Equiangular Spiral Tellurite Photonic Crystal Fiber for Supercontinuum Generation in Mid-Infrared

Y. O. Azabi, Arti Agrawal, N. Kejalakshmy, B. M. A. Rahman and K. T. V. Grattan
School of Engineering and Mathematical Sciences,
City University London,
Northampton Square, EC1V 0HB
Yousaf.azabi.1@ciy.ac.uk

Abstract: We demonstrate very low and flat dispersion (±2ps/nm/km, slope<0.0028ps/nm^2/km@ 1.8-2μm) in the Mid-Infrared band along with high non-linear coefficient (γ=1155W^{-1}km^{-1}@ 1.93μm) achieved in a tellurite photonic crystal fiber for generating supercontinuum with a broad bandwidth.
OCIS codes: (060.4370) Nonlinear optics, fibers; (060.2280) Fiber design and fabrication

1. Introduction

Silica based fibers are restricted by the Silica material parameters such as the low non-linear refractive index and transparency below 3μm [1], which limits the supercontinuum generation (SCG) in these fibers. These limitations have lead to the investigation of new materials, with high non-linear refractive index and transparency in Mid-Infrared (M-IR) region, such as tellurite and chalcogenide classes.

Tellurite based microstructured fibers are promising candidates due to their high non-linearity for SCG. They are being fabricated and analysed widely at present. A recent study reports a tellurite PCF with an SC bandwidth of 4600nm for a 2.8cm length of fiber pumped at 1.93μm with a pulse width of 5ps, with non-linear coefficient (γ) of 140W^{-1}Km^{-1} at the pumping wavelength [2]. In this work, we present an Equiangular-Spiral Photonic Crystal Fiber (ES-PCF) with lower dispersion in IR-B band and much higher γ of 1155W^{-1}km^{-1} at 1.93μm.

2. Fabrication and Design

Spiral shapes play important role in our world as they present various nature phenomena, ranging from simple ones that can be noticed easily such as shells of snails, galaxies and nautilus; and others more complicated like the distribution of the sunflower seeds, which are hardly noticeable to us. The ES-PCF in an earlier work has shown distinct advantage in controlling dispersion and observing large γ for SCG [3].

In the ES-PCF design presented here, the air holes arrangement follow an equiangular spiral centered at a solid core (for a schematic and details of the structure refer to Agrawal *et al.* [3]). In comparison with conventional hexagonal PCF, the ES-PCF is more flexible in air holes adjustment for field confinement and dispersion optimization [3]. The field profile of the fundamental mode at 1.93μm is shown in Figure 1.

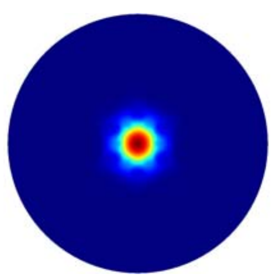


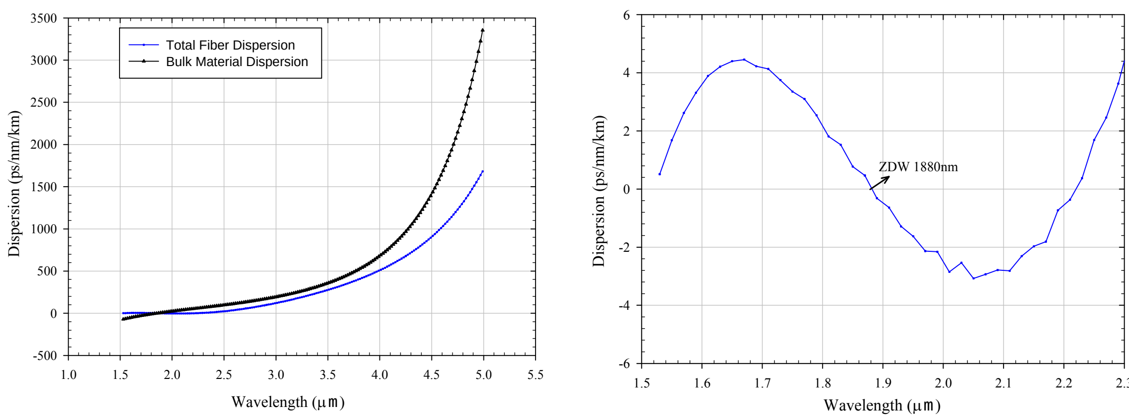
Fig. 1. Field profile of the fundamental mode at 1.93μm

