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Self-written channels in ion-exchanged waveguides; experiment and modelling of photosensitivity

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We demonstrate that a channel waveguide can be self-written in ion-exchanged Nd-doped glass. The initial stages of the waveguide evolution are used to develop a phenomenological model of the photosensitivity process occurring within this material.

If light diffracting through a photosensitive material increases the refractive index significantly, the diffraction of the beam can be overcome and a self-written waveguide starts to form [1, 2]. We report on the first observations of photosensitivity in potassium ion-exchanged Nd-doped (1.5-wt%) Bk7 borosilicate glass, and create self-written waveguides in this material. Gratings have previously been written in a similar material (ion-exchanged silica) where index changes in the order of 10^{-5} were reported [4].

Here an argon-ion Gaussian laser beam at 457 nm is focused down to a FWHM of 7μm at the input face of a 14 mm long planar waveguide formed by a 2μm deep ion-exchanged layer. Fig 1 shows that over time the outcoming beam narrows and becomes more intense due to the increase in refractive index induced by the propagating light. Note that more than half of the change happens in the first hour, with the most significant effects occurring in the centre of the beam. We find that the ion-exchanged layer used in our experiments is homogeneous, which makes the experiment reproducible. In addition, it is straightforward to locate the channel after the exposure, and we observe that the index change is permanent and subsequently can be used to guide light at 633 nm. For these reasons, the ion-exchanged waveguide layer promises to be an excellent host material for self-writing.

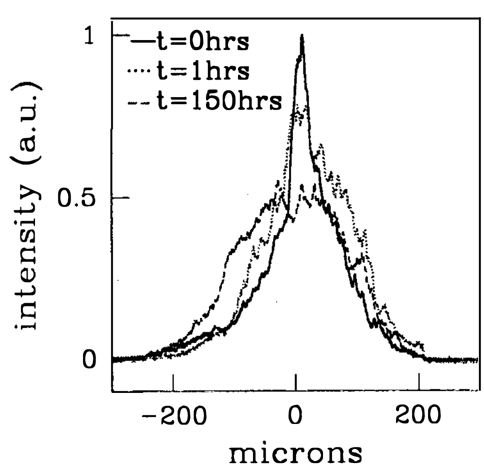

Fig. 1. Beam shapes emerging from the layer during the evolution with a writing beam power of 20 mW.

To investigate the photosensitivity in this material, we explore how the initial speed of the waveguide evolution depends on the writing power (for a given beam width). The points in Fig 2 show the observed output beam width after one hour exposure time. Unsurprisingly the process proceeds faster at higher powers, and in addition a threshold in writing power is evident at approximately 5 mW. This is consistent with the above shown experiment where the greatest changes occur at positions of high intensity (I). Previous theoretical work on self-writing [3] uses a simple phenomenological model for the refractive index change. Numerical simulations can be made to agree well with experiment when this model is adapted to incorporate a power-dependent threshold, and so the speed of the photosensitive index change becomes:

$$\frac{\partial \Delta n}{\partial T} = I^p \left(1 - \frac{\Delta n}{\Delta n_s}\right) \quad P \geq P_{thres}. \tag{1}$$

No change occurs for powers below the threshold. The simulation results are fitted to the experiment via the unknown parameters Δn_s (the saturation refractive index change) and p. The choice Δn_s=3.1×10^{-5} and p=2 (corresponding to a two-photon absorption process) gives excellent agreement for the initial speed of the process (see Fig 2). In addition, this choice predicts the total change in width that occurs during the full waveguide evolution well.

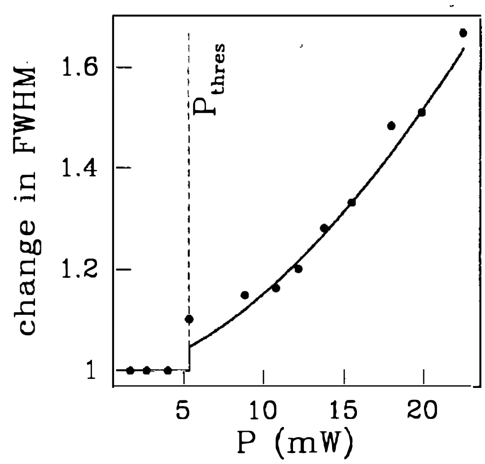

Fig. 2. The speed of the process at different writing powers after one hour: the change in FWHM reflects the index change, points represent experimental results and the line shows the numerical calculations.

We create self-written channel waveguides in potassium ion-exchanged Nd-doped Bk7 borosilicate glass. This material exhibits a threshold in photosensitivity that can be exploited to characterize the waveguide properties after the exposure. At the writing wavelength, strong red luminescence is observed, which gives additional information about the structure of the waveguide. As this material is homogeneous and our numerical simulations describe the process well, it is a promising candidate for further development of self-writing processes in the planar geometry.

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