A Novel Spun Photonic Crystal Fibre with Amoeba Shape

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Abstract: A novel spun photonic crystal fibre with Amoeba shape has been fabricated based on asymmetric self-pressurization. Asymmetry growth dynamics with fibre drawing has been investigated.

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1. Introduction

Since the first demonstration of the structured optical fibres (SOFs) by Bell Labs in the 1970s [1], SOFs, especially periodic photonic crystal fibres (PCFs), have attracted more and more interest due to their unique features that conventional fibres cannot achieve [2], such as endlessly single mode, high nonlinearity, large mode area and more [3-5]. Their features are much dependent upon the structure of SOFs, which grants them more capabilities, like high birefringence [6] and reduced dispersion [7]. Over the past few decades, many SOFs with special structures have been designed and fabricated. For example, flower patterned PCF can generate an ultra-broadband supercontinuum from 350 nm to 2200 nm [8]. Large pitch Kagome-structured hollow-core PCF has broad optical transmission bands covering the visible and near-IR band with relatively low loss and low chromatic dispersion, no detectable surface modes and high confinement of light in the core [9]. Spider-web porous fibre has been identified to achieve low loss and low dispersion THz polymer fibres [10]. Spiral PCF like sunflower seeds offers low bend loss, high nonlinearity, high birefringence and nonzero dispersion [11]. Alternatively, nature offers a huge gallery of unique designs that can be mimicked in fibre design. They involve nearly perfect structures and forms that have evolved over millions of years [12]. Engineers and scientists have already embraced the opportunities arising from mimicking natural materials and translating natural design concepts into man-made products [13]. Here, a spun PCF with the cross section like Amoeba in nature has firstly been fabricated.

2. Experiments and results

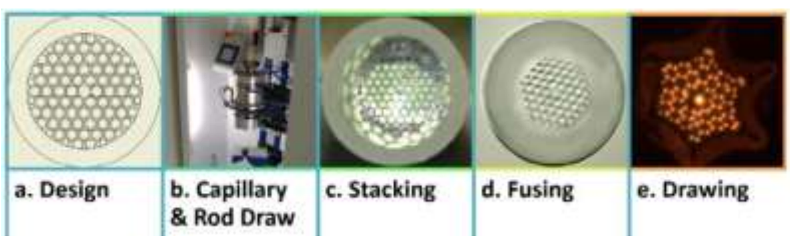

Fig. 1. Course of the fabrication of spun Amoeba-faced PCF from the design to the final drawing.

The fabrication of spun PCF is mainly based on the stack-and-draw technique [14]. The fabrication procedures are schemed in Fig. 1. PCF with a 4-ring structure was designed using Autodesk Inventor as shown in Fig. 1a. It essentially uses slightly thinner capillaries on two sides of the first ring to introduce the birefringence, effectively altering the propagation constants of two polarisation eigenstates. Based on the design in Fig. 1a, capillaries and canes with different size have been drawn on the fibre draw tower as shown in Fig. 1b. Then, with capillaries and canes drawn, PCF preform was stacked as shown in Fig. 1c. The green color in capillaries is from the seal ceramic paste at the other end. Then the stacked preform was fused at ~ 1730 ºC on the lathe to remove interstitial holes. In particular, the PCF preform structure was further tailored by stretching and sleeving, giving out the preform structure in Fig. 1d. The final step is the spun drawing.

For normal PCF drawing, the PCF structure is regulated by the furnace temperature, feeding rate, drawing rate as well as the pressure inside the air holes, controlled by purged N_2. When feeding and drawing rates are fixed, both the structure and dimension of the PCF can be controlled by the temperature and pressure. However, it remains a challenge to sustain pressure in spun PCF drawing. Therefore, self-pressurization is adopted [14], where all the air holes sealed individually at the top of PCF preform as shown in Fig. 2a. As a result, the structure will be maintained with the help from gas sealed inside the air holes in the preform.

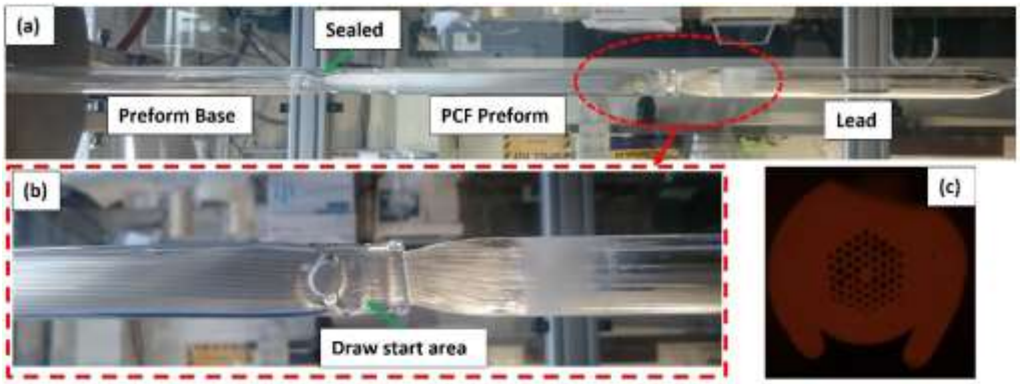

Fig. 2. (a) The whole PCF preform ready to draw, (b) zoom-in of the non-uniformity area at the draw start part, (c) cross section of the start drop.

