

Imaging with microstructured polymer fibre

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Abstract: The imaging capabilities of a multicore microstructured polymer optical fibre with a square array of 112 air holes are demonstrated. Coherent imaging is achieved either by guiding light in polymer cores between air holes, or by guiding light in the air channels themselves. This potentially provides a miniaturised endoscope for medical applications, or a two-dimensional parallel optical data link for high-bandwidth interconnects.

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OCIS codes: (060.0060) Fiber optics and optical communications; (060.2280) Fibre design and fabrication; (060.2430); (160.5470) Polymers; (110.2350) Fiber optics imaging

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1. Introduction

Coherent fibre imaging bundles have been developed as flexible image carriers, which are used for imaging purposes in otherwise inaccessible areas, such as inside jet engines, nuclear reactors and the human body [1,2]. They can be fabricated by bundling individual fibres, by stacking capillaries, rods or fibres to make a preform that is subsequently drawn to fibre, by using complex doping techniques, or by co-extrusion. One of the difficulties encountered with these methods is maintaining the coherency of the fibre bundle and getting full control over the position and size of individual cores (pixels), as well as obtaining a high capturing fraction. In addition, fibre imaging bundles are generally at least a few millimeters in

diameter, which is a limitation for some applications, such as endoscopy of small internal body cavities and/or where tight bending is required (e.g. in the cochlear or arteries).

Another application for fibres with multiple parallel optical channels exists in the context of parallel high-bandwidth links for interconnections such as device-to-device links (video to PC) and within computers (e.g., CPU to memory or CPU to CPU connections). These generally involve short lengths of fibre ribbon with a few tens of channels [3]. However, with increasing demand on transmission speeds and the growing number of channels, two-dimensional formats present distinct advantages (especially with the availability of integrated 2D optical emitter arrays such as VCSEL arrays). This has been demonstrated with a conventional fibre imaging bundle, but there is an associated non-uniformity of the insertion loss as a result of a mismatch between the close-packed hexagonal fibre bundle arrangement and the square symmetry of the elements in the laser/detector array, as well as due to the mismatch between the number of fibre channels and the number of light sources [4].

Microstructured polymer optical fibres (mPOFs) have been developed over the last two years, providing plastic fibres in which light guidance is achieved through the use of microstructure. A range of specific opportunities for applications of mPOFs are being explored [5], including a multicore mPOF for coherent fibre imaging and parallel optical data links as presented here.

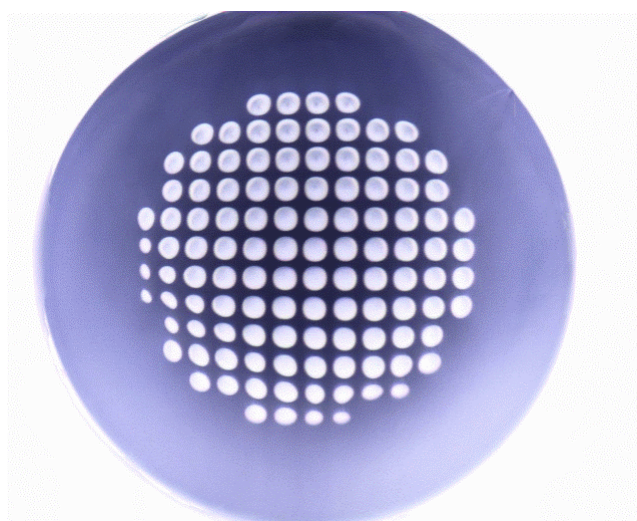


Fig. 1. Microscope image of a multicore 800 µm diameter microstructured polymer optical fibre with a 42 µm hole spacing.

