Modelling and applications of Photonic Bandgap Fibres

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Photonic crystal fibres (PCFs)[1] are one of the most exciting developments in the field of photonics that has emerged in recent years. Not only have they already led to cheap all-fibre high brightness white light sources[2] and have sparked a renaissance in the field of nonlinear optics but they also have the potential to dramatically change the next generation of telecommunication systems. PCFs can be split into two categories, the first have a solid core and guide light by modified total internal reflection, while the second photonic bandgap fibres (PBF) guide light by photonic bandgap effects and typically have a low index core compared to the cladding. Also of interest are "arrow" fibres which have a solid core and guide light due to the arrangement of high index defects in the cladding. In this paper we will be concentrating on designing and manipulating the properties of PBFs

In a PBF there are several main sources of loss, the principle ones being confinement loss, scattering loss and coupling to surface modes with the dominant cause of loss in most fibres being the later. Hence it is important to properly understand the interactions between the fundamental mode and the surface modes in order to reduce or eliminate this loss. Fig. 1a shows an idealized representation of a PBF which we use to model these fibres using a full vector finite element program typical results of which are shown in Fig. 1b which shows the effective index of the various modes of the fibre. Using this idealized model we have looked at how making slight changes to the core shape can dramatically modify the properties of the surface modes. Firstly we have shown that introducing asymmetries into the core shape breaks the degenerancies between the x and y polarized modes. This allows us to design fibres[3] where coupling to surface modes happens preferentially for one mode rather than the other. Thus PBFs can have extremely large polarization dependant loss and birefringence – essential for making single polarization devices.

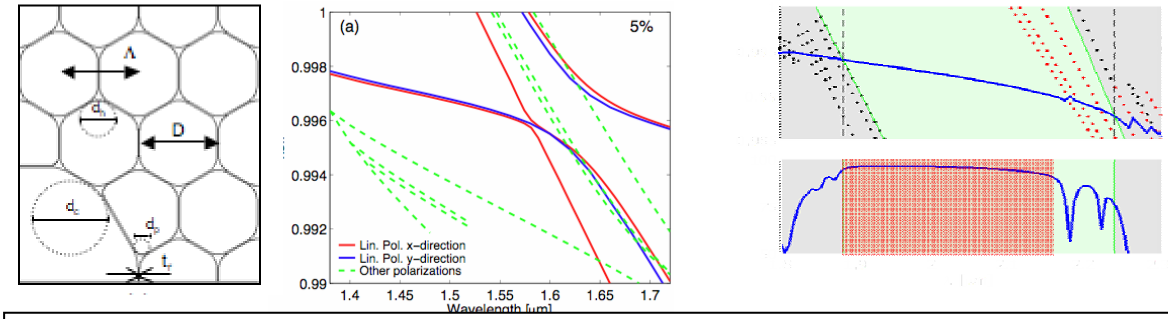

Fig. 1: (a) schematic showing idealised core. (b) Dispersion diagram for a typical PBF with core modes represented by solid lines and surface modes as dotted lines. (c) improved design showing no surface modes across the main bandgap.

A natural extension to the idea of changing the core shape is to look at altering the size of the core and we have done this in a recent paper[4]. In this work we concentrated on designing fibres that were free of surface modes and thus had extremely large useable bandwidths (nearly the entire bandgap in Fig.1c). These wide bandwidth fibres occur when the silica ring around the core is thin compared to the struts supporting the core and thus there is not enough silica to "support" a surface mode localized in the ring. We have found that this regime extends to fibres with different shaped cores and furthermore although these fibres do not have the lowest possible loss they should still be quite low loss over the entire useable bandwidth. We have recently designed and fabricated such a fibre with a passband centred near 2 microns and have shown it to be free from surface modes.

In conclusion we have extensively studied the interactions between the core modes and surface modes in low index PBFs. This work allows us to control many of the properties of the guided modes in the fibres, from the loss and dispersion to the birefringence. Based on these designs we have fabricated new PBFs and found that they perform as expected.

References

[1] P. St. J. Russell, "Photonic crystal fibers," Science **299**, 358 (2003).

[2] J.M. Dudley "Supercontinuum generation in photonic crystal fibre" Rev. Mod. Phys. **78** 1135 (2006)

[3] F. Poletti, *et al*. Opt. Exp. **13**, 9115 (2005).

[4] R. Amezcua-Correa *et al*, Opt. Exp. **14**, 7974 (2006).