Local electro-optic coefficient enhancement in $LiNbO_3$ channel waveguides by domain engineering

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Abstract: UV laser-induced poling-inhibition produces opposite domains in $LiNbO_3$ which overlap significantly with waveguide modes. A 55% enhancement of the effective electro-optic coefficient was observed in such domain-engineered waveguides.

Lithium niobate (LN) is widely used in the photonics industry due to its high 2nd order optical nonlinearity and wide transparency window. Its significant electro-optic (EO) response also enables the fabrication of low-voltage operation, high speed integrated optical modulators that are routinely used in optical telecommunication and integrated optics. Channel waveguides are the basic elements of integrated optical circuits which are commonly fabricated by Ti-indiffusion or proton exchange in LN [1]. Recently, a UV laser direct writing method for channel waveguide fabrication has been proposed [2] along with detailed characterization [3,4]. Here we report the enhancement of the electro-optic response of these UV laser-written LN waveguides as a result of a post-poling process. More specifically a 55% increase of the r_{33} coefficient was observed compared to the bulk material properties in UV-written LN waveguides that has been subjected to poling inhibition [5]. Poling inhibition produces opposite ferroelectric domains which are only a few microns deep. These domains are formed with a high degree of spatial overlap with the UV written tracks which are responsible for the waveguide formation, and they overlap significantly with the propagating waveguide mode as is illustrated schematically in Fig. 1. Due to the polarization-selective transmission in the UV-written waveguides only the r_{33} coefficient could be investigated.

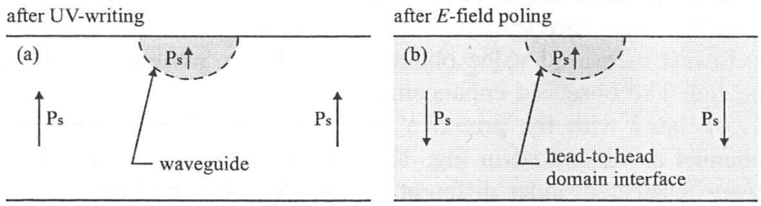

Fig. 1. Schematic of the cross section of a) a UV-written waveguide on a single domain substrate, and b) the tail-to-tail domain arrangement overlapping with the waveguide after poling-inhibition.

Experiment

Optical channel waveguides were fabricated by direct UV laser writing on the +*z* face of a 0.5mm-thick, *z*-cut undoped congruent lithium niobate substrate by scanning a focused c.w. frequency-doubled argon ion laser (244nm) across the surface of the crystal as described in [4]. The focused beam diameter was ~ 7 – 8μm, the writing speed 0.1mm/s, and the writing power 30 – 45mW. The sample was subsequently subjected to electric field poling using an externally applied electric field (~19.5 kV/mm) which resulted in local poling-inhibited domains of limited depth that overlap with the waveguides as shown in Fig. 1b [5,6].

The electro-optic response was evaluated interferometrically by placing the waveguides in one branch of a Mach-Zehnder interferometer as described in [3]. Both *z*-faces of the lithium niobate waveguide substrate were covered by a thin (20nm) gold film in order to apply an electric field along the z-axis for the evaluation of the r_{33} coefficient. The experimental setup which was used for the measurements is schematically illustrated in Fig. 2.

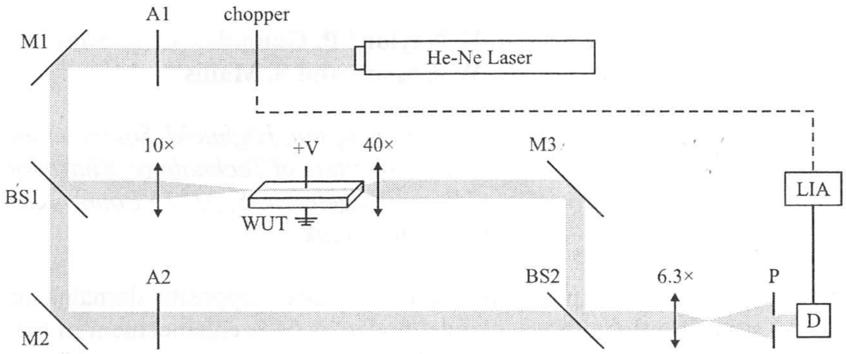

Fig. 2. Experimental setup for the EO coefficient measurement of the waveguide. (A1, A2 = optical attenuator; M1, M2, M3 = mirrors; BS1, BS2 = beam splitter; WUT = waveguide under test; V = applied voltage; P = pinhole; D = detector; LIA = lock-in amplifier.)

The EO phase shift in the waveguide sample was measured by monitoring the movement of the interference fringes in the output of the interferometer as a function of the voltage applied to the sample. The half-wave voltage V_π was measured in this way and the r_{33} coefficient was derived using the expression $r_{33} = \lambda d n_{\text{eff}}^{-3} L^{-1} V_\pi^{-1}$ [3], where λ is the operating wavelength, in our case 632.8nm, d is the substrate thickness (0.5mm), n_{eff} is the effective refractive index of the waveguide, and L is the length of the electrode-covered waveguide section. A set of titanium in-diffused waveguides was used as a control sample to provide a background reference measurement of the r_{33} coefficient for a bulk sample.

Results and discussion

The measured values of the EO coefficient (r_{33}) in poling-inhibited samples proved to be systematically higher than the bulk value. The highest measured value of the r_{33} in the poling-inhibited waveguides was 48pm/V which corresponds to an enhancement of 55% compared to the bulk value (31pm/V), while the lowest measured value obtained with lower writing power (32pm/V) is about the same as bulk as expected. The observed enhancement in the value of the EO coefficient is attributed to the strain which is associated with the presence of a tail-to-tail domain boundary that surrounds the optical waveguide channel as illustrated in Fig. 1b. The enhancement of the EO coefficient varied for waveguides which were fabricated under different UV irradiation conditions. The irradiation conditions affect both the waveguide mode confinement and the depth of the poling-inhibited domains. This suggests that the enhancement can be further optimized and even applied to other waveguide systems such as titanium in-diffused and proton exchanged channel guides.

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