TOWARDS PRACTICAL HOLEY FIBRE TECHNOLOGY: FABRICATION, SPLICING AND CHARACTERIZATION

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Abstract: We report the fabrication of long lengths of mechanically-robust holey fibre and the first demonstration of their splicing. These practical advances have permitted the first detailed characterization of a holey fibre around 1.5µm.

Introduction

A holey fibre (HF) is an optical fibre whose optical confinement mechanism and properties are defined by an array of air holes that run down the entire fibre length. Light can be guided within such fibres by either of two distinct mechanisms. In the limit of periodic arrangements of large air holes, guidance can be obtained through photonic band-gap effects /1/. For this reason HFs are commonly referred to as 'photonic crystal fibres' (PCF) /2/. The second form of guidance results from average index effects, and does not rely on any periodicity of the air holes. Both forms of guidance can give rise to interesting characteristics, such as unique dispersion properties /3/, as well as single mode operation over an extended range of operating wavelengths /2/. However, to date, despite considerable interest, few experimental measurements have been made of even the most basic fibre properties e.g. loss or dispersion. This is due largely to difficulties in fabricating and handling sufficiently long lengths of HF to make reliable and meaningful measurements.

In this paper we describe our recent advances in the development of HF technology, including the fabrication of long lengths (>50m) of mechanically robust HF and the splicing of HF to conventional fibre types. These important practical developments permit the use of reliable and established fibre measurement techniques to characterize the basic properties of HF. We report what we believe to be the first loss and dispersion measurements made on an HF in the 1550nm telecommunications window. The dispersion measurements are shown to be in excellent agreement with predictions from our numerical model /4/. We believe the work presented herein to represent a significant step towards the development of truly practical HF technology.

Fabrication

The fabrication process for the HF was a modification of the process used to produce the first PCFs /2/. Pure silica capillaries were stacked in a hexagonal pattern with a solid silica rod as the core. This stack was drawn in a two stage process. A borosilicate glass outer cladding was added after the first draw. The resulting composite structure was then pulled to a glass-clad HF of ~250µm outer diameter, and coated with conventional polymer coating. The additional strength provided by the two coatings allowed long lengths of fibre to be produced, and ensured that the fibre was easy to handle and work with. To date >50m lengths have been produced, but kilometre lengths could be produced without modifying the procedure. An SEM of the

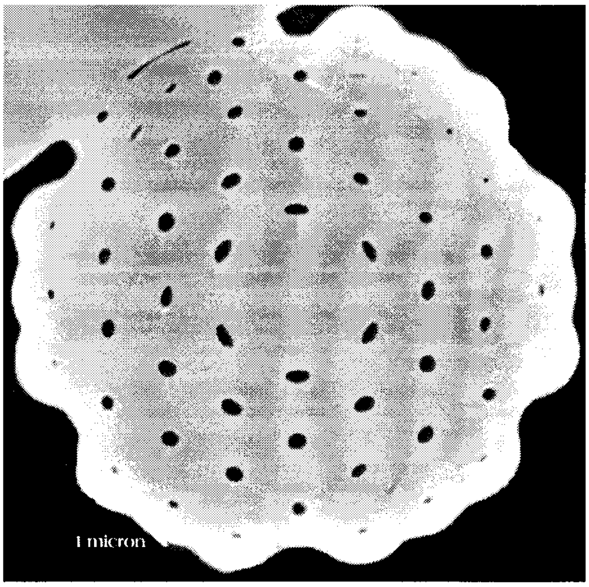

Figure 1: A scanning electron micrograph (SEM) of the fibre tested. The ~20µm HF is attached to the inner wall of the protective glass jacket (outer diameter 250µm). The absence of a hole in the centre forms the core.

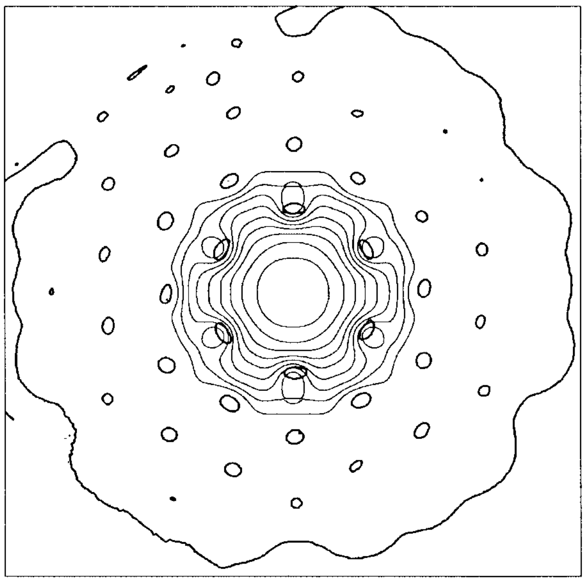

Figure 2: Reconstructed index profile /4/ used within our model as derived from the SEM above. The predicted mode at 1.55µm is superimposed (contours are spaced by 1dB).

particular HF characterised in this work is shown in figure 1. Note that the initial periodic structure becomes slightly deformed during the pulling process, which is particularly significant for the innermost ring of holes. The spacing of the holes is ~2μm, with a hole size of ~0.3μm. The air filling fraction is ~20%.

