Ultra-Low Loss All-Solid Photonic Bandgap Fibre

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Abstract: *We fabricate and characterize an all-solid photonic bandgap fibre with ultra-low transmission loss of 0.65dB/km within the firs-order bandgap band of 1500~1600nm. The bending characteristic of the fibre is also described.*

Introduction

The all-solid photonic bandgap fibre (PBGF) is an specialty optical fibre whose cladding consists of an array of isolated high index rods or rings in a low index background material, and whose core is generally a low index area formed by omitting one or several units[1-3]. So far, several designs of all-solid PBGFs have been reported. However they all exhibit relatively high transmission loss and the light guidance is realized in the higher-order bandgaps[1-4]. G. Bouwmans *et al*[5] has demonstrated an improved all-solid PBGF with a low-loss transmission region (<20dB/km) around 1550nm in its third-order bandgap. Although high-order bandgap can provide lower confinement loss, the PBGF is more sensitive to fibre deformation, resulting in a narrow transmission bands. Compared with the existing all-solid PBGFs whose claddings consist of simple high-index rods or rings, we have proposed and demonstrated an all-solid PBG fibre with low transmission loss (2dB/km) in its first-order bandgap[6, 7]. It has been shown that, by introducing an index-depressed layer around the high-index rods in the periodic cladding, the confinement and bending losses of the all-solid PBGF can be significantly reduced. In this paper, we would like to report our latest result of the realization of an ultra-low loss all-solid PBGF using optimized design and fabrication process.

Fibre Fabrication

To fabricate an all solid PBGF with lower transmission loss, the improved GeO_2-F doped preforms were fabricated by Plasma Chemical Vapor Deposition (PCVD) process based on the refractive index profile design similar to that in the reference[6]. The refractive index profile here was greatly optimized characteristic of fluorine doped area being increased with expectation to reduce confinement loss and bend loss. The preform was composed of a central high-index part (germanium doped) with a quasi-parabola index profile surrounded by an index depressed layer (fluorine doped), while the doped part was overcladded with a pure silica layer. Compared with the pure silica background as showed in Fig.1 (a), the maximum refractive index differences of the germanium-doped and fluorine-doped area were approximately 3.45×10^{-2} and -7.23×10^{-3}, respectively. The outer diameter of the preform was etched to 16.8mm. Then the preforms were cleaned and dried strictly, and drawn to canes for staking and drawing technique. The final preform cladding was made of five rings of canes around a pure silica rod made by PCVD process centered in perform cross section as the fiber core. Finally, the preform was drawn to a PBGF shown in Fig.1(c). The Fig.1 (b) shows the refractive index profile of the fiber used in numerical simulation with three key parameters labeled. The silica cladding diameter of the fibre is 123μm, while the lattice spacing is about 8.6μm. The relative diameters of the high- and low-index layer in the unit cell of the cladding are $d_G/\Lambda=0.39$ and $d_F/\Lambda=0.79$, respectively.

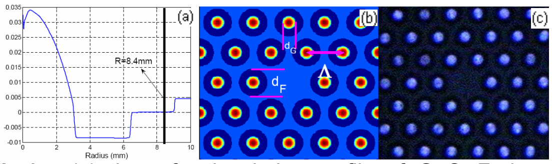

Fig.1: (a) the refractive index profile of GeO_2-F doped preform, (b) the fibre index profile used in numerical simulation, (c) part of an optical photo of the fabricated all-solid PBGF

Fibre Characterization

The spectral transmission through the all solid PBGF is measured by using a photonic-crystal-fiber based supercontinuum (SC) source. The SC source was coupled into a G652.D single mode fibre (SMF) and another end of the SMF is butted against one end of 20m long all solid PBGF under test. The output end of PBGF was also coupled to a G652.D SMF with a purpose of reducing possible cladding mode transmitting through high index rods, then connected to an optical spectrum analyzer (OSA).

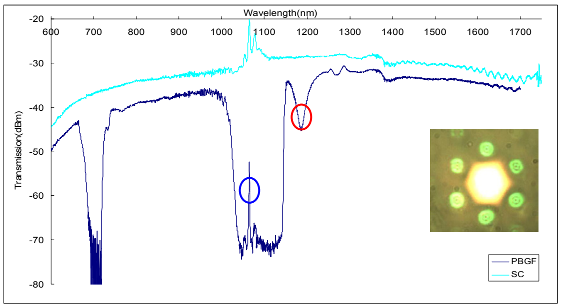

Fig.2: Spectral transmission of the 20m long PBGF, SC spectrum used in measurement is also attached. The inset is the modal profile from the end of 2m PBGF. Peak at 1064nm marked with blue circle indicates the residual pump signal power. The depressed region around 1188 nm marked with red circles is probably induced by higher mode transmission in high index rods in fibre cladding.