2. Fabrication and fibre structure

The fabrication method that we use to prepare mPOF preforms allows full control over the positioning and sizing of the cores. It involves drilling the hole structure into an annealed PMMA rod of 80 mm diameter using a programmable CNC mill that has been optimised for mPOF preform fabrication [5]. Therefore any pixel arrangement is possible, both in terms of symmetry (hexagonal, rectangular etc.) and in terms of core dimensions (multiple core sizes in one fibre are possible). This makes it straightforward to tailor the fibre to match an array of light emitters or detectors with particular symmetry and dimensions. In addition, the fibre is drawn from a monolithic structured preform (rather than a stacked preform) providing further control and stability and no doping is required to create guiding cores.

A microstructured polymer fibre with an outer diameter of 800 µm was fabricated to demonstrate the imaging capability. A microscope image of the fibre structure is shown in

Fig. 1, which consists of a pattern of 112 air holes (white circles) with a spacing of $42\ \mu\text{m}$. A second fibre with a $250\ \mu\text{m}$ diameter was drawn from the same preform, leading to a similar structure with a $15\ \mu\text{m}$ hole spacing.

3. Imaging capabilities

3.1 Operation principles

The microstructured fibre provides an imaging function in two distinctly different ways. Firstly, by creating an island of high-index material in a background of lower refractive index, a guiding core (pixel) is created, which operates similar to conventional microstructured optical fibre guidance [6,7]. A collection of such islands forms the pixel array. In our case, each core is defined by air holes, leaving thin strands of fibre material between the holes. This allows the cores to guide independently (provided the strands are thin enough) and thereby provide the coherent imaging capability. The cores can either be individually single-moded or multi-moded and their shape is generally non-circular.

Secondly, the hollow channels (or channels of low refractive index) in the fibre can guide individually through an anti-guiding mechanism [8]. This has not previously been considered for imaging purposes, presumably due to the relatively high transmission losses associated with this mechanism. Nevertheless, for short-distance applications ($<1\ \text{m}$) this does allow for a very direct way of imaging with a high capture fraction. Contrary to conventional fibre imaging bundles, in which light is guided through total internal reflection in cores of relatively high refractive index, an imaging fibre based on hollow waveguides does not need to be made from a transparent material.

A combination of the first and second methods of imaging is also possible in certain circumstances (dependent on the fibre length and core size), which would provide the largest possible capture fraction (since it simultaneously uses both the low-index channels and the high-index cores for the imaging), which also doubles the pixel resolution.

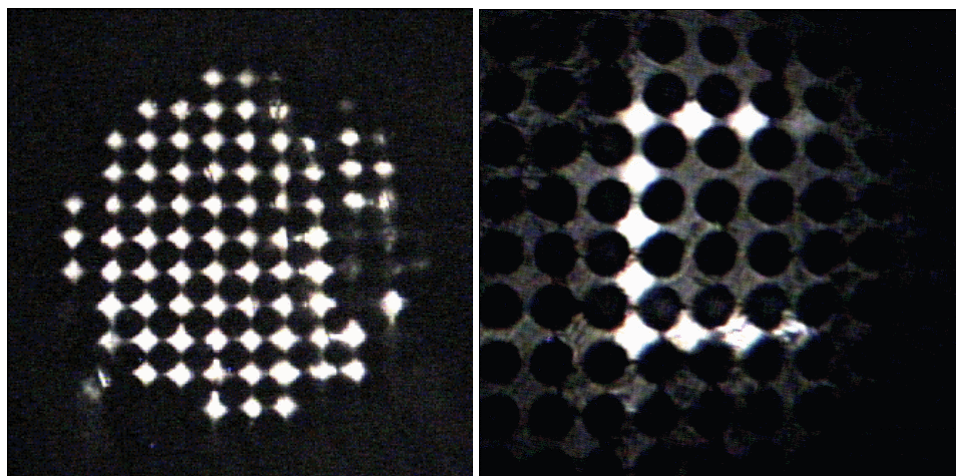


Fig. 2. (Movie 256kB. Imaging MPOF.) Movie of solid-core imaging. CCD camera image of the exit face of the fibre for uniform illumination (left) and with a C shaped screen in front of the white light source.

