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Single-mode microstructured polymer optical fibre

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Abstract: We have fabricated the first microstructured polymer optical fibre (MPOF) and demonstrate the single-mode guiding properties. The advantages of polymer-based microstructured optical fibres over both conventional polymer optical fibres and glass microstructured fibre are discussed.

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1. Introduction

Microstructred optical fibres have aroused considerable interest since their initial invention. Among the interesting novel features associated with microstructured fibres are their “endlessly single mode” [1] properties, easy tailorability for dispersion and polarization control, the possibility of large core single moded fibres [2], and band-gap fibres in which the light is guided in air [3]. These features mean that they are the subject of a growing research and development effort. In this paper we describe the first microstructed polymer optical fibre (MPOF), and discuss the additional features that MPOF may bring to the area of both polymer fibre and microstructured fibre research.

2. The Single Mode MPOF

The MPOFs were fabricated using commercially available PMMA without further purification [4]. Consequently the material losses were extremely high. In unstructured fibre they were measured to be 32 dB/m. Compared to the dimensions of the perform, the fibre has a slightly reduced hole diameter to hole spacing ratio, $d/\Lambda = 0.46$, whereas in the preform $d/\Lambda = 0.67$. The average hole diameter $d = 1.3$ µm and an average hole spacing $\Lambda = 2.8$ µm, which defines a core size of 4.3 µm.

Three experimental tests were performed to establish that the fibre was single moded at 633nm. In the first experiment light was launched into the MPOF by butt coupling from a multi-mode fibre. The resulting field pattern was observed to be stable regardless of the launch conditions and fibre bending. In a second experiment, a HeNe beam was launched directly into the fibre, and the expected near and far field images were observed. Finally, a spatial interference experiment was performed. Light from a HeNe source was split between the MPOF and conventional single mode fibre. The interference of the two outputs gave parallel fringes, with a visibility close to unity. The numerical aperture of the fibre was measured to be 0.07, and it has a critical bend radius of 2mm.

3. Multipole modeling of the mode structure

We modeled the MPOF using a recently developed multipole method [5,6], which has advantages in terms of speed and accuracy compared to other techniques. Crucially it also has the ability to calculate confinement losses. Confinement losses are a function of the number of rings of holes. The results show that the structure has three bound modes, two of which are doubly degenerate, together with a non-degenerate mode located in close proximity to the second degenerate mode. The confinement losses of these modes are very different. In the four-ring case, the fundamental mode exhibits a loss of $3x10^{-6}$ dB/m,

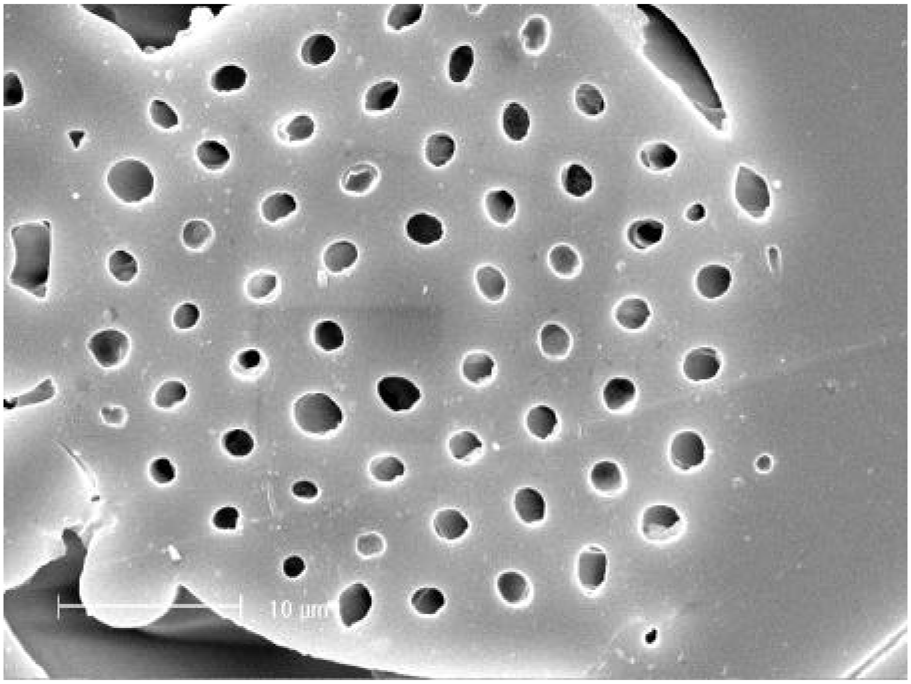

Figure 1. Electron micrograph of the microstructured polymer optical fibre (MPOF), showing the core region surrounded by four rings of air holes (of 1.3 μm diameter) in a hexagonal lattice.

which is much smaller than the absorption loss of 32 dB/m, and is therefore essentially negligible. In contrast, the higher-order modes have a loss around 200 dB/m (see Fig. 2). The theoretical results are therefore entirely consistent with the experimentally observed single-modedness, and suggest that a useful definition of "single-moded" in microstructured fibres could be fibres for which all of the modes other than the fundamental mode experience confinement losses that are too great to observe any transmission.

