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Design of a High-Nonlinearity Single-Mode Holey Fiber with Flattened Dispersion around 800 nm *

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We numerically demonstrate a high-nonlinearity single-mode holey fiber with flattened dispersion around the Ti-Za laser band at 800 nm. The dispersion profile of the fiber has the shape of a quadratic curve, which reaches its maximum 5.96 ps·km^{-1}·nm^{-1} at 800 nm and its minimum −0.897 ps·km^{-1}·nm^{-1} at both 750 and 850 nm. The nonlinear coefficient is 170 W^{-1}km^{-1} at 800 nm and no higher order modes exit. A six-layer air-hole cladding ensures a loss less than 0.067 db/m in the 750 to 850 nm range. Two more air-hole rings will reduce the loss to below 0.1 db/km.

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The control of chromatic dispersion in optical fibers is an important issue in almost all fiber based applications. In many cases, such as flat wideband supercontinuum generation[1,2] and wavelength-division multiplexing (WDM) communication systems, optical fibers with flattened dispersion profiles are preferred. However, due to technology limitation, broadband flattened dispersion is hardly achievable in conventional index guiding fibers.

Holy fiber (HF), also called microstructured optical fiber (MOF), is a new kind of optical fiber whose cladding contains many air holes that run along its length.[3] By manipulating the air-holes diameters d, the pitch Λ between air-holes, even the shape of air-holes, it is possible to engineer its dispersion curve to obtain desirable dispersion properties, such as dispersion compensating property[4−7] or dispersion flattened property.[8−15] Many novel designs of dispersion flattened HFs have been presented. Using the normalized dispersion method, dispersion flattened HFs around 1550nm with identical cladding air-holes have been proposed by Ferrando *et al.*[8,9] To obtain flat dispersion property, a small normalized air-hole diameter d/Λ is needed, about twenty rings of air-holes are essential to ensure a reasonable loss, which makes the making of such HFs difficult. To solve that problem, a novel structure with the air-hole diameter increasing with the distance from the fiber axis was provided by Renversez *et al.*[10] With this new design, researchers require only several rings of air-holes to reach a low loss at 1.55 μm. A highly nonlinear dispersion flattened HF was also provided by Poli *et al.*[11] by tuning the air-hole diameters ring by ring. However, the requirement that each ring has a different air-hole diameter makes it a technical challenge to fabricate this kind of HFs. By using only two different air-hole sizes and four rings of air-holes, Wu *et al.*[12] demonstrated an ultra-board band dispersion flattened HF from 1.295 to 1.725 μm.

So far, most of the fiber designs focused on the telecommunication window band of 1310–1550 nm. However, research works have shown that HFs with flattened dispersion in the Ti-Za laser band can also find potential applications in many areas, such as supercontinuum generation and optical frequency conversion.[16,17] Unlike that around the telecommunication window, the material dispersion of silica is not linear around 800 nm. In addition, the absolute value of the silica's dispersion around 800 nm is large (about 100 ps·km^{-1}·nm^{-1}). It is difficult to make geometrical dispersion counter-balance influence the material dispersion around the Ti-Za band. Few researchers have designed dispersion flattened HFs to cover the Ti-Za laser wavelength range around 0.8 μm.[10]

In this Letter, an HF with high nonlinearity, single-mode and flattened dispersion around 800 nm is achieved. The effective mode index n_{eff} of the HF is obtained by employing an accurate full vectorial method, the multi-pole method (MPM).[18,19] Then, the dispersion D can be obtained by $D = -\frac{c}{\lambda}\frac{d^2\mathrm{Re}(n_{\mathrm{eff}})}{d\lambda^2}$, where c is the velocity of light in vacuum, Re means the real part. The material dispersion of silica is taken into account via the Sellmeier equation. The confinement loss could be calculated by $\alpha = 8.686k_0\mathrm{Im}(n_{\mathrm{eff}})$ db/m, where Im means the imaginary part.

To guarantee its single-mode transmission, we start our design process with an initial model that has a modest air-hole diameter to pitch ratio $d/\Lambda = 0.5$ and six layers of air-holes (see Fig. 1). First, the in-

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fluence of hole-to-hole pitch Λ on the dispersion curve of the HF is analyzed. From Fig. 2, we can see that when Λ is 0.8 μm, the dispersion curve first goes up, then descends rapidly around 750 nm. With the increment of Λ, the value of dispersion after 650 nm increases, this makes the dispersion curves go up at a longer wavelength. The dispersion curve becomes flatter around 800 nm when Λ is about 1.0 μm. Then, set Λ as 1.0 μm and $d_i/\Lambda = 0.5$ ($i = 2, 3, 4, 5, 6$), d_1/Λ of the first inner ring is changed from 0.3 to 0.7 with steps of 0.1. Seen from Fig. 3, changing the diameter of the first inner ring while keeping the other parameters unchanged, the flatness of the dispersion curves around 800 nm has not obviously altered. However, the value of the dispersion increases with the enlargement of first-inner ring diameters. To obtain a positive value of dispersion, a larger d_1/Λ is required.

