2(4) 2076

Chalcogenide holey fibres

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September 14, 2000

Abstract

We report the fabrication of the first non-silica *holey* or *microstructured* optical fibre. The chalcogenide glass Gallium Lanthanum Sulphide (GLS) was used. Applications of such fibres include optical switching, high power-delivery, acousto-optic devices, air-guiding fibres, fibre sensors, mid-IR devices, amongst others. In addition, holey fibre technology provides a improved route towards fabricating single-mode compound glass fibres.

Introduction: In recent years, great interest has been generated by the development of *holey* or *microstructured* optical fibres. The large and controllable variations of transverse refractive index offered by these fibres opens up new opportunities for the control and guidance of light [3], [4]. Until now, holey fibres have been made exclusively from conventional silica glasses. Here we show for the first time that it is possible to fabricate compound glass holey fibres.

Compound glasses offer a range of useful properties not possible in silica glass, making them attractive alternative materials for optical fibres. Examples of compound glasses include suphides, halides and heavy metal oxide glasses [1]. One example of specific interest is gallium lanthanum suphide (GLS) glass which is transparent for wavelengths up to 5 microns, has a high refractive index (2.3 - 2.5), and can be doped with over 10% rare earth ions by weight [2]. Despite their promise, compound glass fibres have not yet found widespread application because it is difficult to fabricate low-loss single-mode compound glass fibres.

Holey fibre technology provides a powerful new technique for producing compound glass fibres. In addition, the holey fibre geometry dramatically increases the range of possible optical properties.

Fabrication: Figure 1 shows a cross-section of a GLS holey fibre. This fibre was drawn from the preform in a single step, and this preform was constructed in a manner analogous to silica HF preforms [5]. A solid rod was used to form the core of the fibre, this rod was surrounded by six capillaries, and this structure was placed inside a larger capillary both for structural support and to increase the preform dimensions. This preform was then drawn into fibre form.

The fibre Fig. 1 has an outer diameter of approximately 100 μm, and a core diameter of 10 μm. The holes in the cladding capillaries range in diameter from 1.5 to 4.0 μm. In this case the inner capillaries did not fit tightly in the supporting capillary, which resulted in the core being loosely attached to the cladding. Figure 1 shows that it is possible to retain the transverse structure during fibre drawing (this was also confirmed using another preform).

The drawing temperature for compound glasses is typically lower than for silica, and conventional equipment and experimental parameters cannot be used. GLS glass is drawn around 700 – 800°C in a furnace with precisely controlled heating. In general, the temperature window available for drawing in compound glasses is much smaller than in silica glasses. The excellent structure retention we have obtained indicates that the viscosity/temperature relationship in GLS glass is well suited to holey fibre fabrication.

Optical properties: The unusual properties of holey fibres result from the fact that the structure in the cladding can be on the same physical scale as the wavelength of light. Compound glass holey fibres have potential applications which include: transmission at wavelengths from the visible to beyond $5\,\mu m$, large mode sizes, highly nonlinearity, novel dispersion characteristics, photonic band gap guidance, endless single-mode guidance, large evanescent fields, amongst others.

To model the optical properties of a holey fibre, it is necessary to describe the transverse refractive index profile accurately. This can be done using a full vector model in which the guided modes and the index profile are described independently [3, 6]. The GLS fibre shown in Fig. 1 can be modelled directly using this approach. Figure 2 shows that this fibre supports a guided mode in the core at $4\,\mu$m. This mode is somewhat leaky due to the thickness of the bridge between the core and cladding regions. The core also supports two higher order leaky modes.

Consider an idealised GLS holey fibre with a hole-to-hole spacing of $5\,\mu$m and holes of size $1\,\mu$m arranged in a hexagonal configuration. Note by reference to Fig. 1 that features of these dimensions can be achieved. The numerical model predicts that this fibre will be single-moded from at least $1.0\,\mu$m to $5.0\,\mu$m. The predicted mode field diameter (MFD) and waveguide dispersion (GVD) for this fibre are given in Fig. 3. Both the MFD and the GVD are relatively flat over this large wavelength range. The increase in the MFD at short wavelengths results from the fact that the guided mode then becomes extended in the regions between the holes. The waveguide GVD is small and anomalous over the entire range. The inset shows the contribution of material dispersion from $1 \rightarrow 2\,\mu$m: note that for this example the contribution of the waveguide dispersion is negligible. We expect the waveguide component of the dispersion to become much more significant when larger holes or smaller structures are considered.