Fig. 2a shows the preform used for Amoeba faced PCF drawing. The preform base (25×19 Heraeus quartz tube) allowed the well mounting into the spin feeder of the draw tower. Following right is the top-sealed PCF preform. The lead is a piece of the tube, fused with the PCF preform. The lead not only allows the air inside the holes ventilating out, but also provides enough weight to start the fibre draw at a lower temperature (~1855 ºC). The drawing starts without spinning and the air holes of the fibre drawn will be sealed slowly. Meanwhile, the air sealed inside the holes will provide enough expansion force to balance the collapse due to the drawing and surface tension. Once the drawing becomes stable, the preform will start to spin. The pitch is determined by the drawing rate and spin velocity. Especially, due to the non-uniformity at the draw start as shown in Fig. 2b, the PCF will finally become asymmetric in one direction, as proved by the start drop fibre in Fig. 2c.

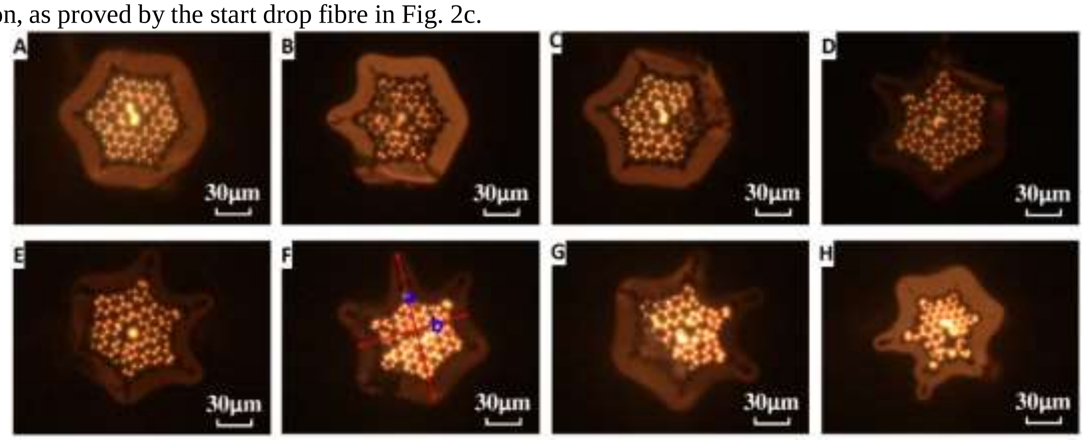

Fig. 3. The cross-section images of fibre samples (A-H) measured under the microscope.

Fig. 1e shows the cross-section image of the typical Amoeba shaped PCF, drawn with furnace temperature T_d = 1855 ºC, preform feeding rate v_f = 0.08 mm/min, fibre drawing rate v_d = 4 m/min and spinning rate v_s = 150 rpm. From these parameters, the physical pitch of the induced helix for this sample is Λ ~ 2.7 cm. Fig. 1e also indicates that this fibre guides light well. The shape of the fibre end is much like an Amoeba. The image seen with eyes under the microscope gives out more structure information. For example, there are some interstitial gaps blown up. In addition, due to the preform spinning, the structure deformed in circular direction. Especially, the head and arm part of this PCF are deformed from the air holes at the 4th ring.

Furthermore, a series of samples have been fabricated as shown in Fig. 3 with the drawing conditions listed in Table 1. Seen from Fig. 3, the fibre deformed from the quasi-hexagon shape to the Amoeba shape with drawing. In addition, it is noted that such fibres are easily cracked due to the non-uniform cross-section, and difficult to cleave uniform ends, as shown in Fig. 3. The head and arm of the Amoeba grows slowly. Such growth mainly attributed to the non-uniform self-pressurization of the individual holes at the head and arm area and made the larger difference with the leg and tail holes. Notably, the existence of the interstitial gap made the deformation more serious.

As listed in Table 1, the dimension increases with the increment of the spinning overall. The asymmetry of Amoeba fibre can be defined and calculated by a/b, where a is the head to tail distance and b is the thinnest position of the waist (marked in Fig. 3F). For samples A-H, the a/b increases from 1.11 to 1.49, indicating that the fibre asymmetry increases with drawing.

Table 1. The drawing conditions and dimension parameters of fibre samples.

Code	**T**	v_f	v_d	v_s	**D_f**	**a**	**b**	**a/b**
	°C	**mm/min**	**m/min**	**rpm**	**µm**	**µm**	**µm**	
A	1850	0.07	4	0	118	122.7	110.1	1.11
B	1850	0.07	4	50	117	116.4	103.8	1.12
C	1855	0.08	4	50	112	123.9	105.4	1.18
D	1855	0.08	4	101	123	123.9	100.7	1.23
E	1855	0.08	4	150	127	125.8	100.7	1.25
F	1855	0.08	4	203	120	129.0	96.6	1.34
G	1855	0.06	4	254	128	135.3	97.5	1.39
H	1855	0.05	2.5	50	111	113.5	76.1	1.49

Note: D_f is the fibre diameter monitored by the draw tower.

4. Conclusions

With the stack-and-draw technique, a novel spun photonic crystal fibre with Amoeba shape has been drawn by the self-pressurization. The novel Amoeba shape can be fine-tuned with controlled pressure and drawing rates. It is mainly attributed to the non-uniform draw start. The drawing process allows the head and arms to grow with asymmetry increasing. Such novel Amoeba faced PCF can be utilised biosensing given both the flexible functionality of air holes at the head and limbs of the design, those at the edges having greatest interactions. The method allows the total surface area of interaction of the fibre to be increased and adjusted, an approach that could lead to more efficient cooling of structured high power fibre lasers for example. It can also improve the attachment and alignment of the fibres.

Acknowledgments
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