Electro-Optic Coefficient Enhancement in Poled $LiNbO_3$ Waveguides

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Lithium niobate crystals (LN) show a significant electro-optic (EO) response which contributes to the fabrication of low-voltage operation, high speed integrated optical modulators routinely used in optical telecommunication and integrated optics [1]. A UV laser direct writing method for the fabrication of optical channel waveguides has been proposed and characterized recently [2–4]. Here we report on the enhancement of the electro-optic response of these 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 LN waveguides, fabricated by direct UV writing, that have 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.

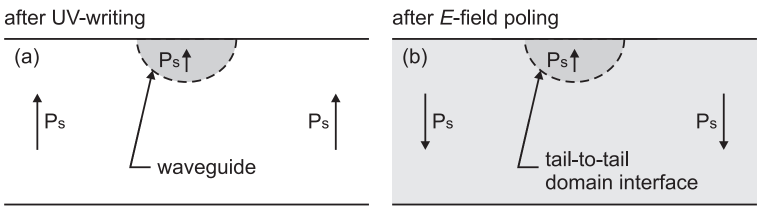

Fig. 1 Schematic of the cross section of a) a UV-written waveguide on a single domain substrate, and b) the tail-to-tail domain arrangement overlapping with the waveguide after poling-inhibition.

Optical channel waveguides were fabricated by direct UV laser focused writing on the +z face of a z-cut undoped congruent LN substrate [4]. 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 [3]. 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. 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 35 pm/V. The highest value of the r_{33} coefficient that was measured in the poling-inhibited waveguides was 44.2 pm/V, which corresponds to an enhancement of 26% as compared to the reference Ti indiffused waveguide sample. 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.

References

[1] K. K. Wong, *Properties of Lithium Niobate* (The Institution of Engineering and Technology, 2002).

[2] S. Mailis, C. Riziotis, I. T. Wellington, P. G. R. Smith, C. B. E. Gawith and R. W. Eason, “Direct UV writing of channel waveguides in congruent lithium niobate single crystals,” Opt. Lett. **28**, 1433-1435 (2003).

[3] C. L. Sones, P. Ganguly, Y. J. Ying, F. Johann, E. Soergel, R. W. Eason and S. Mailis, “Spectral and electro-optic response of UV-written waveguides in $LiNbO_3$ single crystals,” Opt. Express **17**, 23755-23764 (2009).

[4] P. Ganguly, C. L. Sones, Y. J. Ying, H. Steigerwald, K. Buse, E. Soergel, R. W. Eason, S. Mailis, “Determination of refractive indices from the mode profiles of UV-written channel waveguides in $LiNbO_3$-crystals for optimization of writing conditions,” IEEE Journal of Lightwave Technology **27**, 3490-3497 2009

[5] C. L. Sones, A. C. Muir, Y. J. Ying, S. Mailis, R. W. Eason, T. Jungk, A. Hoffmann and E. Soergel, “Precision nanoscale domain engineering of lithium niobate via UV laser induced inhibition of poling,” Appl. Phys. Lett. **92**, 072905 (2008).

[6] C. L. Sones, P. Ganguly, Y. J. Ying, E. Soergel, R. W. Eason and S. Mailis, “Poling-inhibited ridge waveguides in lithium niobate crystals,” Appl. Phys. Lett. **97**, 151112 (2010).