Demonstration of a Wide Bandwidth, Low Loss Hollow Core Photonic Bandgap Fiber in the 1.55 μm Wavelength Region

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Abstract: We report a record wide 3dB bandwidth (235nm) for a low loss hollow core photonic bandgap fiber operating at 1.55µm. It is achieved by increasing the node/strut ratio in the cladding and optimizing surface mode position.

OCIS codes: (060.4005) Microstructured fiber; (060.2280) Fiber design and fabrication

1. Introduction

Hollow core photonic bandgap fibers (HC-PBGFs) allow for light guidance in air, and offer ultralow nonlinearity, ultimate low latency and potential ultralow loss, which makes them an attractive medium for applications ranging from data transmission, high power delivery, to gas/liquid based nonlinear optics. Among other properties, the loss and useable bandwidth are the two key characteristics that determine their suitability for many of their potential applications. Although great progress was made in terms of both parameters in the early stages of HC-PBGF development [1], significant efforts were later focused on reducing the loss, and eventually led to the demonstration of the record low-loss HC-PBGF in 2004[2]. However, this record low-loss fiber had only ~20nm operational bandwidth, which limited its usage, in applications such as data transmission. Having recognized the crucial importance of bandwidth, we demonstrated fibers with 3dB bandwidth as wide as 160nm in 2012 [3] and 200nm in 2015[4], both with state of the art loss values (around 3-5dB/km at 1550nm). A wide bandwidth is also a key enabler for HC-PBGF use for ultra-short pulse delivery/compression, wide-bandwidth gas/liquid based nonlinear optics and Raman spectroscopy.

Two points need to be considered carefully when designing a HC-PBGF with a wide useable bandwidth: the intrinsic photonic bandgap width and the effects of surface modes within the bandgap. A general principle to maximize the intrinsic bandgap is to make its cladding struts as thin as possible and to keep the cladding nodes well separated (but close enough for them to interact and form a photonic bandgap) [5]. In practice, this generally means a large relative hole size (d/Λ) and a high ratio of node/strut (or simply implies increasing the node mass) in the cladding. The other consideration in maximizing useable bandwidth is to control surface modes, which usually means a careful core boundary design is necessary[6]. In this paper, we report a novel design that considers optimization of both the cladding structure (an increase the cladding node mass while maintaining a high d/Λ) and core surrounding (minimizing the effects of surface modes within the bandgap). We have demonstrated, to the best of knowledge, a record 3dB bandwidth (235nm) for a low loss (4.1dB/km) HC-PBGF operating at 1.55µm.

2: Fiber fabrication and characterization

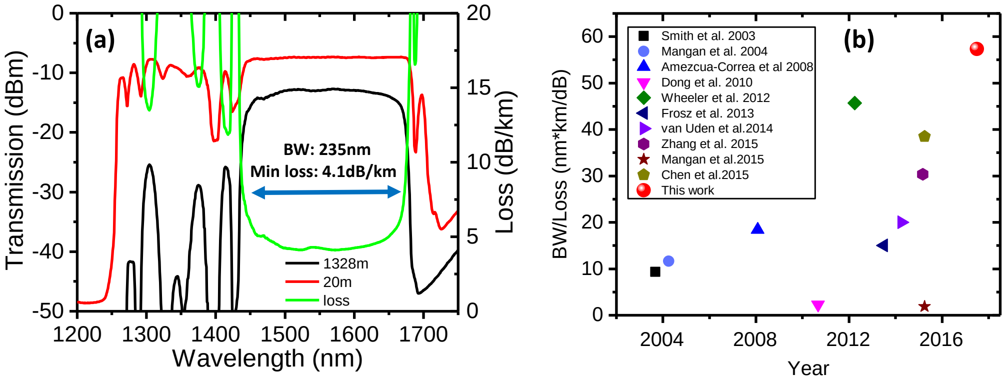

Fig. 1 (a) Cutback measurement results for the reported fiber, showing a 235nm 3dB BW and 4.1dB/km minimum loss. (b) Best performance HC-PBGFs that have been demonstrated by various group worldwide [Refs 1-4, 6, and 8-12]. BW is defined as the wavelength range where the fiber loss is doubled compare to its minimum value.

