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Post-processing of hollow-core photonic crystal fibers: selective hole inflation and tapering

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Abstract—We report on post-processing experiments using hollow-core photonic crystal fibers. We show that, by simultaneously heating and internally pressurizing the fibers, we can taper or modify the sizes of the fiber microstructure features. Particularly, by employing a technique for selectively obstructing the microstructure elements, we could attain tailored modifications of the fiber architecture, namely the inflation of selected cladding tubes, which can be of interest for the development of new devices and sensors.

Keywords—fiber optics, photonic crystal fibers, hollow-core fibers, post-processing, tapers

I. INTRODUCTION

In the 1990s, the proposition of microstructured optical fibers led to a paradigm shift in photonics. Thanks to the possibility of appropriately designing and fabricating fibers exhibiting cross-sectional sets of holes running all along their lengths, unprecedented control of the waveguide’s properties could be reached. This in turn motivated the realization of a myriad of applications ranging from nonlinear optics to sensing. Indeed, this family of fibers keeps evolving at a fast pace, particularly regarding those displaying a void core – so-called hollow-core photonic crystal fibers (HCPCFs) –, which have very recently been established as the lowest loss fiber optics with guidance from the ultraviolet to the infrared [1, 2].

Whilst having a consistent cross-sectional microstructure over long lengths is typically beneficial (e.g., in loss performance demonstrations), post-processing routines that can locally alter the fibers’ microstructures confer an interesting route for tailoring the properties of the studied fibers in applications aiming at supercontinuum generation [3] and the development of fiber devices [4], for example. Additionally, tapered HCPCFs have been used for pulse compression [5] and, more recently, as optical filters [6]. Furthermore, post-processing procedures allow integrating HCPCFs with the existing fiber devices and systems [7].

This paper reports the realization of post-processing experiments using tubular-lattice HCPCFs. We show that convenient obstruction of selected cladding tubes associated with simultaneous heating and pressurization of the fiber internal microstructure allowed us to suitably modify its transverse architecture and obtain fibers displaying one or

more enlarged tubes on their cross-section. Additionally, we show that our setup allows us to taper down HCPCF samples. We believe that the results reported herein identify a new opportunity for the modification of HCPCFs’ structures and may motivate new endeavors toward the development of novel HCPCF-based devices and sensors.

II. POST-PROCESSING OF HCPCFs

A. Selective inflation of cladding holes

The first post-processing routine we report here regards the selective inflation of tubular-lattice HCPCF cladding holes. To do so, we used the experimental setup as depicted in Fig. 1a, which allows for selectively obstructing the HCPCF cladding elements via convenient application of a UV curable glue microdroplet on specific sites of the fiber cross-section. We mention that the system shown in Fig. 1a has been previously reported to be able to obstruct solid- and hollow-fiber microstructures [8] and that we use it here to process new-generation tubular-lattice HCPCFs for the first time.

Specifically, the system is set as follows. The tip of the HCPCF is initially placed in front of a glue-filled micropipette

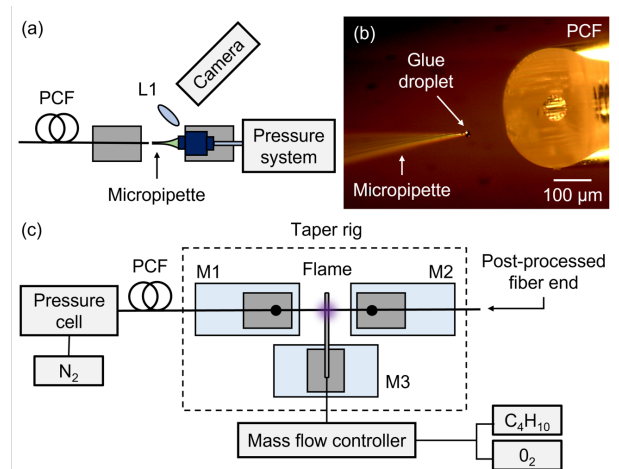


Fig. 1 (a) Diagram of the setup for selective blocking of the HCPCF cladding. L1: lens system. (b) Picture of the micropipette and HCPCF extremities. A glue droplet can be seen at the micropipette tip. (c) Diagram of the setup for HCPCF post-processing encompassing a pressure cell and a taper rig. M1, M2, M3: motorized stages.

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whose end is in turn connected to an N₂ pressurization system. A lens system (L1) and a camera are sequentially positioned at about a 45° angle with respect to the fiber extremity for suitable visualization of its end-face and that of the micropipette – Fig. 1b shows a picture, taken by using our camera system, where one can see the HCPCF extremity and a glue droplet leaving the micropipette tip. As both the HCPCF and the micropipette are attached to precision translation stages, they can be conveniently moved so an adequate view of the fiber cladding tubes, and micropipette tip can be attained. By controlling the position of the micropipette, we can place its tip inside one of the HCPCF holes. Sequentially, by increasing the N₂ pressure in the micropipette, one can pump the adhesive into the fiber cladding tube and block it. Other holes can also be filled if one removes the micropipette from one tube and repeat the process with another. Finally, the post-processed fiber is put into a UV chamber for 20 minutes for glue curing. Fig. 2a shows a picture of a HCPCF (with an obstructed cladding tube) that underwent the procedure described above.