3. Results

The material and total dispersion were calculated using equation 1, where the Sellmeier equation and coefficients [4] were implemented to calculate the refractive index of tellurite glass.

$$D = -\frac{\lambda}{c}\frac{d^2 n}{d\lambda^2} \qquad (1)$$

Figure 2(a) shows both the material dispersion, that has a zero dispersion wavelength (ZDW) at 1.83μm, and total waveguide dispersion which is smoothly flat for a wide wavelength range of 1000nm (1.5-2.5μm). Figure 2(b) shows a graph of the total dispersion from 1.5μm-2.3μm, where the fiber has multi ZDWs at 1.5, 1.88 and 2.22μm. The fiber has very low dispersion in the IR-B band (between ±2ps/nm/km with a slope less than $0.0028ps/nm^2/km$ for 200nm bandwidth, 1.8-2μm) and is also quite low for a wider bandwidth of 500nm (1.5-2.3μm) with value lying in the range of ±4ps/nm/km. In this bandwidth the dispersion slope is less than $0.003ps/nm^2/km$. This result is very important for SCG, as low and flat dispersion in tellurite PCF is not easy due to the large refractive index. The large refractive index leads to rapid effective index variation with wavelength and thus large dispersion and dispersion slope. However, the ES-design allows us to optimize the dispersion and overcome this problem.



(a) (b)

Fig. 2. (a) Material and total dispersion of tellurite ES-PCF with Λ=0.75μm. (b) Total dispersion in the IR-B band (ZDW 1880nm)

The non-linear coefficient, γ is $1155W^{-1}km^{-1}$ at 1.93μm, which believed to be the highest value at this wavelength, and $1754W^{-1}km^{-1}$ at 1.55μm have been calculated using equation 2, where n_2 is the non-linear refractive index, $n_2=5.9x10^{-19}m^2W^{-1}$ for tellurite glass [5,6]. Coupled together, the large γ and low and flat dispersion achieved with ES-design would be very useful for SCG.

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \qquad (2)$$

4. Conclusion

In conclusion, we have demonstrated very low and flat dispersion of ±2ps/nm/km with a slope of < $0.0028ps/nm^2/km$ through a wide bandwidth (1.8-2μm) with high non-linear coefficient of $1155W^{-1}km^{-1}$ at 1.93μm. These results show that dispersion can be controlled smoothly in the specified wavelength range with large γ, which is a promising for generating a wide supercontinuum.

5. References

[1] M. Liao, C. Chaudhari, G. Qin, X. Yan, T. Suzuki and Y. Ohishi, "Tellurite microstructure fibers with small hexagonal core for supercontinuum generation," OPTICS EXPRESS **17**, 12174-12182 (2009).
[2] D. Buccoliero, H. Steffensen, O. Bang, H. Ebendorff-Heidepriem and T. M. Monro, "Thulium pumped high power supercontinuum in loss-determined optimum lengths of tellurite photonic crystal fiber," App. Phy. Lett. **97**, 061106 (2010).
[3] A. Agrawal, , N. Kejalakshmy, B. M. A. Rahman and K.T. V. Grattan, "Soft glass equiangular spiral photonic crystal fiber for supercontinuum generation," *IEEE Photon. Tech. Lett*. **21**, 1722-1724 (2009).
[4] C. Chaudhari, T. Suzuki and Y. Ohishi, "Chalcogenide Core Photonic Crystal Fibers for Zero Chromatic Dispersion in the C-Band," OSA/OFC/NFOEC, OTuC4 (2009).
[5] G. Qin, X. Yan, C. Kito, M. Liao, T. Suzuki, A. Mori and Y. Ohishi, "Zero-dispersion-wavelength-decreasing tellurite microstructured fiber for wide and flattened supercontinuum generation," Opt. Lett. **35**, 136-138 (2010).
[6] G. Qin, M. Liao, C. Chaudhari, X. Yan, C. Kito, T. Suzuki, Y. Ohishi, "Second and third harmonics and flattend supercontinuum generation in tellurite microstructured fibers," Opt. Lett. **35**, 58-60 (2010).