First Demonstration of a Low Loss 37-cell Hollow Core Photonic Bandgap Fiber and its Use for Data Transmission

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Abstract: A low loss (4.5dB/km) 37-cell core HC-PBGF is reported for the first time. Detailed modal analysis using time of flight and S^2 techniques, and error-free 40Gbit/s single mode data transmission are presented.

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1. Introduction

Hollow core photonic bandgap fibers (HC-PBGFs) are emerging as credible candidates for data transmission applications because of their low nonlinearity, low latency and predicted ultralow loss. Recently, 19-cell HC-PBGFs with wide bandwidths (>150 nm) and a loss of a few dB/km have been demonstrated [1]. Their ability to support high capacity data transmission at 1.55 µm and 2µm has also been established [2,3]. However, for HC-PBGFs to stand a realistic chance of competing with current transmission fibers, further loss reduction needs to be achieved whilst maintaining a wide transmission bandwidth. Since the fundamental loss limit of HC-PBGFs is determined by surface roughness scattering [4], one possible route to loss reduction is to increase the core size, e.g. from 19-cell to 37-cell, thus reducing the amount of overlap between optical field and glass. In practice, however, the fabrication of HC-PBGFs with bigger core surrounds presents a number of challenges, including the presence of potentially more surface modes as compared to 7 and 19-cell HC-PBGFs [5], and a substantial increase in the number of core guided modes, to the point that a 37-cell HC-PBGF was previously expected to have little practical value [4].

In this work, we report fabrication of the first ever 37-cell (37c) HC-PBGF. The fiber has a low minimum loss of 4.5 dB/km at 1550nm and a wide 3-dB bandwidth of 85 nm, obtained by applying similar core surround engineering as previously described [1]. Modal characterization using Time of Flight and S^2 techniques, shows that, remarkably, the levels of crosstalk between lower order mode groups is low and comparable to that previously measured in 19 cell fibers, and thus also this 37c HC-PBGF can be operated as effectively single moded. As a proof of that we report 40 Gbit/s error-free single mode data transmission over >300 m of fiber.

2. Fiber Fabrication and Characterization

The 37 cell HC-PBGF was fabricated using the conventional dual-step stack and draw technique. The fiber has 6 ½ rings of cladding holes and 37 capillaries were removed from the center of the array to form the core. To reduce the impact of surface modes inside the bandgap region, no central core tube was used [3]. The fiber has an average pitch, relative hole size and core diameter of 4.4 µm, 0.97 and 37 µm, respectively (Fig 1a). The spectral attenuation was measured via a cutback method using a white light source and optical spectrum analyzer. A large mode area holey fiber (LMA 25 from NKT Photonics A/S) was used to couple light into the HC-PBGF ensuring good match to the mode field diameter of the fundamental mode (LP_{01}). Transmission plots and loss data obtained from a careful cutback from 320 m to 10 m are shown in Fig. 1(b,c). The fiber has a minimum loss of 4.5 dB/km at 1550 nm. Only two groups of surface modes are observed within the bandgap, and by optimizing the relative expansion of core and cladding a 3-dB transmission bandwidth of 85nm was obtained, with significant potential for further optimization.

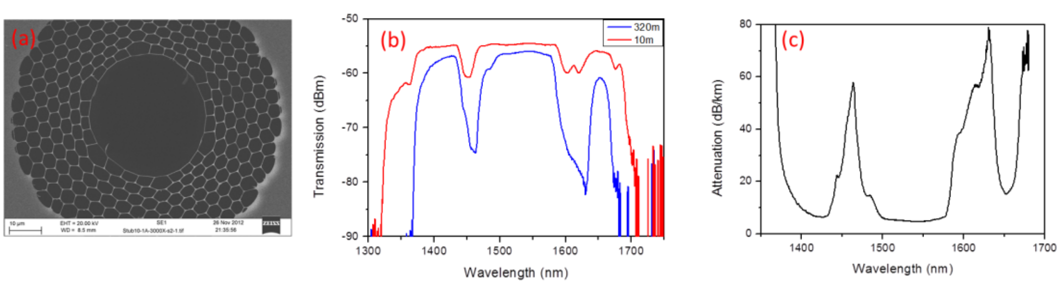

Fig. 1. (a) Scanning electron micrograph of the 37 cell HC-PBGF, (b) White light transmission through 320m (blue) and 10m (red) of 37 cell HC-PBGF and (c) Spectral attenuation measured by cutback (320m to 10m) using white light source

