Light assisted poling and the photorefractive effect in lithium niobate

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Abstract: *Light assisted poling (LAP) in $LiNbO_3$ is examined under the "light" of the photorefractive effect for both congruently melting and MgO doped crystals. Experimental results suggest that a photo-induced space charge is responsible for the effect.*

Introduction

Light assisted poling (LAP) is a method for ferroelectric domain engineering in lithium niobate (LN) where intense light, often from a laser source, is used to reduce (or increase) the coercive field locally hence resulting in a preferential domain inversion upon the application of an external electric field [1-4]. This method has attracted some interest recently due to the large coercive field reductions, up to two orders of magnitude (for MgO doped LN) as reported in the literature [5].

Latent-LAP: In virtually all of the reported LAP experiments the LN crystals are subjected to simultaneous irradiation and electric field application. However, it has been recently reported that the effect can also occur in a latent fashion in congruently melting LN crystals [6]. In latent-LAP the application of the external electric field is delayed with respect to the irradiation. Surprisingly, the coercive field reduction in the latent case was even higher (62%) compared to ordinary LAP (40%) for the same crystals and laser source. The effect has been seen to fade with time as revealed by measurements of the domain inverted area as a function of the delay between illumination and subsequent electric field (E-field) application which are presented in the plot shown in figure 1. The experimental points correspond to the area of latent-LAP domains which are produced with different illuminating laser intensities and an external E-field of 8 kV/mm. While the absolute domain-inverted area is seen to be a function of the illuminating intensity the dynamics of the inverted domain area reduction with increasing time delay between illumination and E-field application remain the same. Latent LAP was observed for time delays up to ~11 hrs however, the quality of the resulting domains deteriorate and the measurements of the poled area become inaccurate.

The latency of LAP combined with the decay of the coercive field reduction in congruently melting LN is reminiscent of the behavior of the space charge field in the photorefractive effect which is formed under the influence of optical irradiation and which decays slowly (in the case of congruently melting LN) in the dark or under the influence of uniform illumination. Furthermore, the refractive index change which is associated with the photo-induced space charge field provides an excellent tool for monitoring the dynamics of the space charge distribution and the associated fields.

Experiments and discussion

A straightforward interferometric setup was used for grating recording in various LN crystals. An ultrashort-pulse laser delivering 150 fs pulses at 250 kHz and at a wavelength of 400 nm was used for the grating recording mainly due to the plethora of relevant LAP data (both simultaneous and latent) already existing and available for comparison. The use of an ultrafast system introduces the need for spatial and temporal overlap of the laser pulses. To this end one of the interferometer's paths was adjustable in order to achieve zero time delay between the two interfering pulses within the grating recording volume. The diffracted HeNe laser beam, incident at the Bragg angle, was used for the real-time monitoring of the photorefractive grating recording and decay.

Several grating recording/decay curves were obtained for a variety of crystals and at different configurations regarding the direction of the grating vector (**K)** with respect to various crystal axes. The decay rate of the photorefractive gratings having their **K -** vector along the z-axis of the crystal was found to be the same as the corresponding rates for grating with **K** along the y-axis. However; the diffraction efficiency when **K** is along the z-axis was much higher and was adopted in some cases where low probe laser power was necessary for improving the signal to noise ratio. Interestingly, the HeNe probe beam was observed to expedite the decay of the grating. The influence of the probe beam power and wavelength on the grating decay rate was also investigated and the results will be presented.

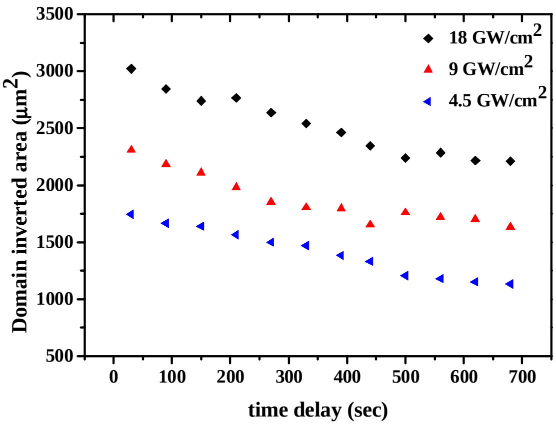

Figure 1. Latent-LAP domain inverted area, for different laser intensities, as a function of the time delay between laser exposure and E-field application.

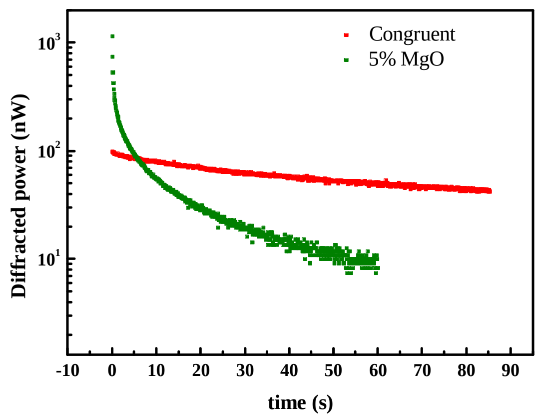

Figure 2. Photorefractive grating decay in congruently melting (red trace) and 5% MgO doped (green trace) LN crystals for the same HeNe probe laser power (3.5 mW)

A plot of the decay of a photorefractive grating which was recorded, under identical conditions, in congruently melting LN and 5% MgO doped crystals of the same thickness is shown in Figure 2. A straight comparison of the two decay curves reveals that a) the grating in MgO doped crystal decays much faster that the congruent one and b) the grating saturation level (represented by the first point in each curve) is one order of magnitude higher in the MgO doped crystal.

The large dark conductivity in MgO doped crystals is responsible for the fast decay of any photo-induced space charge field which explains the absence of LAP latency in MgO doped crystals while the slow decay observed in congruently melting crystals justifies the observed LAP latency in these crystals. Additionally the difference in the value of the saturated diffraction efficiency reflects the level of the coercive field reduction for each crystal in LAP. Both observations suggest a strong link between LAP (both normal and latent) and the photo-induced space charge which is responsible for the photorefractive grating.

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