Selective inflation of the obstructed cladding tube can be readily accomplished by processing the previously prepared sample using a taper rig (Fig. 1c). The fiber is hence fixed on two motors (M1 and M2) so it can be held stretched while a third translation stage (M3) allows a flame to oscillate under the section of the fiber we wish to post-process (we mention that the flame arises from a C₄H₁₀-O₂ mixture driven by a mass flow controller). By attaching the unprocessed fiber end to an N₂ pressure chamber (see Fig. 1c), one can pressurize the interior of the HCPCF while heating it.

Pressurization of the glue-obstructed tube readily allows elevating its internal pressure levels and, as the flame increases the fiber temperature above the glass transition temperature, attaining selective expansion of the blocked cladding tube, as can be noted in Fig. 2b and 2c, which stand for pictures of the same processed fiber, cut at the flame-processing site, and shown with different zoom conditions. To achieve the results shown in Fig. 2b and 2c, we set the N₂ pressure to 5 bar and let the system stabilize for 10 minutes before running the experiments. The flame processing, in turn, has been performed for 15 minutes while keeping the pressure on. The flame oscillation amplitude has been set to 1 cm.

Additionally, to attest to the versatility of our approach, we show in Fig. 2d a picture of a sample in which we obstructed and sequentially expanded two cladding tubes at diametrically opposite locations within the fiber cross-section. We see that, therefore, by using our technique, HCPCFs can be post-processed to achieve the inflation of selected cladding tubes. Future investigations will encompass the application of these structures in HCPCF-based sensors and devices.

B. HCPCF tapering

The setup shown in Fig. 1c also allows producing HCPCF tapers if the motors M1 and M2 controllably pull the fiber in opposite directions while the oscillating flame heats it. By following this method, we tapered a tubular-lattice HCPCF from an outer diameter of 320 μm down to 50 μm, as displayed in Fig. 3 (tapered length: 1 cm). We noted that the cladding tubes could be kept open during tapering. The core size, in turn, has been reduced from 42 μm to 7 μm. Further optimization of the fiber internal pressurization methods is expected to allow tuning of the tube sizes during tapering. Also, our system allows obtaining HCPCF tapers with different lengths, diameters, and transition shapes.

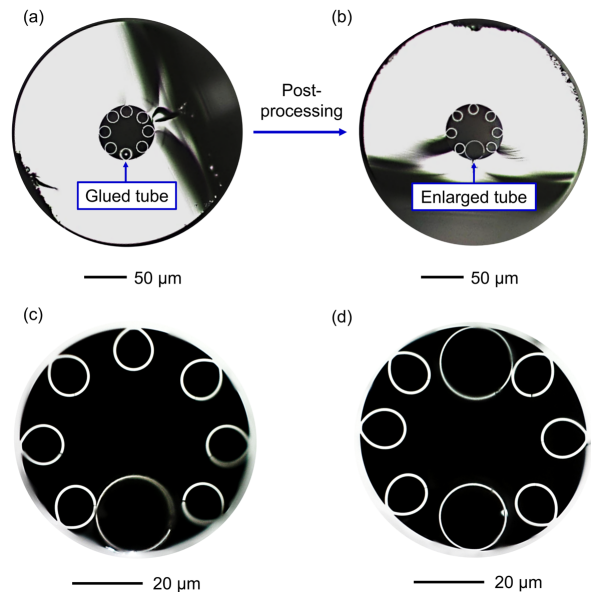


Fig. 2 Images of a HCPCF (a) with an blocked tube and (b) with an enlarged tube after post-processing. (c) Zoom in the HCPCF core as shown in (b). (d) A post-processed HCPCF with two inflated holes.

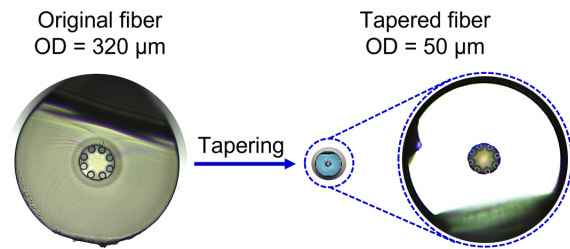


Fig. 3 Optical microscopy images of a HCPCF tapered down from 320 μm to 50 μm. OD: outer diameter.

III. CONCLUSIONS

We reported on HCPCF selective hole inflation and tapering experiments. We believe that our results identify a path for tailoring HCPCF properties and can be of interest to the development of new optical sensors and devices.

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