Defect Resistance and Self-Healing within Spun Photonic Crystal Fibres

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Abstract: We demonstrate that under appropriate conditions it is possible to build in tolerance to poor design of a structured optical fibre like photonic crystal fibre. During drawing its internal symmetry of the structure is improved. © 2020 The Author(s)

1. Introduction

Spun highly birefringent (Hi-Bi) optical fibres, either highly stressed bow-tie and PANDA fibre or Hi-Bi photonic crystal fibre (PCF), have great potential for current sensing, strain and twist sensing, etc. [1-4]. Compared with conventional spun bow-tie and PANDA fibres, spun Hi-Bi PCF (SHBPCF) has low temperature dependence [2]. So far, most of spun PCFs are drawn from a spinning preform with external pressure used to control the PCF structure [2, 5-8]. This overcomes the limits of internal pressure alone. In practice, it is difficult to sustain stable pressure during high speed spinning (v_s > 50 rpm) of the preform. Therefore, by increasing internal pressure, self-pressurization has been shown to be sufficient to keep structure open. Spun Hi-Bi bismuth/erbium co-doped PCF with broadband polarized emission [9] and a novel spun PCF with amoeba shape [10], have been demonstrated. Here, with self-pressurization the SHBPCF has been fabricated. Furthermore, analysis of the structure demonstrates that a resilience to pressure can be built in by controlling the dimensions of the PCF structure. Glass viscosity is key to this control.

2. Spun Hi-Bi PCF Fabrication

The SHBPCF is fabricated using stack-and-draw [9, 10]. The Hi-Bi PCF preform (Fig. 1a) was made by stacking capillaries and canes. Most of the interstitial gaps are then removed by fusing on a modified chemical vapor deposition (MCVD) lathe under pressure control. After further sleeving and stretching, the PCF preform (Fig. 1b) is ready for spin drawing. Gaps in the outer rings are removed but remain around the 1st and 2nd rings.

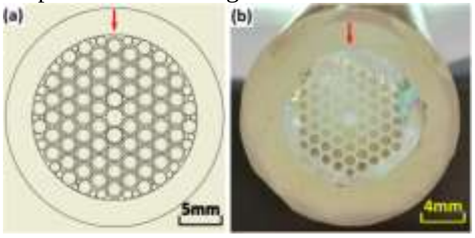

Fig. 1. (a) Design of Hi-Bi PCF preform, (b) The cross section image of Hi-Bi PCF preform. The red arrow indicates Hi-Bi air holes.

The self-pressurization method in [9] is adopted for spun PCF drawing. Here, all air holes are sealed individually at the top preform end. Spin drawing began with normal drawing at T ~ 1870 °C. The PCF structure is well kept by drawing at low temperature (T = 1870 °C) - the viscosity helps to resist the collapse. Self-pressurization enables the internal pressure to increase with drawing. When the fibre diameter is reduced to ϕ < 200 μm, acrylate coating was applied to protect the bare fibre. Meanwhile, T is reduced to ~1865 °C. When the fibre diameter is ϕ ~125 μm, the preform starts spinning at v_s = 50 rev/min (rpm) and then v_s = 150 rpm after drawing ~50 m of fibre (marked as SHBPCF A). Due to a slightly bent preform, the off-axis fibre broke after tens of meters of fibre (SHBPCF B) was drawn. For samples SHBPCF A and B, the preform feed rate v_f and fibre drawing rate v_d were 0.15 mm/min and 3.0 m/min respectively.

Figs. 2 (a -d) show the cross-section of SHBPCF A and B measured with optical microscope (OM) and scanning electron microscope (SEM) respectively. The images in Fig. 2 indicate that self-pressurization alone during spin drawing can maintain the lattice structure. Figs. 2a and 2c indicate that SHBPCF displays good guidance property. The images also show that SHBPCFs drawn retain uniform, hexagonal shapes from strong self-pressurization inside the air holes. Comparing the preform (Fig. 1b) and fibre (Figs. 2b & 2d) structures, the air holes of PCF structure are well retained. The Hi-Bi air holes with thinner capillaries are larger than the normal air holes overall. All the interstitial gaps outside the 3rd ring are fully collapsed. But some interstitial gaps from the core region to the 3rd ring are expanded and destroyed the structure symmetry to some degree. Figs. 2b and 2d show that the air holes are blown up due to the higher pressure building with fibre drawing. Since symmetry is maintained, they actually become rounder greatly improving the symmetry of the structure.

The increase of the roundness and symmetry may be linked with faster spinning and averaging the asymmetry force. The viscosity of the glass at low drawing temperature and its elastic response will get the structure to stay more symmetric, a form of self-healing.

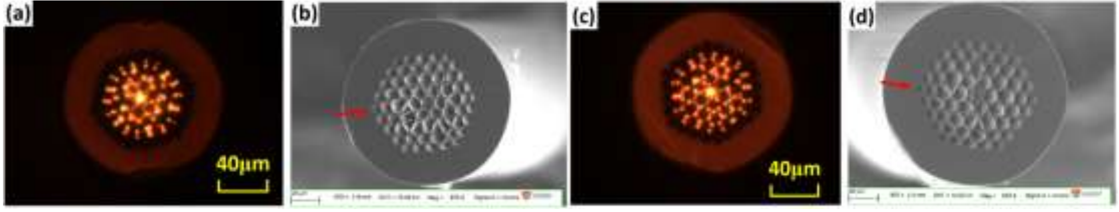

Fig. 2. The cross section images of SHBPCF A (a, b) and B (c, d) measured with an OM and SEM, respectively. The red arrows in (b, d) indicates the direction of Hi-Bi air holes.

3. Preliminarily Test

From drawing and spinning speeds, the induced helix of SHBPCF B was Λ ~ 20 mm, matched well with that obtained from optical microscope (Fig. 3). This pitch is only sufficient to induce elliptical birefringence over long lengths but not enough for circular birefringence. The guidance property of SHBPCF A (Λ ~ 60 mm) is preliminarily investigated using transmission of light at 1050 nm and 1550 nm. The output is measured with the beam profiler and the output pattern is shown in Fig. 4. The asymmetric circular output pattern is seen at both 1050 and 1550 nm, clearly demonstrating the spun structure intrinsically resulted in this fibre.

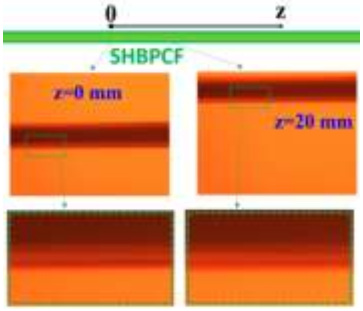

Fig. 3. Side images of SHBPCF B under the optical microscope, indicating an induced pitch Λ ~20 mm.

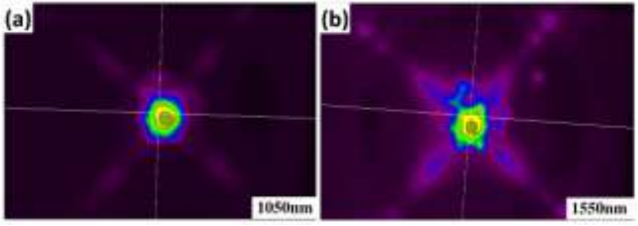

Fig. 4. The output pattern of SHBPCF A at λ = 1050 nm and 1550 nm.

4. Conclusion

Self-healing has been demonstrated, using self-pressurisation, with the fabrication of spun, birefringent structured optical fibres. This is promising approach to improving optical fibre fabrication more generally.

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