Theoretical models indicate a sharp increase in the number of core modes as the core diameter is enlarged. An ideal 37c HC-PBGF structure is predicted to support as many as 80 modes, including degeneracies. To gain insight into the modal behavior of these novel fibers, we have mapped the modal content via an S^2 measurement and observed propagation using a Time-of-Flight (ToF) technique. The results of the S^2 measurement (10m fiber length) are shown in Fig 2(a). The differential group delay (DGD) of the LP_{11}, LP_{12}, LP_{21} and LP_{02} modes was found to be ~4-6, 7-8, 9-11 and 12-14 ps/m, respectively, roughly 50% lower than in a 19c- HC-PBGF, resulting from the larger core and as expected from simulations [6]. Interestingly however, fewer modes are observed than expected in an ideal structure, with an apparent cut-off after the LP_{02} mode that requires further investigation. The ToF measurement was carried out by using sub-ps pulses from a mode-locked laser and a 10 GHz bandwidth sampling oscilloscope. The results for a 310 m length of fiber under LP_{01}-optimised launch conditions are shown in Fig.2(b). The large extinction ratio of ~23 dB with which all high order modes can be suppressed and the low level of distributed cross talk observed in our measurements, indicate the potential of using this fiber for data transmission in an effectively single mode regime.

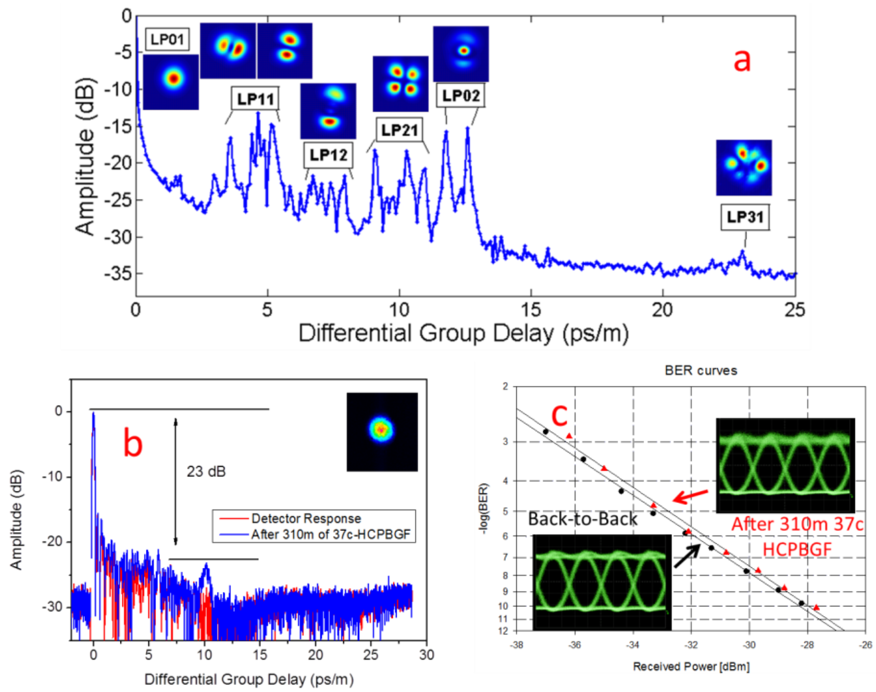

Fig 2 (a) S^2 Modal characterization, (b) ToF measurements showing selective mode excitation, (c) 40 Gbit/s single mode OOK data transmission.

To confirm this, we have transmitted on-off keying modulated 40 Gbit/s data streams through 310 m of this 37c HC-PBGF. Error-free transmission with sub-dB penalty as compared to back-to-back measurements, using a pre-amplified optical receiver and very clean and open eye diagrams were observed (Fig. 2 (c)). It seems realistic that with a suitable mode multiplexing scheme this fiber could be exploited for mode group division multiplexing to achieve high capacity data transmission. We also believe that by further structural and process optimisation there is a realistic prospect of further reducing losses and widening the bandwidth of this fiber type.

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3. References

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