

Enhancement of Effective Electro-optic Coefficient in Domain Engineered UV-written Waveguides in LiNbO₃

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Abstract: UV laser-induced poling-inhibition produces inverted domains in LiNbO₃ which overlap significantly with waveguide modes. We have observed a 26% enhancement of the effective electro-optic coefficient in such domain-engineered waveguides.

OCIS codes: (130.3730) Lithium niobate; (130.0130) Integrated optics; (230.0230) Optical devices

1. Introduction

Lithium niobate crystal (LN) is a very important technological material which is widely used by the photonics industry today due to its significant optical nonlinearity and wide transparent window [1]. It also shows a significant electro-optic (EO) response which enables the fabrication of low-voltage operation, high speed integrated optical modulators that are routinely used in optical telecommunication and integrated optics [1]. For the fabrication of integrated optical circuits in this material it is necessary to produce channel waveguides which are commonly fabricated by Ti-indiffusion [1] or proton exchange [1]. However, a UV laser direct writing method for the fabrication of optical channel waveguides has been proposed recently [2]. The fabrication details and the electro-optic behavior of these waveguides have been reported in [3,4].

Here we report on the enhancement of the electro-optic response of UV laser-written LN waveguides as a result of a post-poling process. More specifically we have observed a 26% increase of the r_{33} coefficient compared to the bulk in UV-written LN waveguides that has been subjected to poling inhibition [5]. Poling inhibition produces inverted ferroelectric domains which are only a few microns deep. These domains are formed exactly in the same place as 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.

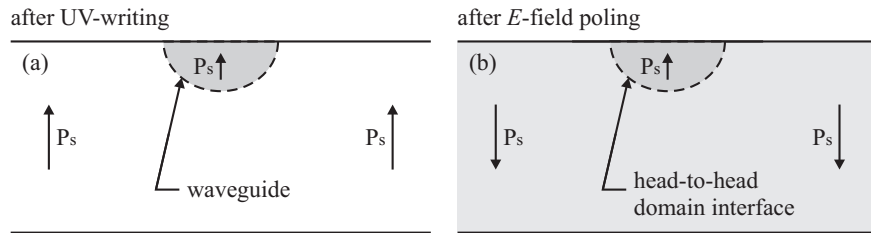


Fig. 1. Schematic of the cross section of a) a UV-written waveguide on a single domain substrate, and b) the head-to-head domain arrangement overlapping with the waveguide after poling-inhibition.

2. 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 $\sim 7 - 8\mu\text{m}$, the writing speed was 0.1mm/s, and the writing power was 45mW. The sample was subsequently subjected to electric field poling (EFP) using an externally applied electric field ($\sim 19.5\text{ kV/mm}$) 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.

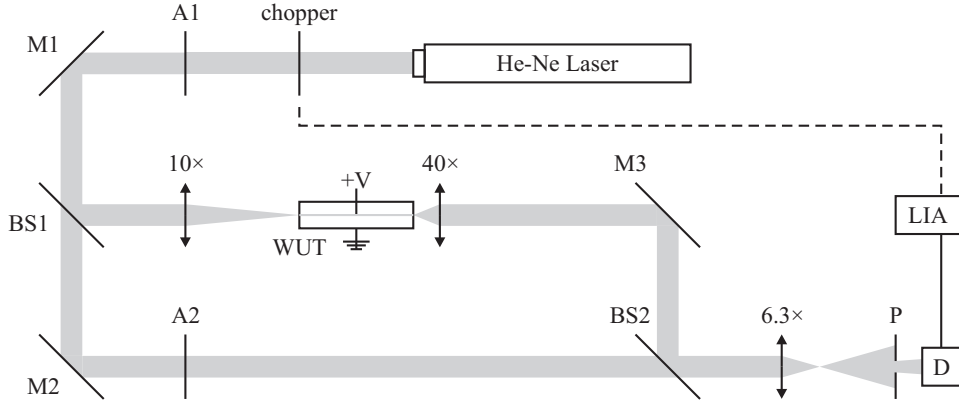


Fig. 2. Experimental setup for the EO coefficient measurement of the waveguide. (A1, A2 = optical attenuator; M1, M2, M3 = mirrors; BS1, BS2 = beam splitter; WUT = waveguide under test; V = applied voltage; P1, P2 = pinhole; D = detector; LIA = lock-in amplifier.)

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 $r_{33} = \lambda dn_{eff}^{-3} L^{-1} V_\pi^{-1}$ [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 the background measurement of the bulk for the r_{33} coefficient.

3. Results and discussion

The measured values of the electro-optic coefficient (r_{33}) in the poling-inhibited samples proved to be systematically higher than the value obtained with the control sample of unpoled titanium in-diffused waveguides which was 35pm/V. The highest value of the r_{33} that was measured in the poling-inhibited waveguides was 44.2pm/V which corresponds to an enhancement of 26% compared to reference sample, therefore the bulk. The observed enhancement in the value of the EO coefficient is attributed to the strain which is associated with the presence of a head-to-head 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.

4. Conclusion

In conclusion, a 26% enhancement of the r_{33} coefficient in UV-written waveguides has been observed in UV laser written lithium niobate waveguides which have been domain engineered by inhibition of poling. The poling inhibition process produces an inverted domain that overlaps with the waveguide mode and an associated domain wall that surrounds the optical waveguide. The strain across the head-to-head domain wall is suggested here to be responsible for the observed enhancement of the EO coefficient.

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