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UV-Written Channel Waveguides in Ion-Exchanged Pyrex

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In this paper we demonstrate that a positive change in refractive index can be induced by UV radiation in bulk Pyrex, an inexpensive, commercially available glass that is not specifically designed to be photosensitive. We describe the fabrication of channel waveguides in Pyrex by direct UV writing and show that a potassium-ion exchanged layer can be used to host single mode waveguides. The change in refractive index due to the UV writing is found to be 2 x 10^{-3}.

Keywords: UV writing, ion-exchange, bulk glass, Pyrex, channel waveguides, planar waveguides

Introduction

Direct UV writing has recently attracted a great deal of attention as a potential route to low cost integrated optical glass components [1,2]. Waveguides can be written due to the localized change in refractive index caused by short wave radiation. UV writing has the advantage that it is a single step process for waveguide fabrication, unlike the traditional techniques of ion exchange or chemical vapour deposition, both of which require multiple processing steps. This typically involves either reactive ion etching or patterning through a photolithographic mask that can be both time-consuming and expensive. In direct UV writing this is avoided by writing the chosen structure in one step into the glass, offering the additional benefit of the flexibility to quickly define new structures at will, without the need to first produce a photolithographic mask.

Much of the UV writing work to date has been performed with deposited layer glasses that rely on germanium for their photosensitivity [3-5]. Other work has shown that photosensitivity can be increased by hydrogen or deuterium loading the glass [6]. There have also been reports of UV induced refractive index change in ion-exchanged channel waveguides in bulk glasses, such as silver ion-exchanged BGG31 [2,7], where the silver ions are reported to be responsible for making the glass photosensitive. There has also been a report of photowriting into a potassium ion-exchanged boroscilicate glass, but in this case it was first necessary to sensitise the waveguide with gamma rays [8].

In this paper we describe the fabrication of UV written channel waveguides in bulk Pyrex without the need for the addition of a photosensitive layer by ion exchange or doping. There are many advantages of using a bulk glass; Pyrex is cheap and commercially available, the composition is customizable, and there is the possibility of introducing a large number of components and active ions to increase the photosensitivity or other useful properties. We show that Pyrex is photosensitive and that a positive refractive index is achieved after irradiation with a frequency doubled argon ion laser at 244 nm. We also demonstrate that single mode channel waveguides can be written into a potassium ion-exchanged layer in Pyrex. Here the ion-exchanged layer acts as a host for the channel waveguide structures, improving the confinement of the modes. This demonstration of photosensitivity provides the possibility, with further optimization, of making more complex structures such as gratings, Y-splitters, directional couplers, and ultimately complete planar lightwave circuits.

Experimental

Two Pyrex samples were prepared for UV writing. Both were cleaned thoroughly, diced to form an area of 25 mm^2 and end-face polished. The first sample was used foe direct UV writing experiments without any additional procedures. The second was placed in a KNO_3 melt at 385 °C for 13 hours and 20 minutes to form an ion-exchanged layer with a depth of approximately 6 μm.

Direct UV writing was performed using a frequency doubled argon ion laser at 244 nm and a high precision three-dimensional translation stage [4]. Focussing the UV beam with a 35 mm lens formed a 3 μm spot and this was adjusted so that maximum intensity was achieved at the surface of the sample. The sample was then translated under the UV beam to induce a refractive index change as shown in Figure 1. To optimise the writing conditions, translation speeds between 1 and 10 mm/min and input powers between 20 and 70 mW were used.

The channel waveguides were observed using an unpolarized HeNe laser and imaged with a microscope objective. Mode profiling of the waveguide output was performed using a silicon camera and computer based evaluation software.

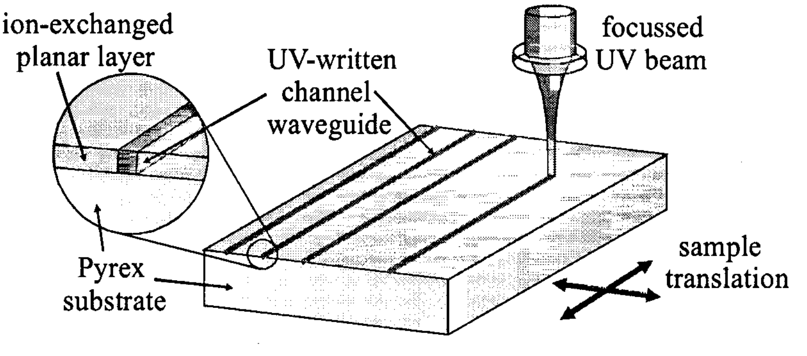

Figure 1. Direct UV writing of channel waveguides using a UV beam focussed to a 3μm spot.

