Single-polarisation mode in air-core holey fibre

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Abstract

An air-core holey fibre design that supports a single-polarisation circularly symmetric mode is presented. The mechanism that isolates the single polarisation, the advantages of the design and fabrication efforts to date will be discussed.

Introduction

In standard single-mode optical fibres the light is guided in the HE_{11} mode [1], which is made up of two degenerate orthogonally polarised modes. Random imperfections in the fibre structure as well as external forces on the fibres can break this polarisation degeneracy, giving rise to phenomena such as polarisation mode dispersion and polarisation fading in interferometers. Polarisation degenerate modes are also supported by the common triangular lattice microstructured optical fibres (MOFs) [2] and photonic band gap fibres (PBG fibres) [3,4], irrespective of the different guiding mechanisms. Polarisation related problems can be avoided through the use of polarising fibres, which abolish one of the polarisations [5,6]. The mode isolated in such cases is always linearly polarised, making the fibre essentially asymmetric, which gives rise to alignment problems when coupling, splicing and some sensing applications are considered.

Recently, an air-core PBG fibre design was shown to support a single-polarisation mode [7]. The design was a Bragg fibre and supported a single TE-polarised mode (a TE-Bragg fibre). The isolated polarisation was not a linear one, allowing the design to remain circularly symmetric, potentially solving both the polarisation and alignment problems. The TE mode was isolated by forcing the condition for Bragg reflection to coincide with the Brewster angle condition, at which TM-polarised light is not reflected. This resulted in a TE band gap but no TM band gap. Hence the TM and hybrid polarised modes (such as the HE_{11}) suffer much higher confinement losses, whilst the confinement loss of the TE polarisation is lower, and can be decreased by adding more layers to the Bragg fibre [8]. The number of guided TE modes can be controlled through the size of the air core [8].

The TE-Bragg fibre design consisted of refractive indices that do not allow it to be fabricated by existing techniques (such as MCVD or recent developments in Bragg fibre fabrication [9]). Here we show that a holey fibre can be designed with the same modal properties, where rings of holes replace the low index layers of the TE-Bragg fibre. Index-guiding fibres where this occurs have been reported [10].

Design

The design is a ring-structured fibre, consisting of a hollow core surrounded by rings of holes. A photograph of a polymer preform for such a fibre is shown in Fig. 1. Unlike the triangular lattice MOF/PBG fibres, two hole spacing or pitch parameters must be specified, Λ_i for the intra-ring spacing and Λ_e for the inter-ring spacing (Fig. 1). The design has a core radius r_{co} of 2.89 μm, followed by rings of holes with $\Lambda_i = 0.403$ μm, $\Lambda_e = 0.578$

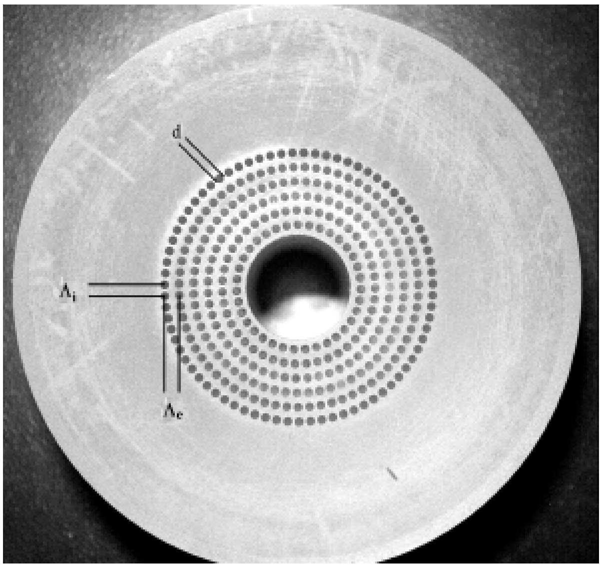

Fig. 1. A photograph of a polymer preform of the fibre design discussed with six rings of holes.

