Table 1 shows the minimum transmittance of the sol-gel material within a broad spectrum ranging from UV to short-wave infrared. Within the narrower bandpass of 400–1100nm, the minimum transmittance of the 27.5µm thick and 17.8µm thick films was 92 and 97%, respectively.

The mean RMS surface roughness values after development listed in Table 1 correspond to a total integrated scatter of 10 and 11% at 587nm [4].

The maximum patterned thickness of the hybrid glass material described in Table 1 can be interpreted in terms of a refractive or a reflective micro-optical element. With a 1.2mm clear aperture, a refractive lenslet can be fabricated with an effective focal length (f_e) of 21mm and a numerical aperture (NA) of 0.03. With a 600µm clear aperture, a refractive lenslet can be fabricated with f_e = 5.25mm and NA = 0.06. With a 600µm clear aperture, a concave micromirror can be fabricated with f_e = 1.3mm and NA = 0.23.

The maximum patterned depths listed in Table 1 were uniformly achieved within wide features and within the narrowest features on the photomask used to create the element shown in Fig. 1. The narrowest patterned zone of the zone plate in Fig. 1 has a radial width of 27.5µm resulting in an aspect ratio of 0.6.

Conclusions: The hybrid glass material described in this Letter represents a step towards obtaining the material properties required by the simultaneous fabrication of optical and opto-mechanical features in micro-optical systems. In addition, this hybrid glass material exhibits superior sensitivity to UV light allowing the fabrication of 17µm deep structures after only a 0.5s exposure. Future efforts will be directed towards patterning this hybrid glass material with a grey-scale photomask to realise more complex micro-opto-mechanical structures.

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Polarisation-independent Bragg gratings in ion-exchanged glass channel waveguides

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The polarisation dependence of Bragg gratings photowritten in ion-exchanged glass waveguides is characterised for waveguides with different mask-opening widths and burial depths. It is found that polarisation-independent gratings can be written in waveguides with a wide variation in fabrication parameters.

Bragg reflection gratings in fibre optic communication systems and sensors have demonstrated numerous applications, such as multiplexing, dispersion compensation and laser feedback [1]. Their widespread use is a clear indication of their importance in these fields. Most applications require polarisation-independent operation due to the specifications of the other components in the systems.

Photowritten Bragg gratings have recently been demonstrated in ion-exchanged channel waveguides, an integrated optics technology currently in commercial use. Single step ion-exchanged waveguides have an intrinsic birefringence due to the asymmetry of the waveguide structure and stress. This results in a strong polarisation dependence of the Bragg reflection, with the transmission dip for TE and TM separated by 0.56nm [2]. Birefringence control in ion-exchanged waveguides has been demonstrated by means of a two step ion-exchange process. However, the study showed a nearly linear dependence of the birefringence on the fabrication parameters. This results in a crossing point for zero birefringence, which can only be achieved by exercising strict control of the fabrication parameters [3].

In this Letter, we demonstrate polarisation-independent Bragg reflection gratings photowritten in ion-exchanged waveguides. The birefringence of the waveguides is eliminated through an additional step, a field assisted burial [4]. This second step buries the waveguide below the surface of the glass, decreasing the asymmetry of both the waveguide structure and the stresses. As a result, it is possible to write a simple Bragg grating with identical performance for both TE and TM polarisations.

The waveguide fabrication is similar to that described in [5]. Five samples were fabricated by silver ion-exchange in BGG31 glass [6], each sample having straight waveguides fabricated from mask openings of 1, 1.5, 2 and 2.5µm. The samples were then buried by field-assisted ion-exchange to different depths: 2.8, 5.6, 8.4, 11.2, and 13.8µm. Gratings were photowritten into each sample using a 248nm excimer laser. With an exposure area of ~2 × 2mm, 5040J of pulsed exposure wrote gratings of 535nm periodicity.

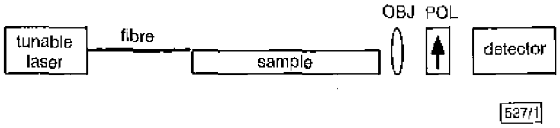

Fig. 1 *Setup for transmission characterisation*

The transmission of each sample was characterised using the setup shown in Fig. 1. The output of a tunable laser was fibre butt-coupled to the sample. The waveguide output was collected with a 20× objective lens and passed through a polariser to allow separation of the TE and TM modes before being detected.