4. Promise and Significance of MPOFs

Microstructured optical fibres fabricated in glass have generally been made by capillary stacking techniques, which result in a hexagonal arrangement of the holes. The large range of processing options available for polymers, including casting, casting around capillaries, extrusion etc. in addition to the thermal fusing of capillary stacks, means that potentially a much larger range of hole structures is possible. In addition, drawing of polymer fibres causes an alignment of the polymer chains, which protects the hole structure from collapse. This means that the drawing process is quite robust, which may make it easier to produce non-circular holes, and potentially band-gap fibres, than in the case of glass microstructured fibres.

Polymers can be tailored in terms of composition to a much larger degree than glass fibres. Doping options for glass are limited by the need to avoid phase separation, and use of materials that do not decompose at glass processing temperatures (about 2000°C). In polymers, the low processing temperatures(100-250°C) mean that organic materials such as dyes or non-linear chromophores can be easily included without decomposition. In addition to doping, the polymer structure can be modified by grafting to allow large mass fractions of the desired material. Surfactant techniques also allow relatively large quantities of inclusions to be added. Examples of the types of materials that could be used in MPOF are: polymers with enhanced non-linearities, electro or magneto-optic effects, metallic or rare-earth inclusions, birefringent materials such as liquid crystals, photorefractive and photochromic materials, dyes, polymers used in the detection of particular compounds and porous materials. The polymers can be specifically designed to allow the fabrication of particular fibre-optic components based on MPOF.

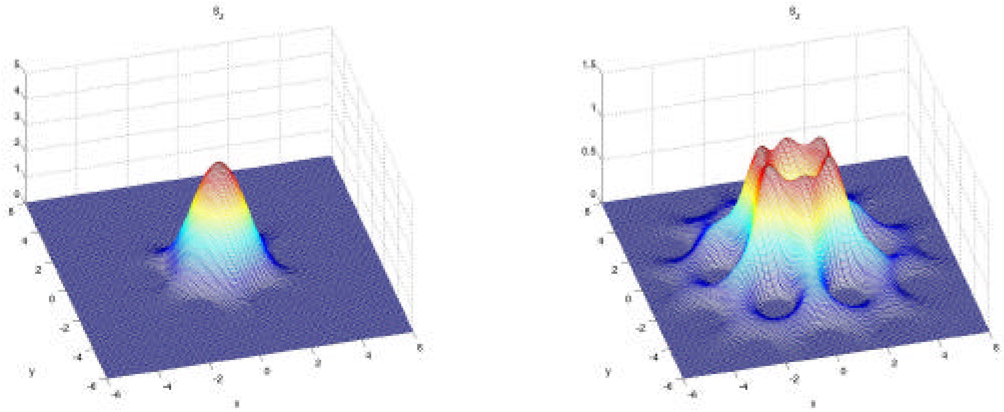

Fig. 2 The axial component of the Poynting vector for the first two degenerate modes of a two-ring MPOF. The fundamental mode (left) experiences a confinement loss of 3×10^{-6} dB/m and the second and higher-order modes a loss greater than 200 dB/m.

MPOFs can be fabricated from a single polymer, without the need for dopants to modify the refractive index. As a result, a much larger range of polymers is available for MPOF, including condensation polymers, catalytically formed polymers, biopolymers, sol-gel polymers and chain addition polymers. In addition, by using closely spaced holes that are small compared to the optical wavelength, virtually any refractive index profile can be obtained as the spatial average of the polymer-air matrix, without the use of any dopants [7].

5. Conlcusions

A single-mode microstructured polymer optical fibre (MPOF) was fabricated and the guiding properties were demonstrated. Using the multipole expansion technique we found that all of the modes other than the fundamental mode experience very large confinement losses, which is the basis of single mode propagation in microstructured fibres. The advantages of MPOF over both conventional polymer optical fibres and glass microstructured fibre were discussed. The versatility and low-cost of the manufacturing methods and the chemical flexibility of the polymers provide great potential for applications in data communication networks and for the development of a range of new polymer-based fibre-optic components. The field of microstructured polymer fibres therefore promises to be a rich field of research for some time to come.

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