μm, and hole diameter *d* = 0.335 μm. These parameters were chosen so that the azimuthal arithmetic mean of the refractive index closely matches that of the TE-Bragg fibre (such an approach was shown to be valid in index guiding fibres [10]).

Modelling

The fibre design given above was modelled using the adjustable boundary condition method [11] with a finite difference discretisation along the radial direction and a Fourier decomposition in the azimuthal direction. The fibre was modelled with one, two, three and six rings of holes and the confinement loss as a function of wavelength is shown in Fig. 2 for the TE_{01}, TM_{01} and HE_{11} modes. Increasing the number of rings results in the confinement loss of the TM_{01} and HE_{11} modes remaining largely unchanged, whilst the confinement loss of the TE_{01} mode reduces significantly (note the different scales on the vertical axes in the two graphs of Fig 2). The confinement loss of the TE_{01} mode as a function of the number of rings is shown in Fig. 3. The loss decreases exponentially with the number of rings, consistent with the formation of a TE polarisation band gap. This is not observed for the TM and HE modes.

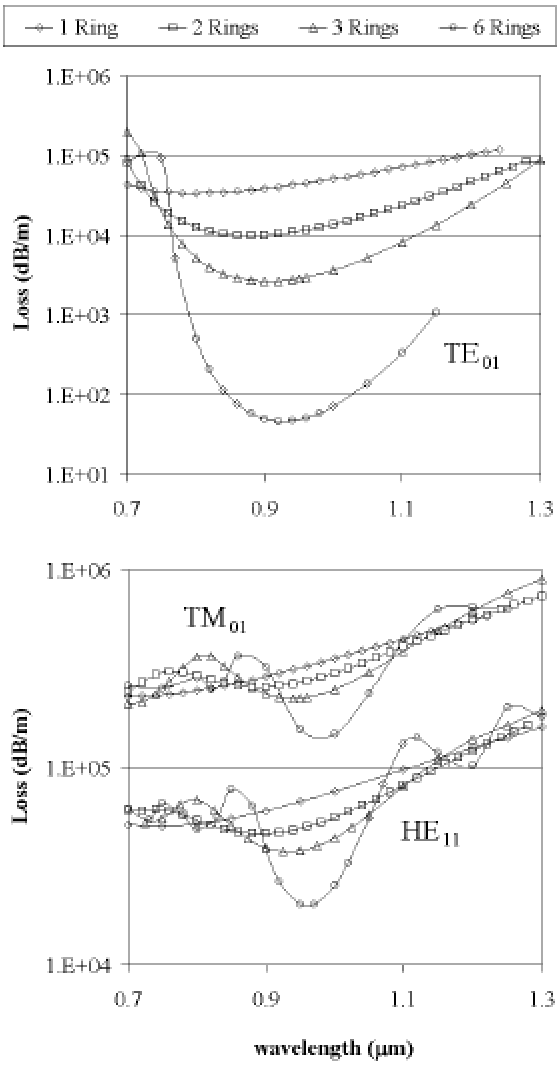

Fig. 2. The confinement loss as a function of wavelength and the number of rings for the TE_{01}, TM_{01} and HE_{11} modes for the ring-structured Bragg fibre discussed in the text. The formation of a TE band gap centred on $\lambda \approx 920$ nm is observed.

The lowest loss wavelength for the TE_{01} mode for six rings of holes is around 920 nm and the loss is 46 dB/m. The graph in Fig. 3 is extrapolated to show that nine rings are required to reduce the loss to 1 dB/m. These values for the loss and number of rings are similar to those obtained for triangular lattice band gap fibres with similar d/Λ values [4]. The isolation of the TE polarisation can be highlighted by comparing the losses of the modes: with one ring the TE_{01} mode has a 1.5 times lower loss than the HE_{11} mode (at the lowest loss point of the TE_{01} mode with loss measured in dB/m), whilst with six rings it is 560 times less lossy, the difference increasing as more rings are added.