Discussion and conclusions: As mentioned earlier, it is difficult to fabricate low-loss single-mode compound glass fibres using conventional techniques. Problems arise from the different physical properties of the core and cladding materials. In addition, the heating steps required to fabricate a single-mode compound glass fibre tends to promote crystallisation, inducing losses. Here we demonstrate a new class of optical fibre, the *compound glass holey fibre.* Holey fibres can be made from a single-material, and so the problems induced by the core/cladding interface can be eliminated. They can also be made using a single heating step, which should reduce crystallisation problems, and so significantly reduce the fibre loss. In this way holey fibres provide a new route towards the successful development of low-loss single-mode compound glass optical fibres.

If the holes are periodically arranged, then the fibre may guide light via photonic band gap effects. The larger refractive index contrast possible using compound glasses should ease the fabrication difficulties associated with photonic band gap structures.

The holes in HF also open up opportunities of exploiting the interaction of light with gases and liquids via evanescent field effects. Many gases have absorption signatures in the $3-5\,\mu$m range, and using a compound glass holey fibre, the concentration of pollutants in a gas could be measured efficiently and compactly.

In conclusion, our results demonstrate the feasibility of extending holey fibre technology to compound glass, providing great flexibility and practical advantages for the development of fibre devices in the 0.5-5 micron wavelength range.

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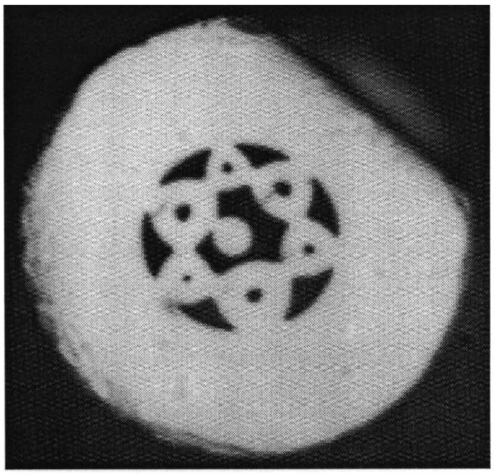

Figure 1: A GLS (gallium lanthanum suphide) holey optical fibre. The core is supported by capillaries, which form the cladding region.

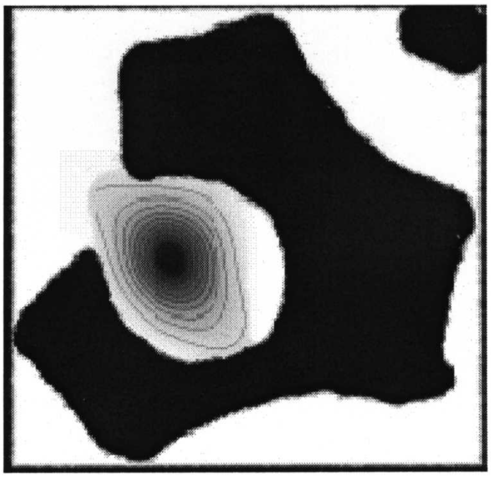

Figure 2: The (leaky) fundamental mode guided by the fibre in Fig. 1 is superimposed on the transverse fibre profile.

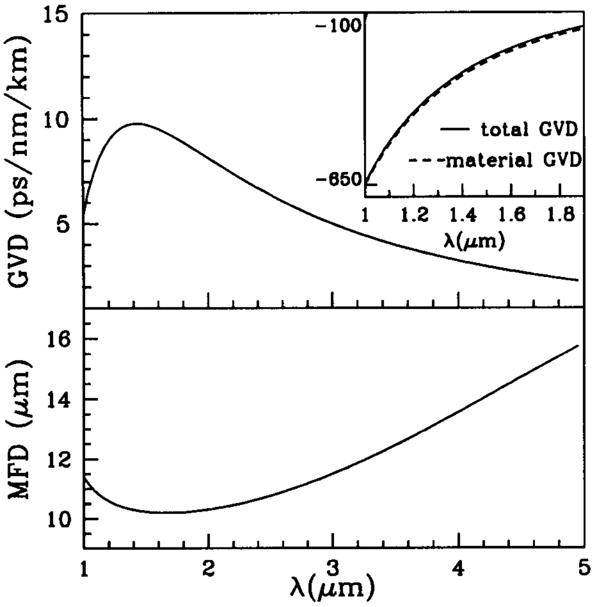

Figure 3: MFD and waveguide GVD for GLS fibre with 1 μm holes separated by 5 μm over the GLS transmission window. The inset shows the material and net dispersion over the wavelength range for which data is available.