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Extruded single-mode non-silica glass holey optical fibres

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We report the fabrication of the first microstructured single-mode non-silica optical fibre. Extrusion has been used for the first time to produce the microstructured fibre preform. The final drawn fibre has an effectively air-suspended 2μm core. Single-mode guidance is observed from 633-1500nm.

Introduction: Since the development of the first holey fibre (HF) in 1996 [1], the development of this field has been explosive. The combination of wavelength-scale features and the design flexibility offered by HFs leads to a broader range of optical properties than is possible in conventional fibres. HF preforms are typically produced by stacking capillaries around a rod, and to date, most HFs have been made from pure silica glass, although recently compound glass [2] and polymer [3] HFs have been fabricated. One exciting application of HFs is in the development of high effective nonlinearity fibres. In silica HFs, this has been achieved by combining small core dimensions with a high NA to produce tight modal confinement. Such fibres promise the development of compact devices based on nonlinear effects that can operate at low powers (e.g. devices for optical data regeneration [4] and Raman amplification [5]).

Compound glasses offer a range of properties not possible in silica, making them attractive materials for optical fibres. However, their development has been limited because it is difficult to fabricate low-loss single-mode fibres using conventional techniques. HF technology provides a powerful new technique for producing compound glass fibres [2]. In addition, the material nonlinearity (n_2) of compound glasses can be more than an order of magnitude larger than that of silica, and so compound glass HFs are of particular interest for nonlinear applications. We describe here the first single-mode non-silica glass HF.

Fabrication: We use SF57 glass, a commercially available Schott glass. The high lead concentration of this glass leads to a high refractive index of 1.83 (at 633nm) and 1.80 (at 1.53μm) with losses in the bulk glass of 0.7dB/m (at 633nm) and 0.3dB/m (at 1.53μm). Note also that the nonlinear refractive index (n_2) measured at 1.06μm is 4.1×10^{-19} W^2/m [7], more than an order of magnitude larger than that of pure silica glass fibres [8]. Since the effective nonlinearity of a fibre is $\gamma=n_2/A_{eff}$, the combination of this glass with the small effective areas (A_{eff}) possible in HFs allows for dramatic improvements in the nonlinearity that can be achieved.

SF57 glass has a low softening temperature (519°C) and so it was possible to extrude the HF preform from bulk SF57 glass. A cross-section through the extruded preform, which has an outer diameter (OD) of 16mm, is shown in Fig.1(a). The structure is comprised of a central solid core supported by three long thin membranes, and this transverse structure extends along the preform length. The preform was then caned on a fibre drawing tower down to an OD of 1.6mm, and a cross-section of this cane is shown in Fig.1(b). It is evident that the geometry has been maintained well during the reduction process. The cane is inserted within an extruded jacketing tube, and this assembly is then drawn down to 120μm OD fibre (see Fig.2). In this way, extremely small features have been retained without compromising practicality and handling.

Visual inspection indicates that this cross-sectional profile remained essentially unchanged over more than 50m of fibre. The core diameter is ≈2μm and the core is suspended by three ≈2μm long supports that are less than 400nm thick. These supporting struts allow the solid core region to guide light by helping to isolate the core from the outer solid regions of the fibre cross-section.

Guidance properties: Robust single-mode guidance was observed in this fibre at both 633nm and 1500nm, and an experimental mode-profile is shown in Fig.3 for 633nm. Using the SEM from Fig.2 to define the transverse structure, the model from Ref [9] was used to predict the properties of this fibre at 633nm. Fig.3 shows the predicted mode profile superimposed on the core region, for which $A_{eff}=2\mu m^2$, comparable to the smallest areas achieved in silica HFs. Hence these fibres offer values of γ that are three orders of magnitude higher than conventional silica optical fibres.

Although single-material fibres support only leaky modes, it is possible to design low-loss fibres of the type shown in Fig.1 [9]. This can be done by ensuring that the supporting struts are long and fine enough that they act purely as structural members that isolate the core from the external environment. The fibres can be effectively single-mode over a broad range of wavelengths since the confinement losses associated with any higher order modes are significantly higher than that of the fundamental mode. Note that confinement losses typically increase with wavelength.

We observe approximately 3dB/m loss at 633nm and 10dB/m at 1550nm, significantly larger than the material loss at each wavelength. We anticipate that the confinement loss would decrease significantly if longer struts were used. The strut length in the fibre in Fig.2 was not limited by the extrusion process, as Figs 1(a) and (b) attest, and so we anticipate that further improvements to the drawing procedure should allow the practical application of this new class of microstructured fibre.