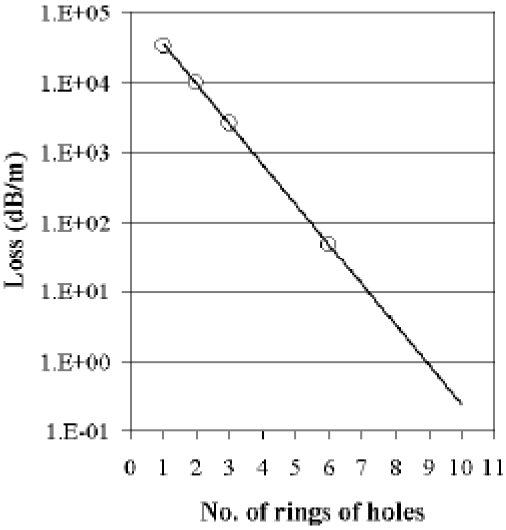

Fig. 3. The confinement loss of the TE_{01} mode as a function of the number of rings shows an exponential dependence. The graph is extrapolated to show that nine rings are required for a 1 dB/m confinement loss.

An apparent challenge to the single-mode nature of this design is the possibility of higher order TE modes, which will be guided in the same band gap as the TE_{01} mode. The confinement loss of these modes responds to changes in the number of rings in the same way as the TE_{01} mode, hence it may appear that an increasing difference in loss cannot be used to eliminate these modes. However, as in the TE-Bragg fibre, the core size can be adjusted to solve this problem [8]. Changes in the core size shift the low loss wavelengths of the different modes, so that higher order modes can be moved away from the TE_{01} mode. Choosing the appropriate size of the core will ensure that a single TE mode is guided at the required wavelength.

Fabrication Efforts

A ring-structured Bragg fibre was fabricated using poly methylmethacrylate (PMMA) from a preform similar to that in Fig.1 but with only five rings of holes. The preform was prepared and drawn to fibre as described in [12], however the final dimensions were larger than the fibre modelled here.

When white light was launched into the fibre strong colouration was observed in the cladding, the colour changing with the incidence angle of the light. This indicates that coherent reflection was taking place but a guided mode was not observed. It can be seen from Fig. 3 that five rings of holes are insufficient to support a low loss mode. Defects in the fibre structure would have contributed to increasing the confinement loss further. We are in the process of fabricating a fibre with a larger number of rings, in which low loss band gap guidance may be observed.

Conclusion

A holey fibre design supporting a single-polarisation mode has been presented. Numerical modelling of the design shows the formation of a TE polarisation band gap in the absence of a TM polarisation band gap, this being the mechanism through which single-polarisation guidance is achieved.

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References

[1] A. Snyder and J. Love, *Optical Waveguide Theory*, Chapman and Hall, 1983, London.

[2] J.C. Knight, T.A. Birks, P. St. Russell and D.M. Atkin, Opt. Lett. **21**, 1547 (1996).

[3] R.F. Cregan *et al*, Science **285**, 1537 (1999).

[4] K. Saitoh and M. Koshiba, IEEE Photon. Technol. Lett. **15**, 236 (2003).

[5] J. Noda, K. Okamoto and Y. Sasaki, J. Lightwave Tech. **4**, 1071 (1986).

[6] A. Ferrando and J.J. Miret, Applied Phys. Lett. **78**, 3184 (2001)

[7] I. Bassett and A. Argyros, Opt. Express. **10**, 1342 (2002).

[8] A. Argyros, Opt. Express. **10**, 1411 (2002).

[9] B. Temelkuran *et al*, Nature **420**, 650 (2002).

[10] A. Argyros *et al*, Opt. Express **9**, 813 (2001).

[11] N.A. Issa and L. Poladian, J. Lightwave Tech. In press (April 2003).

[12] M.A. van Eijkelenborg *et al*, Opt. Express. **9**, 319 (2001).