Up-tapering of Optical Fibers Using a Conventional Flame Tapering Rig

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Abstract: We demonstrate the fabrication of low-loss up-tapers in SMF-28 using a conventional tapering rig. Waist diameters of 240 µm, uniform over several cm, have been produced. The technique also works for photonic crystal fibers.

OCIS Codes: (060.2310) Fiber Optics; (060.2280) Fiber design and fabrication

1. Introduction

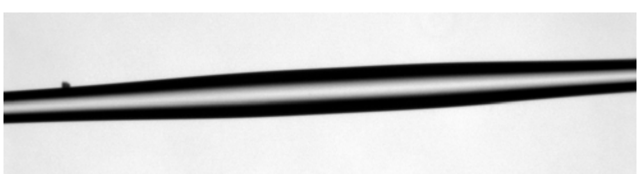
Tapered optical fibers are useful in numerous applications. Conventional tapering involves heating and stretching optical fibers so as to form a structure comprising a taper waist (a thin filament with uniform diameter) which is connected to the unstretched fiber via two taper transitions [1-2]. If instead of being stretched the fiber is compressed, the result will be exactly the opposite. The structure will consist of a section of uniform waist of thicker diameter connected to the untreated fiber via two transitions that taper in the opposite direction to that of the stretched fiber case. We will refer to this process as up-tapering of optical fibers.

There are many applications where two (or higher) mode fibers are required [3-7]. The larger core size of the up-tapered section of the fiber can shift the LP_{11} mode cut-off of SMF-28 from 1260 nm to wavelengths lying in the 1300 and 1550 nm telecommunications windows. Transformation of the mode field diameters of optical fibers is an important technology in many areas in photonics. Up-tapering is an alternative to more elaborate beam expansion techniques [8-9]. It can also be applied to photonic crystal fibers (PCFs), where the larger core of the up-tapered section improves the launch efficiency of small core PCFs used in ultra-short pulse experiments (hole inflation and tapering has a similar effect, except that the length of the resulting small-core section is highly limited [10]).

In this paper we demonstrate the fabrication of low-loss up-tapers, up to several centimeters in length, starting with SMF-28 and using a conventional flame tapering rig.

2. Experiment

The up-tapered fibers were fabricated with a rig that uses the well-established flame brushing technique [1]. A small (1.5 mm) oxybutane flame from a metallic nozzle was swept back and forth over a length of fiber as it was pushed in from both sides at a constant speed. The fiber ends were held in place using V-grooves placed on commercial high precision linear translation stages. The stages were aligned with each other to wavelength accuracy in order avoid fiber deformation and instabilities while pushing. The motor stages were controlled with custom-made control software.



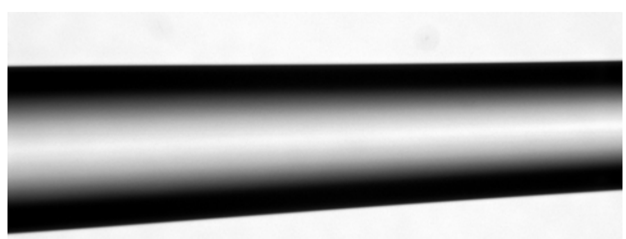


Figure 1:LHS: Optical micrograph of the up-tapered section of SFM-28. RHS: Close-up of a taper transition.

A micrograph of an up-tapered fiber is shown in Fig. 1. The LHS picture shows the whole up-tapered fiber section while the RHS shows a close-up of a taper transition. The pushing rate was 0.01 mm/s, the heated length was 3.5 mm and the flame performed 300 reversals with a speed of 3.0 mm/s. These parameters gave an up-tapered fiber section with maximum diameter of 196 µm over a length of ~1mm. From [1] the pull distance x required to obtain a desired tapered radius r_d is given by

$$x=2L_o \ln(r_o/r_d)$$

where L_o is the length of the uniform heating zone and r_o is the initial radius. Inserting the parameters for the up-tapered fiber into this formula gives the correct value for x, but with negative sign since x is, in our case, the pushing and not the pulling length. The transmission of the fiber was monitored with a diode laser at 1548 nm throughout the up-tapering process. Loss of less than 0.01 dB was measured for all the samples fabricated up to a diameter of 240 μm, which is the maximum we have achieved so far; this indicates that the taper transitions are adiabatic.

