Anaheim, CA, USA, paper Th5A.1 (2016).

[4] T. Gonda, K. Imamura, R. Sugizaki, Y. Kawaguchi, T. Tsuritani, "5-core fiber with heterogeneous design suitable for migration from single-core system to multi-core system," presented at *ECOC'16*, Düsseldorf, Germany, paper W.2.B.1 (2016).

[5] T. Matsui, T. Sakamoto, K. Nakajima, "Step-index profile multi-core fiber with standard 125µm cladding to full-band application," presented at *ECOC'19*, Dublin, Ireland, paper M.1.D.3 (2019).

[6] M. Takahashi, K. Maeda, K. Aiso, K. Mukasa, R. Sugizaki, D. Soma, H. Takahashi, T. Tsuritani, M. Mitrovic, B. Pálsdóttir, Y. Arashitani, "Uncoupled 4-core Fiber with Ultra-low Loss and Low Inter Core Crosstalk," presented at *ECOC'20*, Brussels, Belgium, paper ThA1-5 (2020).

[7] T. Nagashima, T. Hayashi and T. Nakanishi, "Productivity Improvement of Multi-Core Fiber Fabrication Process by Rod-in-Tube Drawing method," *IEICE Transactions on Communications (Japanese Edition)*, vol. J101-B, n° 9, pp. 798-805 (2018).

[8] I. Ishida, T. Akamatsu, Z. Wang, Y. Sasaki, K. Takenaga and S. Matsuo, "Possibility of Stack and Draw process as Fabrication Technology for Multi-Core Fiber," presented at *OFC'13*, Anaheim, CA, USA, paper OTu2G.1 (2013).

[9] R. Fukumoto, K. Takenaga, K. Aikawa, "Multi-core Fiber Fabrication in Over-Cladding Bundled Rods Method Applying Polygonal Rods," presented at *OECC'19*, Fukuoka, Japan, paper TuC3-1 (2019).

[10] J. Yamamoto, T. Yajima, Y. Kinoshita, F. Ishii, M. Yoshida, T. Hirooka and M. Nakazawa., "Fabrication of Multi-Core Fiber by using Slurry Casting Method," presented at *OFC'17*, Los Angeles, CA, USA, paper Th1H.5 (2017).

[11] M. Takahashi, K. Maeda, R. Sugizaki, M. Tsukamoto, "Multicore Fiber Fabricated by Modified Cylinder Method,"

presented at *OFC'20*, San Francisco, CA, USA, paper Th2A.17 (2020).

[12] J.-F. Bourhis, R. Meilleur, P. Nouchi, A. Tardy, G. Orcel, "Manufacturing and Characterizations of Multicore Fibers," in Proceedings *International Wire and Cable Symposium (IWCS'97)*, pp. 584-589 (1997).

[13] R. Dorn and C. Le Sergent, "Preform technologies for optical fibers," *Electrical Communication*, vol. 62, n°3/4, pp. 235-241 (1988).

[14] Y. Sasaki, R. Fukumoto, K. Takenaga, S. Shimizu, K. Aikawa, "Optical Fiber Cable Employing 200μm-Coated Multicore Fibers for High Density Wiring in Datacom," presented at *OFC'21*, San Diego, CA, USA, paper Tu6B.2 (2021).

[15] P. Sillard A. Amezcua-Correa, H. Maerten, C. Mentzler, A. Pastouret, "180μm-Coated Bend-Insensitive Fiber and Micro-Duct Cable," presented at *ECOC'21*, Bordeaux, France, paper We1A.3 (2021).