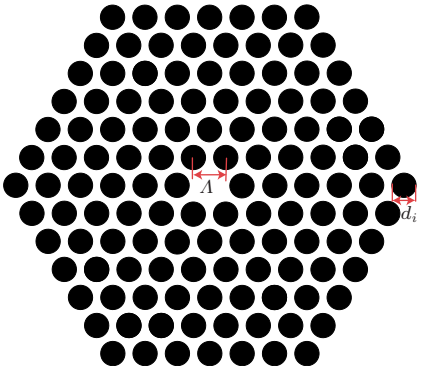


Fig. 1. Cross section of the simulated model (d_i represents the ith inner ring).

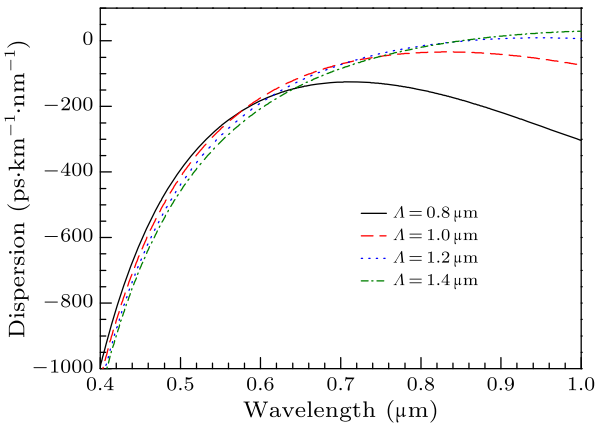


Fig. 2. Dispersions of HFs with $d/\Lambda = 0.5$ and the pitch from 0.8 to 1.4 μm with steps of 0.2 μm as a function of wavelength.

Based on the above analysis, $\Lambda = 0.94$ μm, $d_1/\Lambda = 0.64$ and $d_i/\Lambda = 0.5$ ($i = 2, 3, 4, 5, 6$) are chosen to proceed to next stage refinement and we now focus our interest on the 800 nm Ti-Za laser band. The individual influence of the air-hole diameter of the second and third ring on the HF dispersion property is demonstrated in Figs. 4(a) and 4(b). We can see that changing the second- and third-air-hole diameters have similar impacts on the dispersion curves: by increasing the diameter of the air-holes, the whole dispersion curve is elevated, and this trend is more obviously at the longer wavelength than that at the shorter wavelength. Considering that when the air-hole diameter is small, the dispersion at 750 nm is larger than that at 850 nm, the most flattened dispersion curve will be achieved if only one can engineer the curve to make the dispersion value equal at 750 and 850 nm.

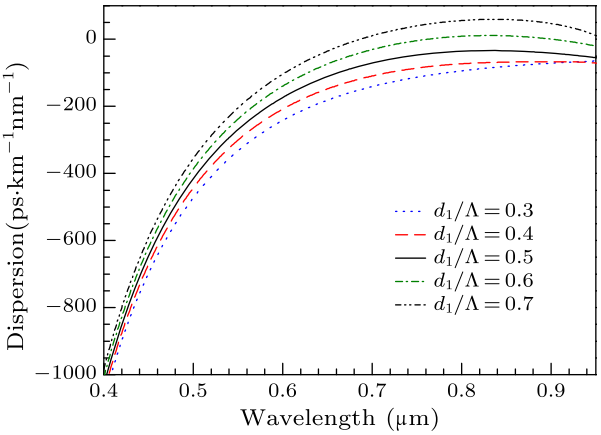


Fig. 3. Dispersion of HFs with $\Lambda = 1.0$ μm, $d_i = 0.5$ ($i = 2, 3, 4, 5, 6$) and $d_1/\Lambda = 0.3$–0.7 at a step of 0.1 (from bottom to top).