Characterization

From observations of the near field image the fibre appears to be single mode from at least 532-1550nm. The loss of the fibre was measured to be $0.24dBm^{-1}$ at 1550nm using the cutback method. This is not an unreasonable value at an early stage of a fibre's development, and it is believed that significantly lower losses should be obtainable with improved cleanliness and fibre design. Indeed, the recent report of losses of $0.05dBm^{-1}$ at 1300nm in another HF confirms this /5/. In any event, the current losses are still acceptable for many device applications, and has allowed measurements of the dispersion of the fibre reported here.

The HF was spliced to conventional dispersion shifted fibre (DSF), using a modified routine on a commercial splicer. To our knowledge, this is the first report of splicing of a HF. The loss across the splice was ~1dB at 1.55μm, this was less than the loss observed when butt-coupling the two fibres. This indicates that the loss is mainly due to the mode-mismatch between the DSF and the HF. Whilst the mode in the HF studied is reasonably circular at 1.55μm (see figure 2), the mode areas are significantly different (HF~$30\mu m^2$, DSF~$50\mu m^2$) and therefore a splice loss of 1dB is not unreasonable. Although such splice losses are not prohibitive, it should be possible to reduce them using a buffer fibre of intermediate spot size. Splicing of HF is an important development since it allows them to be easily incorporated into conventional fibre systems.

We measured the group velocity dispersion (GVD) of a 6.5m HF over the wavelength range 1480-1590nm using a conventional electronic phase-measurement technique which employs a tunable, narrow-linewidth laser and network analyser /6/. A previous spot measurement of the GVD of an HF at 813nm was presented in /7/. However this measurement was made on a short length of HF (26mm) in which it would be difficult to eliminate the influence of cladding modes. Our dispersion results are shown in figure 3. The GVD is ~50 ps nm^{-1} km^{-1} and the GVD slope is 0.09 ps nm^{-2} km^{-1} at 1.55μm.

The profile obtained from the SEM was used in our numerical model to calculate the fibre properties (see figure 2). We found that it was necessary to use the exact refractive index profile since the deformation of the first ring of holes has a significant effect on the predictions. Excellent agreement with experiment was obtained in this way (shown in figure 3). Other fibre structures modelled using the same technique have been predicted to show interesting dispersion characteristics including anomalous dispersion below 1.3μm and flattened dispersion around 1.5μm /3/.

Conclusion

We report progress towards practical HF technology. The fabrication of long lengths of mechanically-robust holey fibre has allowed the first reported measurements of dispersion and loss of an HF in the third telecommunication window. By modelling the exact structure the predicted GVD was found to be in excellent agreement with measurement. This provides a convincing validation of our numerical model which can now be used with confidence to predict fibre properties prior to fabrication. Finally, we have shown that holey fibres can be spliced directly to conventional fibre types, demonstrating that holey fibres can be integrated with established fibre technology.

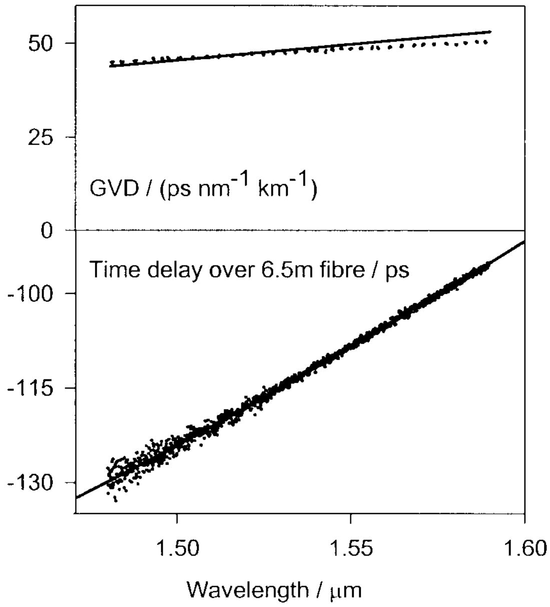

Figure 3: The group velocity dispersion (GVD) and time delay observed for pulses propagating through 6.5m of holey fibre. The solid line in the top graph is the GVD calculated from a quadratic fit to the time delay. This fit is the solid line in the lower graph and the dotted line in the upper graph is the GVD calculated from our numerical model.

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