Conclusions: We report for the first time light guidance in a non-silica glass microstructured optical fibre. The fibre is observed to be single-mode over a broad wavelength range. In addition, we report the first use of extrusion to produce a HF preform. Extrusion offers a controlled and reproducible method for producing complex structured preforms with good surface quality, and makes efficient use of raw materials. By avoiding stacking, fewer interfaces are involved, and so ultimately, extrusion may offer lower losses than existing techniques. In addition, extrusion can be used to produce structures that could not be created with capillary stacking approaches, and so a significantly broader range of properties should be accessible in extruded HFs. Single-material fibre designs avoid core/cladding interface problems, and so should potentially allow low-loss fibres to be drawn from a wide range of novel glasses.

Acknowledgements

The authors acknowledge D. Payne and X. Feng for useful discussions, N. Sessions, N. Fagan, E. Weatherby and P. Hua for technical assistance. T.M. Monro and D.J. Richardson acknowledge the support of the Royal Society.

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Figure captions:

Fig.1 Photographs of (a) the extruded microstructured SF57 preform (OD=16mm) and (b) the cane produced by drawing this preform (OD=1.6mm).

Fig.2 SEM photograph of the cross-section of the extruded SF57 microstructured fibre.

Fig.3 Predicted mode intensity profile (left, with dB-spaced contour levels) and (right) a cross-section through the observed mode profile for this fibre at 633nm.