A 2-stage stack-and-draw technique was utilized in which glass capillaries were used to form the primary preform, which had a cladding constituted by 6½ rings of capillaries, and a core obtained by replacing 19 central elements with a thin-walled core tube. We carefully chose the wall thickness of the core tube, which was thin enough to minimize the surface modes that may be present in the final fiber, but also thick enough to help to minimize core shape distortion during fiber fabrication. In order to increase the node/strut ratio in the final fiber, we filled all the interstices between cladding capillaries with small solid rods. The fabricated fiber has a 34µm core, an averaged pitch of 5µm, a relative hole size (d/Λ) of 0.987, and an averaged strut thickness of 65nm. The loss spectrum was determined via the cutback technique using a supercontinuum source and OSA (The fiber was cut from 1328m to 20m), and shows a minimum loss of 4.1dB/km at 1574nm, Fig 1 (a). Note that the loss spectrum is very flat and wide, ultimately giving a 235nm wide 3dB bandwidth. To the best of our knowledge, this is the widest bandwidth ever reported in a low loss (less than 20dB/km) HC-PBGF.

Figure 2(b) summarizes the best performing HC-PBGFs that have previously been reported by research groups worldwide. We utilize a figure of merit defined by BW/Loss, and plot it versus the date on which these results were reported. Note that the BW is defined as the wavelength range where the fiber loss is doubled compare to its minimum value, which is sometimes called "3dB BW" in literatures. The HC-PBGF results reported here represent a ~20% increase in BW and ~30% reduction in loss compare to our previous results [4]. Note that we did not focus on ultra-long fiber lengths in this study as this capability has already been demonstrated before [4].

In order to understand how the BW can be affected by the node/strut ratio in the cladding and the potential to further increase the achievable BW, we have performed a series of finite element simulations based on a geometry reproduced from a SEM image of the fiber [7]. Starting from the case which matches our experimentally measured node size (matching nodes size) and which gives a simulated bandwidth of 230nm (agreeing well with the experimental measurement of 235nm), we performed two further simulations with the node size increased (decreased) by 10% and adjusted the strut thickness accordingly to ensure the total mass of glass was conserved. This mimics in principle the subtle changes of glass distribution in the HC-PBGF cladding during a fiber draw when accurate pressure control can be achieved. It is shown that the long wavelength edge of the bandgap moves to longer wavelengths when the node size becomes larger. As a result of this, and the blue shift in surface mode peak, the 3dB BW changes from 150 nm to 320 nm, Fig 2.

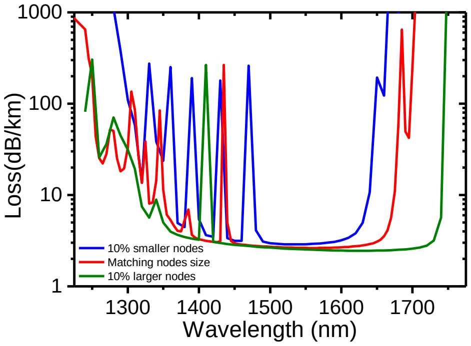

Fig. 2: The simulated loss spectra (from which 3dB BW can be calculated) for the three cases described in the text that correspond to 10% smaller nodes, the matching nodes, and 10% bigger nodes in the cladding of the HC-PBGF.

3: Conclusion

We have presented a low loss (4.1dB/km), record wide bandwidth (235nm) 19-cell HC-PBGF operating at 1.55µm. This was achieved by a combination of optimized surface modes positions and increased node/strut ratio (by adding interstitial rods in the stack stage) in the cladding. Our simulation results indicate that more than 300nm bandwidth is possible from the same preform as long as the ratio of node size and strut can be increased. In experiment, this may be obtained by pushing the d/Λ even further, for example, more than 0.99. This value is high but is practically achievable since values as high as 0.992 have already been demonstrated previously [4].

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4. References

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