Ultra-short light-pulse assisted electric field domain engineering of lithium niobate

C.L. Sones, C.E. Valdivia, S.Mailis, R.W. Eason
Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, SO17 1BJ, U.K.
E-mail: cls@orc.soton.ac.uk

While several techniques to achieve ferroelectric domain inversion in materials such as lithium niobate (LN) and lithium tantalate (LT) have been successfully demonstrated over the past years, even the 'best' established technique of electric field-induced domain inversion (E-field poling) fails when domain inversion at periodicities of a few microns and below are desired. To overcome the limitations associated with electric field poling, we have been investigating the feasibility of an alternative route, which we refer to as light-assisted E-field poling (LAP). This approach takes advantage of the simultaneous interaction of an intense continuous wave (cw) visible laser light to engineer domains in an E-field biased ferroelectric LN crystal. A few light-assisted domain manipulation experiments, using an ultraviolet light-induced change in the coercive field of the illuminated LN crystal to transfer a patterned light distribution into an equivalent domain structure in bulk crystals have also been reported for lithium niobate. With an end goal of tailoring the shape, size and depth of the light-assisted periodic domain structures in doped and undoped LN, we have been investigating the use an ultra-short laser source instead of a cw laser source used in our earlier LAP experiments. This paper will report the results of our attempts to demonstrate the practicality of an ultra-short LAP technique that employs intense ultra-short laser light pulses of ~130 fs from the near-ultraviolet (305 nm) to near-infrared (800 nm) in conjunction with a dc field to induce periodic domain inversion in doped and undoped LN.

Compared to the reduction achieved in the cw LAP case, the use of ultra-short laser pulses have allowed a comparatively greater reduction of the field required to nucleate domains in undoped congruent LN to 41%, and in 5-mol% Mg-doped congruent LN to 98%. The reduction for the latter, doped above the optical damage threshold (and hence less susceptible to photorefractive damage), meant that domain inversion could be induced with the crystal biased to significantly low fields of about 100 V/mm.

Additionally, illumination of an unbiased crystal (V=0) by a fs laser can induce a coercive field reduction. For this case of "latent ultra-short LAP", a ~30% reduction of the coercive field is observed long after the illumination of an undoped congruent LN crystals.

Periodic domain inversion was achieved by imprinting patterned light on the crystal faces generated by the use of phase masks or an amplitude mask imaged on, or directly in contact with, the crystal face. The smallest illumination period attempted using a phase mask was 5.25 μm, and this was successfully transferred into a corresponding domain pattern in a Mg-doped LN crystal.

The ultra-short LAP poling technique also resulted in the formation of features with arbitrarily shaped domain walls that do not necessarily conform to the allowed crystallographic orientations, an advantage that would be desired for certain applications.

As the electric field required for achieving domain inversion in Mg-doped LN is considerably reduced by the ultra-short LAP technique, we have also attempted to extend its applicability for the fabrication of periodic domain structures in thicker crystals (5 mm) that hold greater promise for high power non-linear applications. We have been able to produce domains that extend through the entire thickness of the crystal. However we are still experimenting on the method to form the much desired periodic domains through the bulk of the crystal.

We have also been using the ultra-short LAP technique to study the effect of light on the field required to induce domain inversion in a few other doped (Zn, Fe) lithium niobate crystals and will report on them.

References