Figure 1

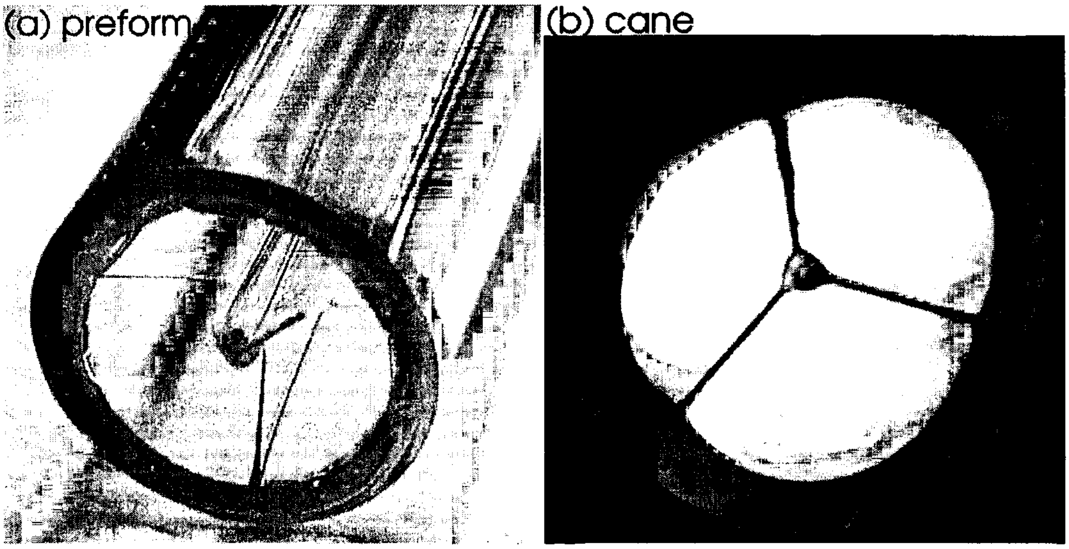


Figure 2

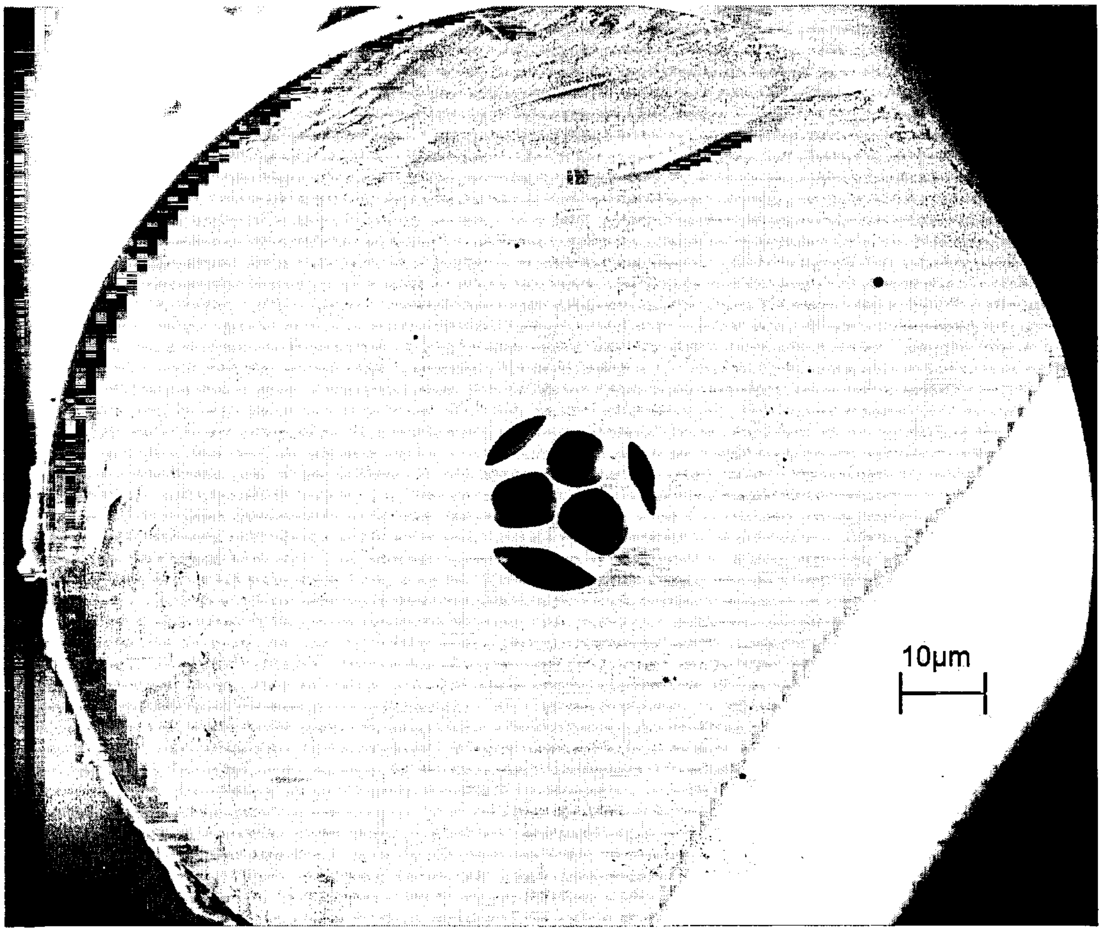
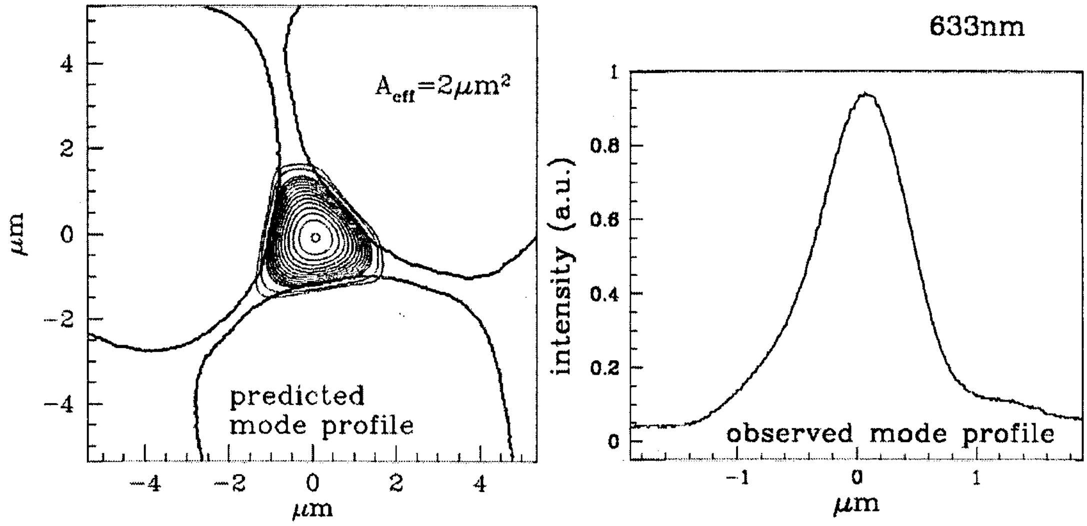


Figure 3



4
2
0
−2
−4
μm
A$_{eff}$=2μm^2
predicted
mode profile
−4
−2
0
2
4
μm
633nm
1
0.8
0.6
0.4
0.2
0
intensity (a.u.)
observed mode profile
−1
0
1
μm