The typical transmission spectrum of the fabricated fibre was plotted in Fig.2. Meanwhile a typical spectrum of the used SC source was also attached for the ease of comparison. The inset of Fig.2 is a modal profile at the output end of 2-meter long PBGF.

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This modal profile was sampled by a CCD with dynamic range below 1100nm, after output light from the PBGF was focused by a 40× microscope object lens. The wavelength span is from 600 to 1750 nm, which is limited by the detection bandwidth of the OSA. Based on numerical simulation, it can be seen from Fig.2 that the first three orders of bandgaps of the PBGF are located at 1150nm and above, 730-1010nm and lower than 670 nm, respectively. Though the ranges of the first and third bandgaps overstep the detection range of the OSA, we can see clearly the typical signature of light guidance by a PBG effect. It is noted that there appears loss peak located at 1188nm in the spectral transmission (marked with red circle in Fig.2). The phenomenon is believed to be induced by higher-order mode transmission in high index rods in cladding.

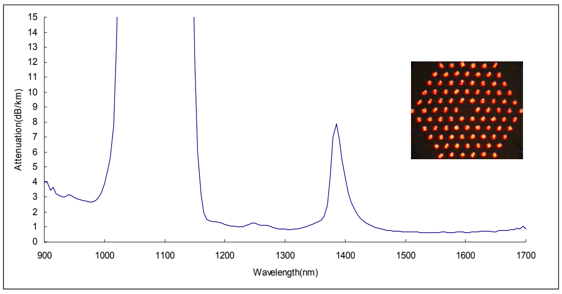

Fig.3: Attenuation spectrum of the PBGF measured with length of 1 km by cut-back technique. The minimal loss (0.63 dB/km) occurs at 1600nm. The inset is a cross section photo of the PBGF when directly illuminated by red light pen.

The attenuation spectrum of 1 km long PBGF has been measured by the cut-back technique and plotted in Fig.3. Broadband transmission with ultra-low transmission loss has been observed from 1150 nm to more than 1700 nm, which is only constrained by the detection bandwidth of the measurement equipment. The typical loss from 1500 nm to 1600 nm is around 0.65dB/km with a minimal loss of 0.63dB/km at 1600 nm. To the best of our knowledge, it is the lowest transmission loss ever reported for all solid PBGFs. It is worth noting that the transmission loss at the first bandgap is greatly decreased, compared to our early reported result[7]. Furthermore, the minimal loss region has been successfully shifted to around 1550 nm by optimizing perform design. The peaks of transmission loss at 1383 nm, 945 nm and 1245 nm are due to the OH^- absorption. It is believed that the transmission loss can probably be further reduced by improving our fabrication techniques.

The effect of bending on the bandgap of PBGF was also investigated by measuring the transmission spectrum of 20 m PBGF with different bend radii but with the same ten turns. The transmission spectra of PBG fibre under different the bending radii was plotted in Fig. 4. It can be seen that the first bandgap of the fabricated PBGF was very wide and less insensitive to the bending effect, even the bending radii was decreased to 5mm. However, we find that, the second and third bandgaps of the PBGF were more susceptible to the bending induced by deformation. Nevertheless, the bending characteristic of our fabricated PBGF is adequately excellent for its nearly invisible variation when bending the fibre to 30mm radii. It must be pointed out that the serial values in the frame at top right of Fig.4 are bending diameter.

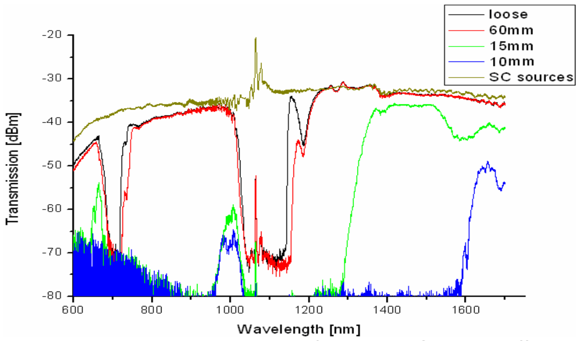

Fig.4: Transmission spectrum of 20 m PBGF with different bend radii (R=30, 7.5, and 5mm) for the ten turns. The spectrum transmission of the PBGF in loose state is also shown.

Conclusions

An all-solid PBGF with ultra-low transmission loss within the first bandgap has been realized based on an improved design and fabrication process. It is worth noting that typical transmission loss of the fibre is as low as 0.65dB/km within the first bandgap of 1500-1600nm. Moreover, we find that the first-order bandgap of the fabricated PBGF is less insensitive to the bending effect.

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