Results

Refractive index structures were first written in the plain Pyrex sample. We observed that the waveguides written into the Pyrex extended approximately 1 mm into the sample so that a stripe rather than a spot was observed. This is due to the weak absorption of Pyrex at 244 nm. Due to the shape of the mode and the poor contrast between the UV induced refractive index change and that of the background; it was not possible to take an image of the mode profile. However, the positive index change observed, even at depths of up to 1 mm, where the incident power was much lower than that at the surface, indicates that Pyrex is itself a photosensitive glass. Closer examination of the surface of the samples using an alpha-step profileometer showed that there was no measurable expansion or compaction of the surface due to the UV writing. This indicates that the induced index change is not due to localized compaction of the glass or to ablation but may be defect driven as in other silica glasses [4].

In order to achieve better confinement of the mode, an ion-exchanged sample was used as previously described. An example of a typical mode profile obtained is shown in figures 2a and 2b. It was observed that the output was in the fundamental spatial mode, with Gaussian like mode profiles in both guided directions. The spot size ($1/e^2$ intensity diameter) was found to be 6 μm x 14 μm in the vertical and horizontal (UV written) planes respectively. The mode is confined in the vertical plane by the higher index of the ion-exchange layer compared to that of the substrate (1.474 and 1.471 respectively). The ion-exchanged layer may also increase the photosensitivity of the glass although this has yet to be investigated. It has been shown that the addition of silver ions through silver-ion exchange increases the photosensitivity of BGG31 [8] and this may be evidence that potassium ions have a similar effect. The width of the mode is dependent on the UV writing conditions: the spot size, writing speed and incident power. Through optimisation of these parameters it should be possible to produce more confined modes. Improved mode shape and confinement could also be achieved by burying the waveguide through field assisted ion-exchange or by adding a secondary ion-exchanged layer to reduce the refractive index near the surface.

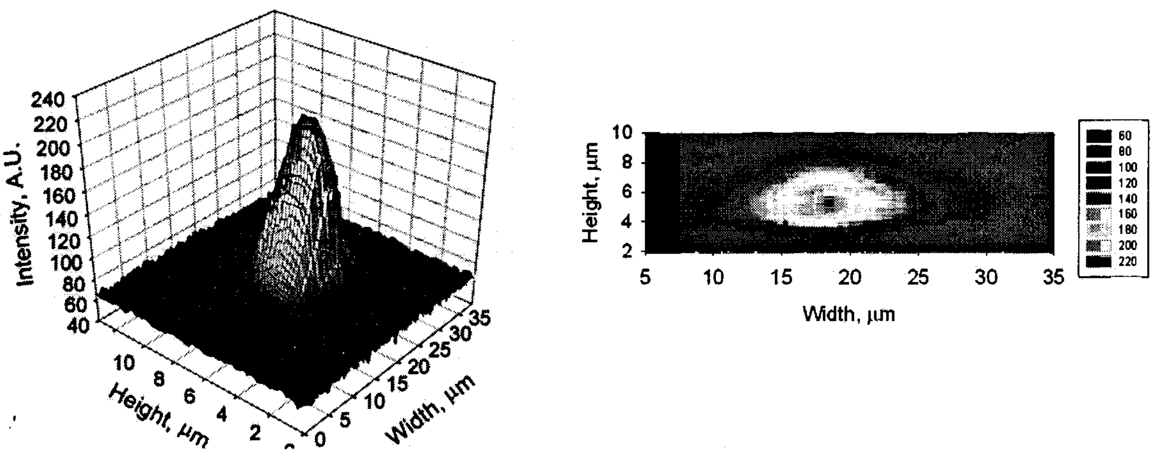

Figure 2. Typical mode profiles obtained from UV written channels in ion-exchanged pyrex; a) 3d mode profile b) 2d intensity plot.

The effective index (n_{eff}) of the guided mode in the UV written channel waveguide was measured using prism coupling giving an n_{eff} of 1.475. A BPM (beam propagation method) computer simulation package was used to calculate the refractive index of the channel, which would give an effective index of 1.475. For this calculation the thickness of the layer was assumed to be 5μm, refractive index of the ion exchanged Pyrex was taken to be 1.474 and the refractive index of Pyrex was 1.471. A value of 1.476 was found for the refractive index of the UV written channels. This gives a change in refractive index of the ion-exchanged layer, due to

UV writing, of 2 x10^{-3}. In order to confirm this measurement, a separate calculation was performed using the BPM software. In this case the width and refractive index of the waveguide were varied until the mode profile calculated was similar to the mode profile measured from the channel. Using this method, a channel width of 4 μm and a refractive index of 1.476 was obtained. This is in good agreement with the value measured by prism coupling.

Conclusions

In conclusion we have demonstrated that Pyrex is a photosensitive glass and that a positive refractive index change can be induced by irradiation at 244 nm. We have shown that by introducing an ion-exchange layer, channel waveguides with mode dimensions of 6 μm x 14 μm can be written. Further work is in progress to measure the losses and to optimise the writing conditions. It is expected that these results will lead to better mode confinement and more complex waveguide structures in ion-exchanged Pyrex glass. The ability to incorporate rare-earth ions, such as Erbium and Ytterbium, into the bulk glass also provides a route towards efficient low-cost integrated channel waveguide laser devices [9].

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