Rectangular-core microstructured polymer optical fibre for interconnect applications

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A multimode microstructured polymer optical fibre is presented in which a large rectangular core is suspended by thin supporting bridges. Measurements of the near- and far-field patterns, the numerical aperture and polarisation mode-mixing are presented.

Introduction: Multimode optical fibres with wide light acceptance angles are essential for a variety of applications such as beam shaping, light delivery, short distance communications and more recently for cladding-pumped fibre lasers [1] and the interconnection of electronic systems over short distances [2]. Fibres with the highest numerical aperture (NA) reported to date are of the 'suspended core' microstructured fibre type, where a large core is suspended in air by a system of very thin bridges that connect to an outer cladding. For such fibres, the effective core to cladding refractive index contrast is very large and NAs of 0.9 have been reported [3].

In the field of interconnects, rectangular-core fibres and line-to-bundle converters have received some attention to increase coupling efficiencies from laser diode bars and laser arrays to fibre [4, 5]. A rectangular-core fibre with a core of 10 × 0.5 µm was demonstrated for efficient coupling to a semiconductor laser diode [6]. A rectangular-core double-clad microstructured silica fibre has been reported [7], but the details remain unpublished. The difficulties in making such fibres in glass, however, have hindered their development.

Microstructured polymer optical fibres (mPOFs) have been developed over the last four years [8]. Here we report on a multimode rectangular-core mPOF of the thin-bridge suspended-core type. The combination of large core size, potentially very high NA, freedom to design the core shape and the fact that even thick polymer fibres remain flexible make them promising candidates for interconnect applications as their core shape and NA can be designed to suit emitter or detector specifications in both transverse dimensions.

Fabrication: An mPOF preform is prepared by drilling 96 holes of 2 mm diameter with 0.3 mm wall thickness in a rectangular two-layer configuration into a PMMA rod of 70 mm diameter using a programmable CNC mill that has been optimised for mPOF preform fabrication [8]. This process allows for a large degree of freedom in terms of creating holes of different sizes in almost any position in the preform, making it straightforward to tailor the fibre core shape and NA. The preform was drawn in two stages with intermediate sleeving to a final diameter of 495 µm. In the fibre the major axis of the core is 144 µm and the minor axis is 16 µm (a 9 : 1 ratio). The average bridge thickness δ in the structure is 1.1 µm, with bridges ranging in thickness from 1.53 to 0.44 µm. Fig. 1 shows scanning electron microscope pictures of this fibre. The lower row of 'broken' bridges is a deformation resulting from the razor blade cleaving.

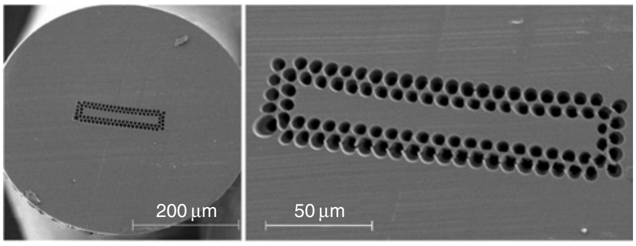

Fig. 1 *Electron microscope images of rectangular-core microstructured polymer optical fibre with 144 × 16 µm core*

Characterisation: The near-field pattern of the rectangular-core fibre transmission was recorded by imaging the fibre end-face onto a CCD camera (Fig. 2). It was observed to be independent of launching conditions for all fibre lengths, down to the shortest 20 cm length that was tested, indicating very efficient intermode coupling with an equilibrium length shorter than 20 cm.

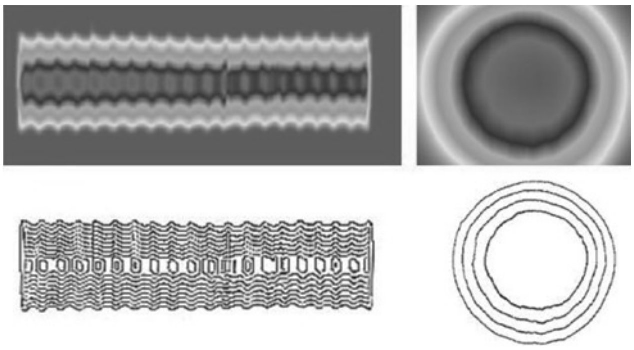

Fig. 2 *Measured near- (left) and far-field intensity distributions for rectangular-core mPOF with white light excitation (shades of grey relate to intensity levels)*

