Nonlinear Optical Waveguide Devices Based on Femtosecond Laser Direct Writing and Thermal Poling in Bulk Fused Silica

Guangyu Li and Kim A. Winick
Department of Electrical Engineering and Computer Science, University of Michigan, 1301 Beal Ave., Ann Arbor, Michigan 48109
guangyul@engin.umich.edu, winick@eecs.umich.edu

Ali Said, Mark Dugan, and Philippe Bado
Translume Inc. 655 Phoenix Drive, Ann Arbor, MI 48108
alisaid@translume.com, markdugan@translume.com, philippebado@translume.com

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Abstract: Thermal poling, together with femtosecond laser writing, is used for the first time to demonstrate an electro-optic waveguide modulator and SHG in glass. A novel technique to produce quasi-phase-matched structures in glass is also reported.
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Electro-optic (EO) [1] and nonlinear optical devices [2] have been previously demonstrated in glass using the thermal poling technique [3]. Similar waveguide devices in bulk fused silica have yet to be reported because standard fabrication methods cannot be used to fabricate the necessary waveguides. Higher $\chi^{(2)}$ values have, however, been obtained in bulk fused silica, thus making the use of bulk fused silica an attractive possibility for waveguide devices. We report for the first time the use of femtosecond laser direct writing [4], together with thermal poling, to demonstrate a waveguide electro-optic (EO) modulator in bulk fused silica. A simple technique is also reported for inducing quasi-phase matched (QPM) waveguide structures in bulk fused silica using femtosecond laser writing, thermal poling and an electron-beam deposition system.

A waveguide Mach-Zehnder interferometer (MZI) structure, as illustrated in Fig.1, was directly written in Herasil fused silica substrate using a femtosecond laser operating at 790 nm with a 238 kHz repetition rate. The MZI arms were written close to the surface in order to maximize the spatial overlap between the waveguide mode and the thin nonlinear layer induced by thermal poling. After waveguide writing, the substrate was thermally poled at 275 °C for 10 minutes using an applied voltage of 4 kV. Gold electrodes were patterned along one arm of the MZI. TE-polarized light from an ASE source, operating in the vicinity of 1.55 µm, was coupled into the MZI, and the output signal was measured as a function of the applied DC electrode voltage using an optical spectrum analyzer. The results are shown in Fig. 2. An average spectral shift of 1 nm in the output spectrum was achieved with an applied voltage of 400 V. Based on this measurement, the effective EO coefficient was computed to be 0.17 pm/V. We believe that this is the largest value reported to date for a thermally poled waveguide device.

A bulk fused silica substrate was thermally poled in the same manner as described above and coated with a 3 µm thick layer of photoresist. A deep 43µm period grating was etched into a 200 µm thick silicon wafer, and the wafer was subsequently mounted on top of the poled glass sample to serve as a mask. The combined piece was placed on a sample holder inside the chamber of an electron-beam evaporator. A standard deposition run was made after which the mask and PR were removed. A subsequent HF etch step, as shown in Fig. 3, indicated that the poled region was periodically erased. Using this technique, we achieved QPM SHG in femtosecond laser written waveguides and demonstrated thermal tuning of the phase matching condition at 1.06 µm. These results will be described as will the method of selective erasure in the poled regions [5].

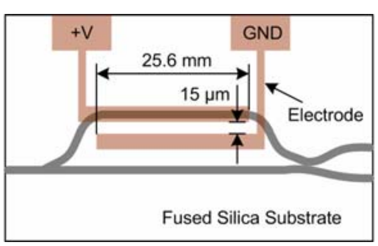

Fig.1. Illustration of the MZI-type EO modulator.

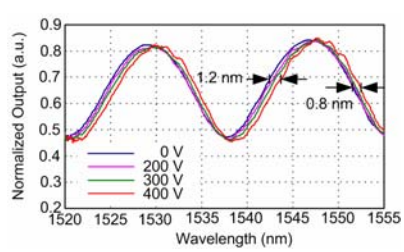

Fig.2. Spectral response at different applied voltages.

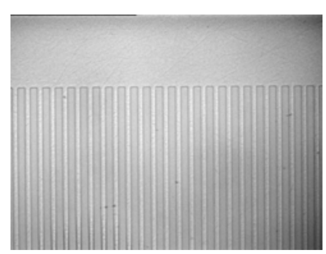

Fig. 3. Etching revealed domain of QPM grating with period of 43 µm.

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