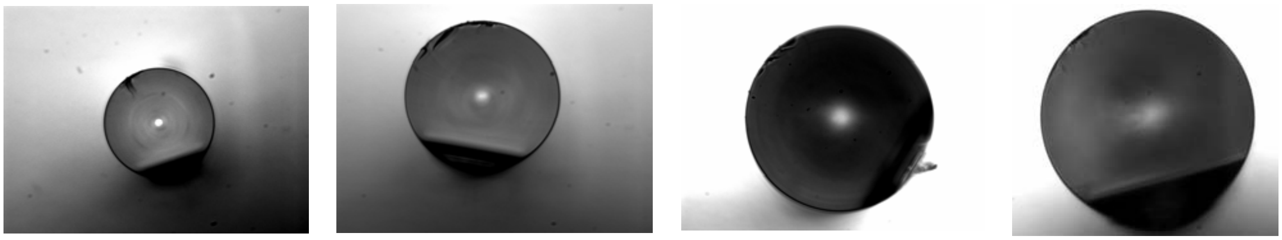


Figure 2. Optical micrographs of the **c**ross sections of up-tapered fiber samples. Diameters from left to right: untreated SMF-28 125 μm (Core diameter:8.6 μm) ; 173 μm(Core diameter:11.9 μm) ; 220 μm (Core diameter:15.1 μm) ; 243 μm (Core diameter:16.7μm).

In Fig. 2 the optical micrographs of the cross-sections of three up-tapered fiber samples are shown together with the cross-section of an untreated SFM-28. The core diameters scales exactly with the outer diameter of the up-tapered fiber. Since each section of fiber spends only a very short time at high temperature, no dopant diffusion from core into cladding is expected. The core diameter for modal cut-off at 1548 nm is ~10 μm, which scales up to an outer diameter for the up-tapered fibers of ~153 μm. All the treated fibers in Fig. 2 operate below cut-off at 1548 nm and can support modes of higher order than LP_{01}. Using a combination of down-tapering and up-tapering in the same experimental apparatus, one could potentially shift the modal cut-off of SMF-28 to all useful wavelength ranges in a single piece of fiber.

3. Conclusions

Conventional SMF-28 fiber can be successfully up-tapered using a flame tapering rig. Uniform waists several cm long with diameters up to 240 μm have been fabricated with negligible insertion loss. Up-tapering can be extended to PCF by applying pressure to avoid hole collapse – although the starting PCF structure must have holes with highly uniform diameters to avoid structural distortion.

3.References

[1] T.A. Birks and Y.W. Li "The shape of fiber tapers," J. Lightwave Tech. **10** 432 (1992).
[2] G. Kakarantzas, T.E. Dimmick, T. A. Birks and P. St.J. Russell "Miniature all-fiber devices based on CO2 laser microstructuring of tapered fibers," Opt. Lett. **26**, 1137 (2001).
[3] S. Ramachatran, "Novel photonic devices in few mode fibers," IEE Proc. –Circuits Devices Syst. **150** 473 (2003).
[4] H.S. Park, K.Y. Song, S.H. Yun, and B. Y. Kim, "All-fiber wavelength-tunable acousto-optic switches based on inter-modal coupling in fibers," J. Lightwave Tech. **20**, 1864-1868 (2002).
[5] H.S. Park, S.H. Yun, I.K. Hwang, S.B. Lee, and B.Y. Kim, "All-fiber add-drop wavelength-division multiplexer based on inter-modal coupling," IEEE Photon. Technol. Lett. **13**, 460-462 (2001).
[6] A.M. Vengsarkar, W.C. Michie, L. Jankovic, B. Culshaw, and R.O. Claus, "Fiber-optic dual-technique sensor for simultaneous measurement of strain and temperature," J. Lightwave Technol. **12**, 170-177 (1994).
[7] T.J. Chen and Y. H. Lin "Use of modal interference for probing birefringence induced in a bend optical fiber," Opt. Lett. **31,** 3231 (2006).
[8] K. Shiraishi, Y. Aizawa and S. Kawakami "Beam expanding fiber using thermal diffusion of the dopant," J. Lightwave Tech. **8**, 1151 (1990).
[9] H.M. Presby, N. Amitay, A.F. Benner and P.F. Glodis "Optical up-tapers with high beam Expansion ratios for component fabrication," J. Lightwave Tech. **7**, 820 (1989).
[10] W. Wadsworth, A. Witkowska, S. Leon-Saval, and T. Birks "Hole inflation and tapering of stock photonic crystal fibres" Opt Exp **13**, 6541 (2005)