3.2 Solid core imaging

To demonstrate the imaging capability of the solid-cores, a metal screen with a \square shape cut out is placed in front of a white light source. This screen is imaged onto the cleaved fibre end face with a small lens ($f\sim 5\text{mm}$). The fibre transmits this image over its $42\ \text{cm}$ length and the

fibre end face is imaged onto a CCD camera with a 10x microscope objective. The resulting image is shown in Fig. 2, along with an image resulting from uniform illumination of the fibre. The slight irregularities in the transmission pattern originate from the imperfections of the razor-blade fibre cutting method.

The diamond-shaped solid cores clearly transmit the image in a coherent way, and moving of the imaged screen can be followed at the fibre output, as shown in the movie. Similar results were obtained for the 250 μm diameter fibre, in which the image is maintained down to a bending radius of 3mm, beyond which the overall transmission losses become significantly higher

3.3 Hollow-core imaging

A slight variation of the previous experiment is used for the demonstration of the hollow waveguide imaging properties. Here, a 20 cm long piece of the 800 μm diameter fibre is used, and a single pinhole screen is imaged. The result is shown in Fig. 3. The image on the left shows the result for uniform illumination. The slight blue colouration of some of the cores is common for hollow-waveguide guidance, which favours short wavelengths, especially for small air-hole diameters [8]. The image on the right shows the result for imaging of a pinhole. When the pinhole is shifted, the bright spot in the image moves accordingly, demonstrating that the air channels act as individual guiding cores, thus ensuring that coherent imaging is possible. Since light is guided in hollow-cores, this imaging mechanism can be utilized in any material, irrespective of the transparency.

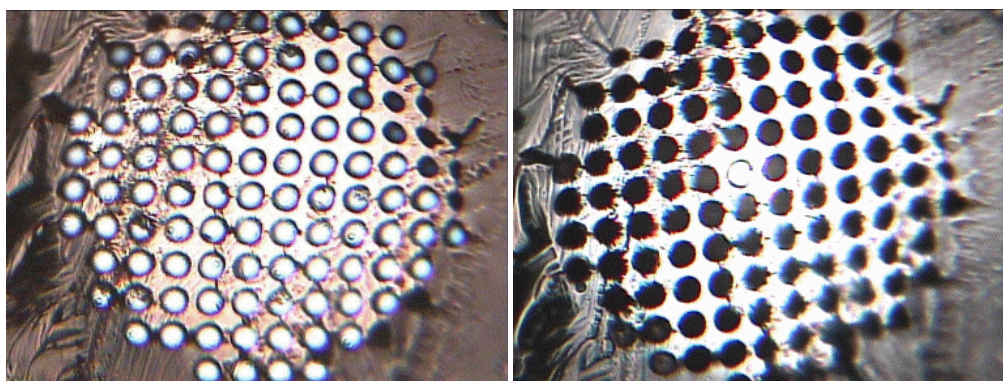


Fig. 3. (Movie 807kB. Imaging mPOF air guide.) CCD camera image of the exit face of a 20 cm long fibre of 800 μm diameter demonstrating the hollow-waveguide imaging function (imaging of a single a pinhole).

4. Conclusion

The imaging capabilities of multicore microstructured polymer optical fibres were demonstrated, with strong promise for miniaturisation of medical endoscopes and for two-dimensional parallel interfaces for interconnects. Two different guiding mechanisms were investigated, namely solid-core and air-hole guidance, both of which showed coherent image transmission through the fibre for bending radii down to 3mm. The combination of the two mechanisms could provide an enhanced capture fraction and higher resolution.

Acknowledgments

We would like to thank G. Henry for fabrication of the fibre and B. Reed for preform fabrication. We also acknowledge useful discussions with A. Argyros, J. Elsey, S. Fleming, M. Large and N. Waalib-Singh of the Optical Fibre Technology Centre, M. Sceats and C. Scott of Australian Photonics Pty. Ltd., C. Treaba, M. Mackiewicz and K. Meagher of Cochlear Ltd., and F. Ladouceur and I. Mann of the Bandwidth Foundry Pty Ltd. The Australian Photonics CRC is acknowledged for funding of this work.