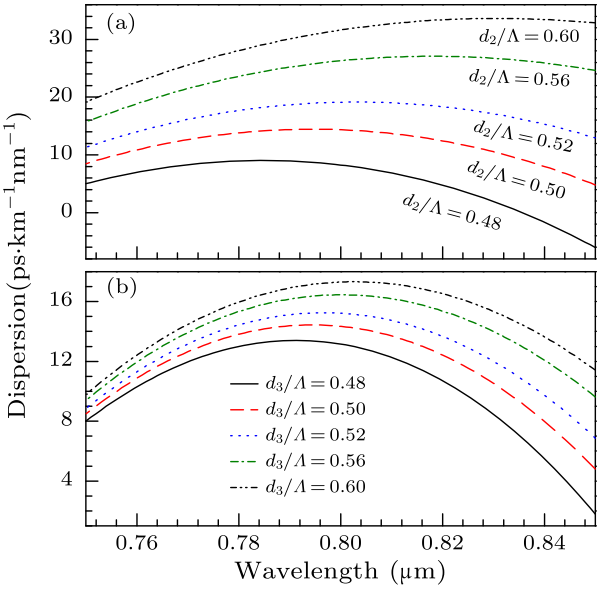


Fig. 4. Dispersion of HFs with $\Lambda = 1.0$ μm, $d_1/\Lambda = 0.64$ by changing (a) d_2/Λ and (b) d_3/Λ, respectively.

Lastly, the dispersion flattened HF with $\Lambda = 0.94$ μm, $d_1/\Lambda = 0.615$, $d_2/\Lambda = 0.521$, $d_3/\Lambda = 0.478$, $d_i/\Lambda = 0.501$ ($i = 4, 5, 6$) is obtained. The maximal dispersion value is 5.96 ps·km^{-1}·nm^{-1} at 800 nm, and minimum value is -0.897 ps·km^{-1}·nm^{-1} both at 750 and 850 nm. The dispersion value varies in the range of 4.23–5.96 ps·km^{-1}·nm^{-1} from 775–825 nm

band (Fig. 5). The effective mode area is 1.38, 1.27 and 1.14 μm^2 at 850, 800, and 750 nm, respectively, corresponding to nonlinear coefficient value of 148, 170 and 203 $W^{-1}km^{-1}$. The loss of the fundamental mode is less than 0.067 db/m at the 750 to 850 nm band. In most of the Ti-Za band applications, only several meters of HF are needed. Thus, the loss of the designed HF is low enough. By employing more air-hole rings, the loss of this HF can be reduced with little influence on the dispersion and effective mode area. For example, two more rings of air-hole with $d_i/\Lambda = 0.501$ ($i = 7, 8$) will guarantee a loss less than 0.1 db/km. Due to small hole to hole pith and modest air-holes' diameters, there are no higher order modes.

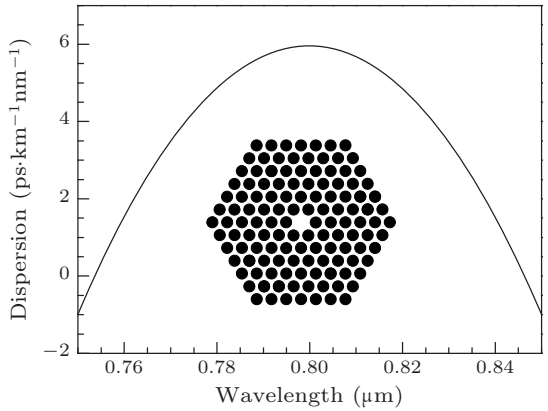


Fig. 5. Dispersion of the designed dispersion flattened HF as a function of wavelength (the inset is the cross section of the designed HF).

In conclusion, by tuning the cladding air-hole diameters d and hole to hole pitch Λ, HF with highly nonlinearity, single mode and flattened dispersion around 800 nm is designed. The dispersion has a quadratic curve like shape, which reaches its maximum 5.96 $ps{\cdot}km^{-1}{\cdot}nm^{-1}$ at 800 nm and its minimum $-0.897\,ps{\cdot}km^{-1}{\cdot}nm^{-1}$ at both 750 and 850 nm. The dispersion amplitude varies from 4.23 to 5.96 $ps{\cdot}km^{-1}{\cdot}nm^{-1}$ in the range 775–825 nm. Due to the small pitch Λ and the modest air-holes' diameters, the HF supports single mode transmission. The nonlinear coefficient values are 148, 170 and 203 $W^{-1}km^{-1}$ at 850, 800 and 750 nm, respectively. The HF with six layer air-hole cladding ensures a loss less than 0.067 db/m. Two more air-hole rings will reduce the fiber loss to the level of 0.1 db/km.

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