Microstructured POF and Applications

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Abstract

Since mPOF were developed in 2001[van Eijkelenborg 2001] there has been considerable interest in identifying the applications for which they have a competitive advantage over other technologies. Some of the features that have been explored in this context are the ability to tailor the refractive index profile by changing the hole structure [van Eijkelenborg 2004]; the ability to make highly birefringent [Issa 2004] or high numerical aperture fibre [Issa 2004], and most recently to guide light in low index material through photonic bandgap guidance [Argyros 2005]. In this paper we explore how these applications have been developed, specifically to include fibres for high bandwidth, interconnect applications, and transmission within the absorption region of the polymer, as well as sensing. We report the first use of a bandgap fibre for liquid core guidance, and its use in detecting optical activity in a solution.

Transmission

Most mPOF activity to date has focussed on short distance, high bandwidth applications, which probably represent the main future applications for POF in general. In previous studies [Barton 2003, van Eijkelenborg 2004], fibre loss restricted the measurement of bandwidth to relatively short distances. The measured bandwidth was 4 GHz over 9 meters, corresponding to 2.4 Gbits/s over 100 m [assuming strong mode coupling]. The fibre used in that test suffered from substantial mode-mixing due to scattering. Such mode mixing can both increase the loss [by coupling to leaky modes] and improve the bandwidth. Thus, it was not clear that a fibre with reduced scattering would have a similar bandwidth performance. A more recently produced fibre is shown in Figure 1, and had a loss of approximately 0.5 dB/m at 650 nm, compared to 0.87 dB/m for the earlier sample. A 25 m sample of newer fibre was tested using the same experimental set up as previously [van Eijkelenborg 2004]. It was found to have a bandwidth of 4.4 GHz, corresponding to 4.4 Gbits/s over 100m again with the assumption of strong mode mixing.

We are currently undertaking extensive theoretical analysis of this fibre, which we hope will yield insight that will allow us to improve this performance even further. We also hope to be able to predict the bandwidth performance at larger core diameters, although making such fibres will require changes to our current fabrication methods.

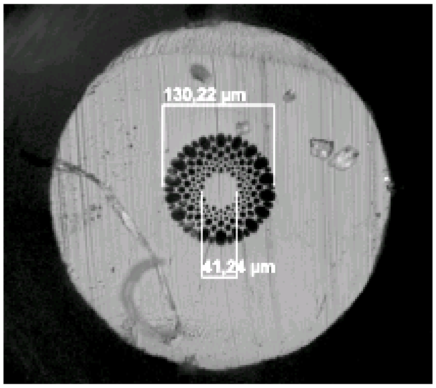

Figure 1: The GImPOF used in the bandwidth experiments.

Another application of interest is that of photonic interconnects, in which the distances involved may be very short, but the requirements on bend loss and fibre radius may be demanding. The large refractive index contrast between core and cladding that is possible in mPOF make this an attractive application, and preliminary results are indeed promising. A 5 hole suspended core fibre was tested by wrapping it several times around a cylinder of defined diameter, and averaging the loss per turn. As shown in Figure 2, this remained well below 0.2 dB/turn, even for bend diameters of 4mm.

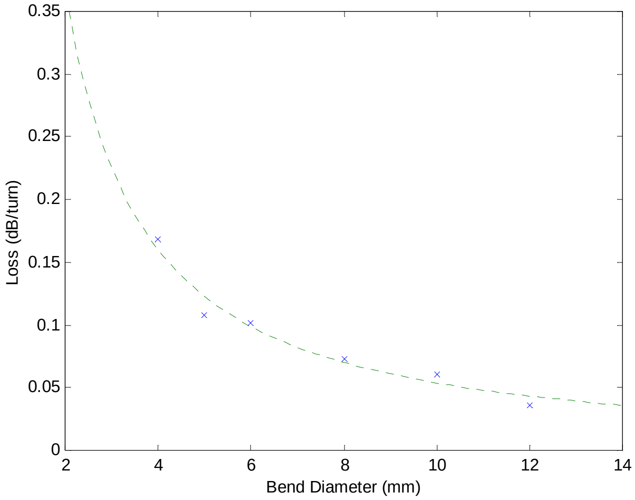

Figure 2: Macro-bend losses for a five hole suspended core mPOF. The fibre diameter was 250 microns, and the core was 80 microns.

Another significant development has been the demonstration of hollow core mPOF [Argyros 2005], which is particularly attractive for transmission applications within the absorption bands of the polymer material.

Sensing

There are a number of reasons why mPOF has attractions for use in sensing. The ease in making single mode POF by this technology is one of these, which enables it to be used in interferometric applications. Gratings, a key technology in sensing, have recently been demonstrated in mPOF, both long period gratings [van Eijkelenborg 2004] and Bragg gratings [Webb 2005]. Both of these preliminary results offer considerable scope for improvement, by making the gratings permanent in the former case, and improving the grating strength, by, for example, doping the core, in the latter case.

These functionalities however, merely replicate those already well established in other technologies. The key advantages of mPOF in this area are related to the use of microstructures. They include:

- being able to introduce fluids such as liquids or gases into the microstructure
- being able to modify the structure to maximize the evanescent field, for example by the use of shielded nano-wires
- being able to chemically functionalise the surfaces of the holes, and ensure a significant interaction with the surface
- allowing the guidance of light in low refractive index material either by effective index guidance or bandgap guidance

These advantages are only just beginning to be explored, with the first sensing mPOF [Jensen 2005], although there has been considerably more work done in similar silica based fibres, including filling the holes of a single mode microstructured fibre with high index fluids to produce photonic crystal guidance [Larsen 2003], and the use of hollow core fibres for gas sensing or low threshold Raman effects [Benabid 2002, 2005, Fini 2004, Ritari 2004].

In our preliminary experiments, we used a hollow core mPOF, and showed that we could obtain guidance in water. A HC mPOF, (core diameter ~60um) was filled with water by applying negative pressure to one end, the filling time being several minutes. The spectrum of this piece of fibre was recorded from 450-1750nm, and discrete transmission bands indicating bandgap guidance, were observed. Several pieces with the same structure but scaled dimensions were tested, and as expected for bandgap guidance, the wavelengths of the transmission peaks shifted accordingly. Transmission in the IR was not observed, due to the high absorption of water in this region. We then used this used fibre to demonstrate sensing of optical activity for the first time.

A saturated aqueous solution of β-cyclodextrin (98%, Sigma) was used to fill the HC mPOF. This molecule is chiral, with specific rotation $[\alpha]=161 \pm 3^{o}$ [Szejtli 1998]. Measurements in the bulk solution indicate that the concentration of this saturated solution was approximately 9.5mM. (~1^{o} polarisation rotation through 6cm solution in beaker). A 21cm piece of fibre was filled with the chiral solution and the polarisation rotation, α, was measured to be 3.5 ± 0.5^{o} at 750nm, or ~0.17^{o}/cm. This wavelength was selected for the polarisation measurements as it falls in a transmission band of the fibre. Bragg guidance in the solution-filled fibre was confirmed by the observation of bandgaps in the spectrum. For comparison, both an air-core and water-filled fibre were tested. No rotation of the polarisation was observed in either case.

While these results are preliminary, we believe they highlight an important new application area for mPOF.

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