The transmission of the samples through the waveguide with the 2µm mask opening is shown in Fig. 2 for burial depths of 2.8, 5.6, 8.4 and 13.8µm. The flat bottom evident on the dip is the result of the limited dynamic range of our measurement setup. A different setup unable to distinguish polarisations measured a 60dB dip in the transmission on one of our samples. The asymmetric shape results from imperfections in the grating writing process. A slightly Gaussian shape to the beam profile in the transverse direction will result in a slight Gaussian apodisation of the grating in the longitudinal direction when the beam is not perfectly aligned to the waveguide. This, combined with a negative induced refractive index change, would yield the asymmetric shape observed [7].

Fig. 2*a* shows a small polarisation dependence remaining for the 2.8μm deep burial. The transmission dip is shifted by ~0.1nm from TE to TM. This is much less than previously reported polarisation dependence [2], which is surprising for such a short burial depth, although it is still unacceptable for most system applications. This polarisation dependence is quickly reduced as the waveguides are further buried to a depth of 5.6μm. Fig. 2*b* shows that this sample has a negligible polarisation dependence of ~0.01nm. Even this is eliminated with further burial. The 8.4μm deep burial, shown in Fig. 2*c*, reveals no measurable polarisation dependence.

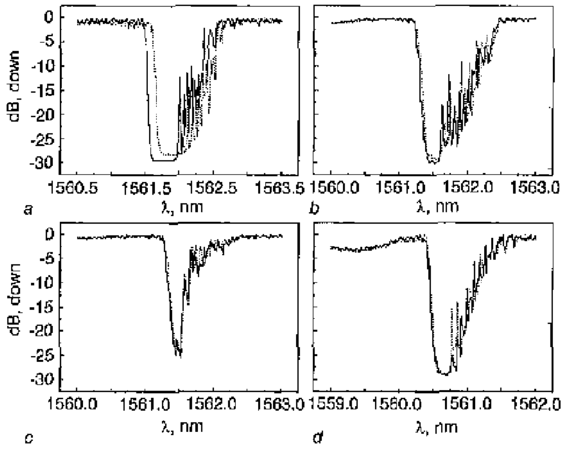

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Fig. 2 *Transmission of 2μm mask opening waveguides with different burial depths*

Burial depths:
a 2.8μm
b 5.6μm
c 8.4μm
d 13.8μm
- - - - TE
——— TM

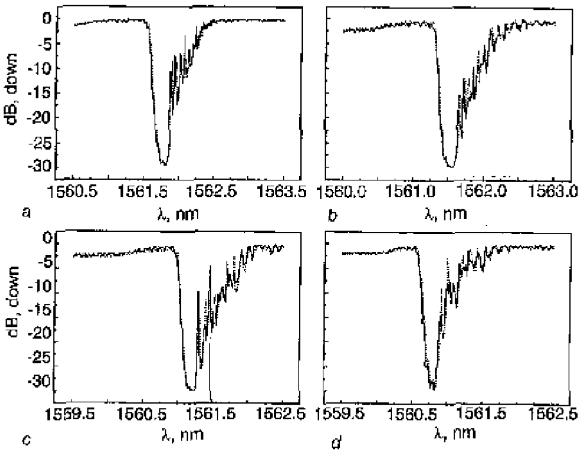

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Fig. 3 *Transmission of waveguides with burial depth of 11.2μm and different mask opening widths*

Mask opening widths:
a 1.0μm
b 1.5μm
c 2.0μm
d 2.5μm
- - - - TE
——— TM

It is important that further burial does not result in increased polarisation dependence. As previously mentioned, the birefringence is eliminated in two ways by the burial process. Both the shape of the waveguide and the stresses become more symmetric. It was a concern that the waveguide structure asymmetry might diminish more rapidly, resulting in an opposite birefringence (the transmission dip for TM at longer wavelengths) for deeper burials. Such an effect would result in a crossing point for polarisation-independent performance, requiring strict control of the fabrication parameters and limiting the potentially achievable waveguide structures. However, Fig. 2*d* shows that continuing the burial to a depth of 13.8μm still resulted in a polarisation-independent grating.

Additionally it is important to note that the polarisation dependence was the same for all waveguides of identical burial time, regardless of the mask-opening width. Fig. 3 shows the characterised transmission through waveguides with 1.0, 1.5, 2.0 and 2.5μm wide mask openings for a burial depth of 11.2μm. None of the waveguides showed any significant polarisation dependence. Although not shown here, the polarisation sensitivity of the gratings showed no dependence on the waveguide mask-opening width for all of the burial times characterised.

In conclusion, we have demonstrated polarisation-independent gratings photowritten in ion-exchanged glass waveguides. Waveguide birefringence is quickly eliminated by a second ion-exchange step of field-assisted burial, with almost polarisation-independent gratings resulting after just a 5.6μm deep burial. Additionally, the birefringence remains negligible with further burial, resulting in a wide range of burial times with polarisation-independent gratings. This allows for greater flexibility in the fabrication parameters and resulting waveguides.

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