Note that near-field images have 2× scaled up minor axis for increased clarity

The numerical aperture for optical fibres is generally defined as NA = sin $\theta_{\max}$, where $\theta_{\max}$ is the maximum angle at which a meridional ray entering the fibre will be guided. It is measured from the far-field angular intensity distribution by determining the half-angle at which the intensity has decreased to a standard 5% of its maximum value [9]. White light was launched with a 60× (NA = 0.8) microscope objective into the centre of the core and the cladding modes were stripped off. The far-field transmission spectra were recorded at all angles (in 1° increments and in the wavelength range from 450 to 850 nm) by sweeping a multimode silica fibre connected to an optical spectrum analyser in an arc about the end-face of the mPOF at a distance of 10 cm. The solid angle of detection is thus constant for all angles and wavelengths. The 3D data set of transmission against angle and λ is reduced to a 2D set of NA against λ by using the 5% criterion at each angle. The wavelength is normalised to the bridge thickness δ and the results shown in Fig. 3. The largest bridge thickness of 1.53 µm is used in the normalisation as this predominantly determines the NA [10, 11].

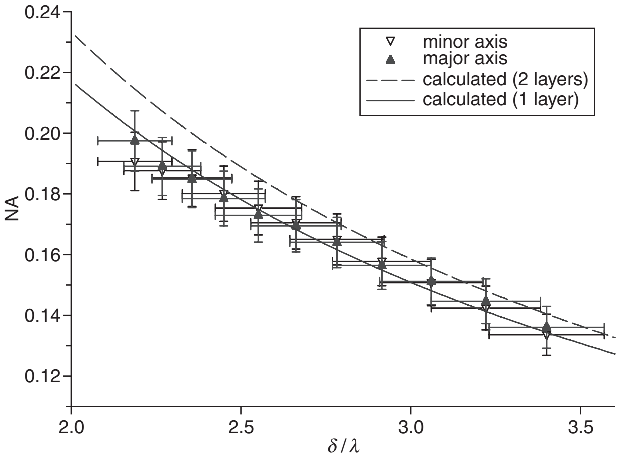

Fig. 3 *Numerical aperture measurements against normalised wavelength of 210 cm long rectangular-core mPOF with maximum bridge width 1.53 µm*

Drawn and dashed curves show calculated results for 1 and 2 layers of holes

The curve in Fig. 3 shows the NA as calculated for a circular core fibre with the same bridge thickness (1.53 µm) using the propagation constant of the TE bridge modes (single layer result) and that of the TM bridge modes (multiple layer result) [10, 11]. Good agreement is obtained, even though the mode distribution in the rectangular fibre is fundamentally different from that of a circular core fibre. This prohibits a literal comparison from the circular-core theoretical results. Note that no significant differences between the major and minor axis NAs were observed.

The fibre transmission losses and the degree of polarisation maintaining were measured by launching an HeNe laser (633 nm) with a low NA objective lens into 240 cm of fibre. By launching white light from the opposite end and creating a near-field image it was possible to obtain the orientation of the core at the launching end and to launch into the centre of the fibre core with light polarised in the direction parallel to the major axis. The power at the far end was measured without a polariser (P_{total}) and with a polariser parallel ($P_{\|}$) and perpendicular to the major axis ($P_{\perp}$). The fibre was then cut back in steps of 10 cm and the measurements repeated. Measurement P_{total} showed an exponential decay with fibre length, which gave an overall fibre transmission loss of 1.2 dB/m. Fig. 4 shows the measured degree of polarisation $\equiv (P_{\|} - P_{\perp})/(P_{\|} + P_{\perp})$ against fibre length. An exponential dependence with fibre length is observed with a correlation length ($1/e$ decay length) of 60 cm ($r^2 = 0.905$) due to polarisation mode mixing. This is significantly longer than the equilibrium length for (transverse) intermode mixing, which was found to be shorter than 20 cm.

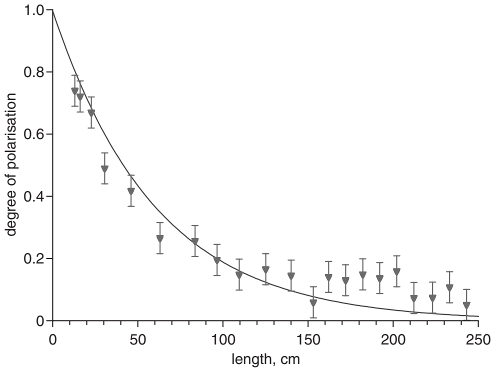

Fig. 4 *Measured degree of polarisation against fibre length*

Conclusions: A rectangular-core multimode microstructured polymer optical fibre has been fabricated and numerical aperture measurements presented and found to be in good agreement with calculations. Multimode suspended-core microstructured optical fibres show promise as an effective fibre technology with both core shapes and numerical apertures independently modifiable in both transverse dimensions. This allows matching to asymmetric emitter or detector dimensions. Polymer optical fibres provide further advantages in terms of their large degree of design freedom and their robust fabrication technology that can be scaled to high volume production.

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