Simultaneous Poling and Planar Waveguide Fabrication in Glasses

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Abstract: Fabrication of buried planar waveguides with 2nd order nonlinear susceptibility in the upper cladding is carried out in soda-lime and BK7 glass substrates in one step by thermal poling.
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1. Introduction

Multicomponent glasses are very versatile materials for integrated optics applications. For instance efficient Yb/Er energy transfer and high gain for optical amplification [1], high photosensitivity for grating writing [2], and high $\chi^{(3)}$ for all-optical switching [3], have all been demonstrated in silicate glasses. The latter reveals a potential for realization of high $\chi^{(2)}$ electro-optic waveguides through poling. In principle, all these phenomena may be combined in one substrate in which waveguides can be fabricated to realize a low-cost multifunctional integrated optical technology. In the last two decades a number of techniques, generally known as poling, have been reported to introduce a 2nd order nonlinear susceptibility, $\chi^{(2)}$, into glasses [4-13]. In particular thermal poling of sodium-bearing glasses yields regions with induced 2nd order nonlinearity, $\chi^{(2)}$, through a "frozen-in" space-charge electric field acting on the inherent third-order nonlinearity, $\chi^{(3)}$. Initially demonstrated in silica glass (Herasil) which has a Na^+ ion concentration of tens of ppm [4], thermal poling was also proven to be effective in alkali-rich glasses, where the Na^+ concentration is up to six orders of magnitude higher than that in Herasil. These included Pyrex [5], soda lime silicate [10], BK7 [11], sodium niobium borophosphate [12] and potassium niobium silicate [13]. The values of $\chi^{(2)}$ of 5.0 pmV^{-1} and 3.8 pmV^{-1} obtained in [12] and [13] respectively yields the potential for practical electrooptic modulation in waveguides made in alkali-rich glasses. In this work the simultaneous formation of optical waveguides with buried cores [14] and 2nd order nonlinear susceptibility, $\chi^{(2)}$, in the upper cladding by thermal poling of alkali-rich silicate glasses such as soda lime and BK7 is described.

2. Experimental

The fabrication of buried planar waveguides by a constant-current thermal poling procedure in soda-lime (Fisher premium) and BK7 glasses is performed as described in [14]. Samples measuring 25 mm by 25 mm by 1 mm thick were cleaned, and circular 7-mm-diameter aluminum electrodes of thickness 400 nm were deposited centrally on both faces by vacuum evaporation through a shadow mask. To apply an electric field at elevated temperature we placed each sample in a holder with the cathode pressed onto a silicon wafer, and a high-voltage supply was connected between the anode and the silicon wafer. The assembly was placed in a vacuum chamber with a radiant heater, the chamber was pumped to below 3×10^{-6} mbar, and the samples was heated until it reached equilibrium at the desired temperature. The high-voltage supply was then turned on, and a variable voltage was applied so that a constant external current of 20 μA was maintained for the process time. Each sample was cooled to room temperature with a constant voltage applied equal to that achieved at the end of the poling process. The external currents fell to zero after approximately 2 min of cooling time. The temperature, current, and applied voltage were continuously recorded from the application of the initial voltage until the samples reached room temperature. The soda-lime and BK7 samples were processed at 200 °C for 120 min and at 300 °C for 180 min, respectively. The voltage applied to maintain a constant current of 20 μA rose approximately linearly over the entire duration of the poling process at elevated temperature, as reported in [10, 13, 14]; the applied voltage varied from 90 V to 2.5 kV for soda-lime glass and from 150 V to 4.1 kV for BK7 glass. The electrodes were then removed by use of a commercial aluminum etchant and waveguide modes were observed in the region immediately below the removed anodes using the standard prism coupling technique, as reported in [14]. To determine the relative positions of the guiding and of the nonlinear regions the samples were diced and end polished to allow near-field measurements of the modal profiles and 2nd harmonic scanning [15] of the cross-section of the poled glass region underneath the removed anode. Light from a He–Ne laser at a wavelength of 633 nm was coupled into the waveguides using a monomode optical fiber, and the modal intensity profiles of the waveguide were measured by imaging onto a CCD camera with a 63× objective. The position of the substrate surface was determined by imaging the illuminated end face of the waveguide with the same apparatus. These measurements were calibrated with a micrometric graticule replacing the waveguide edge. Unpolarized mode profiles obtained using this imaging apparatus are shown in Fig. 1 and Fig. 2 for BK7 and soda-lime samples, respectively, with the scales and the absolute positions of the depth axis aligned with an accuracy of ±0.25 μm, showing that the waveguide mode is buried substantially beneath the substrate surface. A focused Q-switched, mode locked Nd-YAG laser producing a high peak power output with a wavelength of 1.064μm was used for 2nd harmonic generation. The nonlinear region was detected by scanning the cross section of the samples with the focused beam and measuring the reflected 2nd harmonic signal as described in [15]. Fig. 1 and Fig. 2 also show the 2nd harmonic (SH) scanning intensity profiles which show that a 2nd order nonlinear region has been introduced between the surface and the guiding region in the upper cladding of the waveguide.

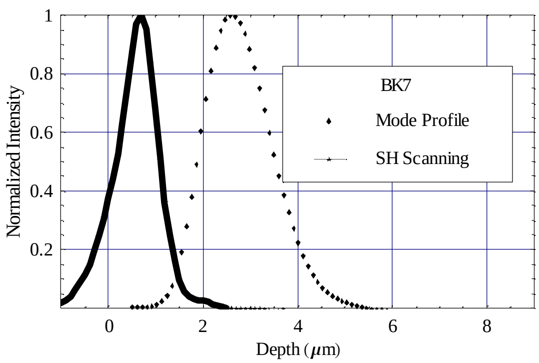

Fig 1. Mode profile and SH profile of a BK7 sample.

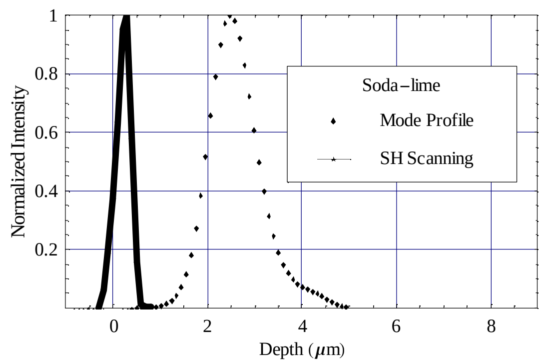

Fig 2. Mode profile and SH profile of a soda-lime sample.

3. Conclusion

We have shown that buried planar waveguides with a 2nd order nonlinearity in its upper cladding can be fabricated in one step by a thermal poling procedure. The waveguides are formed by the redistribution of the cations from the surface of the glass to a buried region by differential ionic drift as described in [14]. The resultant electric field due to the depletion of ions from the surface results in a 2nd order nonlinearity in the surface cladding layer. Further experiments are to be carried out for a better characterization of the waveguides and of the nonlinearities obtained and in order to investigate the possibility of electrooptic modulation and 2nd harmonic generation in the waveguide modes.

4. References

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