Air-core photonic band-gap fibres without polarisation degeneracy

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Abstract: **An air-core holey fibre design that supports a single, circularly symmetric, polarisation non-degenerate mode is presented. The mechanism through which polarisation non-degeneracy is achieved, the consequent advantages, applications and fabrication methods will be discussed.**

The majority of single-mode optical fibres available have the property that the mode they support is polarisation degenerate, i.e. the mode is in fact two orthogonally polarised modes. This, when combined with unavoidable birefringence caused by perturbations along a fibre, can give rise to problems such as polarisation mode dispersion and polarisation fading in interferometers. These can be avoided through the use of polarising fibres, which support only one linear polarisation, but these fibres inherently lack circular symmetry and alignment issues arise when coupling or sensing applications are considered.

Recently, an air-core band-gap fibre design was reported which supports a single polarisation non-degenerate mode, whilst retaining circular symmetry. The design was a Bragg fibre that supported a single TE-polarised mode (a TE-Bragg fibre) [1]. In TE-Bragg fibres, the condition for Bragg reflection is forced to coincide with the Brewster angle condition (TM polarised light is not reflected at the Brewster angle), resulting in TM and hybrid polarisation modes suffering very high confinement losses, whilst TE modes can be supported with orders of magnitude lower confinement loss. The superposition of the Bragg and Brewster angle conditions serves to close the TM band gap, leaving the TE band gap virtually unaffected. Furthermore, the number of TE modes supported can be reduced to one by appropriately adjusting the core size [2]. Such a fibre has the advantages of air-guidance and singlemodedness, whilst potentially eliminating both polarisation and alignment problems and is, to the authors' knowledge, the only design with all these properties. It would essentially allow for light to be treated as a scalar quantity. The design in [1], however, cannot be fabricated using existing techniques, as conditions on the refractive indices in the fibre [1] are not satisfied by any materials currently used in optical fibres (for an example of Bragg fibre fabrication see [3]).

One approach to fabricating TE-Bragg fibres is to use a holey fibre design in which the average refractive index approximates the index profile of the TE-Bragg fibre [4]. The fibre would be a ring-structured fibre consisting of a hollow core (to eliminate index guiding) surrounded by rings of holes to mark the low-index layers of the TE-Bragg fibre. Index guiding analogues of such fibres have already been fabricated using polymers [4].

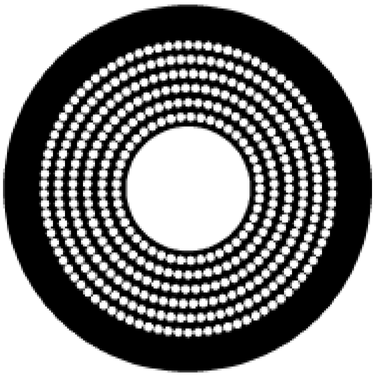

FIG. 1: Refractive index profile of a ring-structured TE-Bragg fibre, consisting of rings of holes (white) in a host material (black). The values used were n = 1.49 for the host material, $\Lambda_i = 0.403\ \mu m$, $\Lambda_e = 0.578\ \mu m$, hole diameter $d = 0.335\ \mu m$ and core radius $r_{co} = 2.89\ \mu m$.

The ring-structured analogue of the TE-Bragg fibre is shown in Fig. 1, the design being chosen so that the azimuthal arithmetic mean of the refractive index closely resembles the index profile of the TE-Bragg fibre. This approach was shown to be valid in the past for index guiding fibres [4]. Unlike conventional triangular lattice band gap fibres (e.g. [5]), two hole spacing parameters must be specified in this case: Λ_i is the intra-ring hole spacing and Λ_e the inter-ring

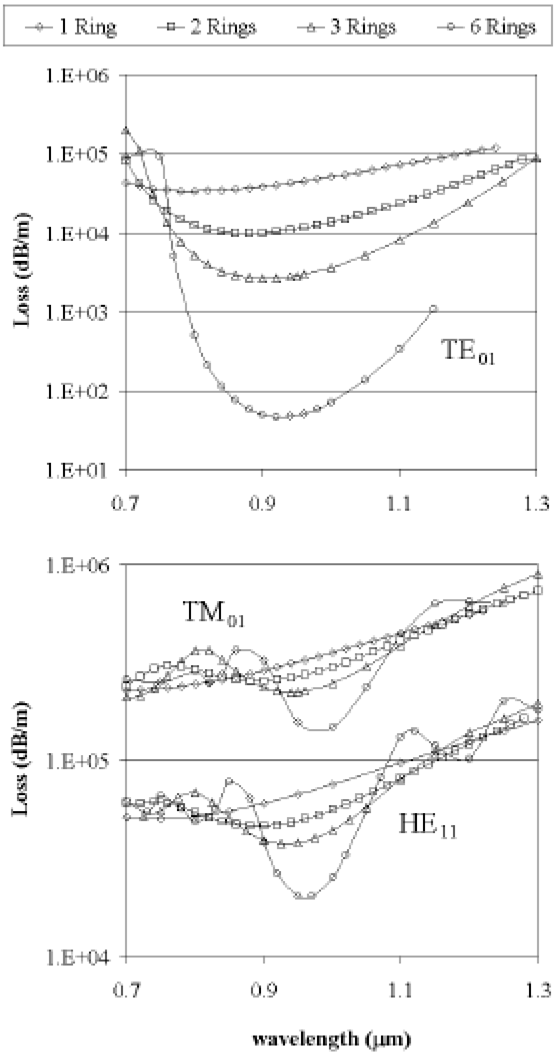

FIG. 2: The confinement loss of the TE_{01}, HE_{11} and TM_{01} for the ring-structured TE-Bragg fibre in Fig. 1 as a function of wavelength and the number of rings. In the numerical modelling the host material was assumed to be infinite. It is clear that there is only a TE band-gap forming, centred on $\lambda \approx 920$ µm.

hole spacing; intuitively $\Lambda_i/\Lambda_e < 1$ is required for the rings to be well defined. This fibre design was numerically modelled using the adjustable boundary condition method [6] with finite difference discretisation in the radial direction and a Fourier decomposition in the azimuthal direction.

The confinement loss of the various modes was examined as a function of the wavelength and the number of rings for the structure in Fig. 1, the results appear in Fig. 2. It was observed that the loss of the hybrid and TM-polarised modes did not change significantly when the number of layers in the fibre was increased, in contrast to the TE modes, where the loss dropped by several orders of magnitude over a particular wavelength range, where a TE band-gap forms (note the different vertical scales for the graphs in Fig. 2). With 1 ring of holes the HE_{11} mode has a 1.5 times higher confinement loss when compared to the TE_{01} mode (at the lowest loss wavelength of the $TE_{01,}$ with loss measured in dB/m). The ratio increases with the number of rings and the value with 6 rings is 560.

Although the losses given in Fig. 2 may seem high, they are similar to those of conventional triangular lattice band-gap fibres with a similar number of rings of holes and d/Λ values [7]. The confinement losses can be decreased through the addition of rings of holes, the confinement loss decreasing exponentially with the number of rings as expected for a band gap fibre. In the current design the lowest loss for 6 rings of holes is around 46 dB/m and 9 rings of holes would be required to reduce the loss to 1 dB/m.

Fabrication of these fibres has been initiated, and colouration has been observed in the cladding of fibres with five rings of holes. This indicates that wavelength selective Bragg reflection is taking place. We are currently in the process of fabricating such a fibre with six rings of holes, which may exhibit a low enough loss for band-gap guidance to be observed.

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