Novel Design of a Microstructured Fiber Taper

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Abstract
A new design concept is proposed for microstructured fiber taper to be produced on a traditional optical fiber draw tower with multi-pressure control.

Introduction
In recent years, there have been renewed interests in optical fiber tapers, due to the advancement of microstructured fibers. It is possible to taper such fibers on a standard fiber draw tower [1]. Longitudinal variation of the fiber structure can leads to a comprehensive control of dispersion and nonlinearity, for spectral control under general condition [2]. The possibility of custom draw-tower fiber tapering can leads to exciting applications in nonlinear fiber optics, such as uniform and stable supercontinuum generation for telecommunications spectral slicing [3] and adiabatic soliton compression [1].

The early dispersion decreasing microstructured fibers were fabricated with radial (2D) designs consisted of uniform air hole size, and then tapered down either by reducing the pressure of all the air holes, or reducing the outer diameter of the fiber when drawn. The disadvantage of such tapering schemes is that when the features reduce in size, the associated confinement loss increases. Therefore, a large number of rings of air holes is needed to reduce the loss to a low level; and the preparation of large amount of capillaries is labor intensive. Moreover, decrease of the outer diameter of the fiber; may reduce the mechanical strength of the fiber, at the same time, increase the difficulty to connect it to standard fibers.

It has been reported that selective holes within a microstructure can be independently pressurized during the fiber drawing process [4]. Together with the possibility to vary the pressure of the holes during the drawing process, reported in [1], more complex 3D fiber designs can be achieved.

We proposed a new design concept for microstructured fiber taper to be produced by stacking of silica capillaries, and to be drawn on a traditional optical fiber draw tower with multi-pressure control.

The proposed tapering scheme consist of microstructure features with a few rings of large air holes, and the holes of the inner rings are tapered longitudinally by an independent pressure control, while keeping the outer diameter of the fiber constant. Here, the study of the simplest case is presented, in which, only the innermost ring of holes is varied in size. Thus, the core is made of 7-cell defects at the beginning of this index guiding taper, and the core is reduced to a 1-cell defect at the end of the taper, see figure 1.

Fig. 1. A schematic of the proposed taper scheme. The core size is reduced by introducing the innermost ring of holes; a 7-cell defect core is found in the beginning of the fiber, and a single-cell defect core is found at the end of the fiber.

In this work, a finite-element-method (FEM) based vectorial optical mode solver (Mode Solutions™ by Lumerical) was used to study the fiber design. The fiber is assumed to be made of pure silica. The modal behavior at different positions along the tapered fiber is investigated, and the characteristics of the dispersion and effective mode area are simulated at a pump wavelength of 800 nm, which coincide with many fs-pulse sources.

The design has a structure consists of six rings of air holes, with a constant hole-to-hole spacing, \( \Lambda = 0.5 \) µm. The air-filling fraction \( (d_1/\Lambda_1) \) of the innermost ring (ring 1) is varied from 0 to 0.9. The air-filling fraction \( (d_6/\Lambda_6) \) of ring 2 to 6 is set to be 0.9. We studied the characteristics of the taper by simulating ten 2D cross sections...
sections along the fiber, which had $d_1/\Lambda_1 = 0, 0.1, 0.2...0.9$. The effective refractive index, confinement loss, effective mode area and the dispersion profile of each section are obtained, and the results are presented in figures 2 and 3.

Fig. 2. (a) The simulated effective index of the fundamental mode and the 1st higher order mode along the tapered fiber at 800 nm. (b) The simulated confinement loss of the fundamental mode and the 1st higher order mode along the tapered fiber at 800 nm.

Figure 2 shows the simulated effective index and confinement loss of the fundamental mode and the first higher order mode along the fiber at 800 nm. It shows that when $d_1/\Lambda_1 > 0.5$, the confinement loss of the higher order mode is at least 10000 times greater than that of the fundamental mode. Therefore, one half of the fiber can be treated as effectively single mode, whereas, the other half is slightly multi-mode. Note that, the result is presented with a general fiber length scale. In practice, depending on how the pressure is varied with time during the drawing process, the length of particular portions of the fiber can be chosen according to application requirement. A taper produced on a fiber draw tower can have length of a few meters up to tens of kilometers.

As shown in Figure 3(a), the mode field diameter and the effective area decrease along the fiber as the core size decreases with $d_1/\Lambda_1$ increases. By choosing $\Lambda = 0.5 \mu m$, a portion of the fiber has a sub-wavelength core, thus greatly enhanced the nonlinearity. Dispersion profiles simulated from a few cross sections along the fiber are presented in Figure 3(b). The tapered fiber covers large range of normal and anomalous dispersion at 800 nm and 1060 nm wavelengths. Moreover, with relatively flat dispersion slope, especially at 1060 nm, the dispersion-flattened dispersion-decreasing nature of the fiber would provide the profile for generation of highly uniform and stable supercontinuum, which is required in telecommunication and optical frequency metrology applications [3]. If fiber taper technology is to be employed in telecommunication networks, then the proposed constant fiber outer diameter is preferred when connecting to standard fiber via strong fusion splicing [5].

Fig. 3. (a) The simulated effective mode area ($A_{\text{eff}}$) and mode field diameter (MFD) of the fundamental mode along the tapered fiber at 800 nm. (b) The simulated dispersion profile of the fundamental mode at various positions along the fiber.

Conclusions
A new design concept for microstructured fiber taper is proposed. A study of the simplest case is presented. However, by designing a more complex 2D fiber structure [6] together with the extra 3D design degree of freedom proposed here, one would expect this approach further extend the versatility of the microstructured fiber technology. We aim to fabricate such fibers in the near future.

References