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Influence of different concentrations of Mg on the photorefractive gain in $LiNbO_3$

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Abstract: Dependence of photorefractive response on c-axis orientation for $LiNbO_3$ at several magnesium contents has been observed. When c-axis is perpendicular to the incidence plane the optical damage persists even above threshold and diminished below threshold.

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1. Introduction

The photorefractive effect can modify in electro-optic materials, generally under long-time exposition of laser light, the optimum conditions for anharmonic-oscillator-type nonlinear optical applications[1], such as second harmonic generation, self-focusing, and optical bistability between other novel effects. Doping with In, Zn, or Mg the photorefractive response of lithium niobate almost vanishes, giving the opportunity of taking advantage of its Lorentz-oscillator-type nonlinear optical properties[2]. In the particular case of Mg: $LiNbO_3$ exist a threshold in Mg content for which the photorefractive effect is almost destroyed. This threshold value is around 4.6 mol % MgO in congruent melt[3]. In this work, we have estimated the range comprising the threshold concentration of Mg incorporated in $LiNbO_3$. In addition, photorefractive gains at 532 nm for six $LiNbO_3$ samples at two c-axis orientations with different Mg content levels, using the two-wave coupling technique have been obtained. An outstanding anisotropic behavior of photorefractive inhibition against polar axis orientation is observed.

2. Experimental procedure

In this work we investigated six single $LiNbO_3$ crystals with different Mg concentrations acquired from a commercial supplier. These samples were grown by the conventional Czochralski method in air. They were pulled along the c-axis and so the polar axis was parallel to pulling direction. Atomic absorption spectroscopy was used to measure the amount of Mg incorporated in each crystal. Photorefractive gain as a function of fringe spacing using the two-wave mixing technique in co-propagation configuration was also obtained. The laser light polarization was vertical, i.e. perpendicular to the incident plane. Two crystal orientations were considered: I) c-axis of sample parallel and II) perpendicular to the incidence plane of beams which are referred as case I, and case II respectively. A continuous-wave Nd: YVO_4 laser operating at 532 nm with a coherent length ~10 cm and an output optical intensity of 0.69 W/cm^2 was used.

According to the two-wave coupling setup the photorefractive gain involving the incidence angle and/or grating spacing is given by

$$\Gamma = \frac{2\pi n_{o,e}^3 r_{13}}{\lambda \cos\theta} E_q \sqrt{\frac{E_D^2 + E_{PH}^2}{\left(E_D + E_q\right)^2}} \tag{1}$$

where n_0 and n_e are the ordinary and extraordinary refractive indices for case I and II respectively, r_{13} is the effective linear electro-optic coefficient, λ is the light wavelength, θ is the angle between one of the beams and the incidence face normal, $E_q=qN^+\Lambda/2\pi\varepsilon\varepsilon_0$ is the trap-limited saturation field, $E_D=2\pi K_B T/q\Lambda$ is the diffusion field and $E_{PH}=p\gamma_R N_A/q\mu s(N_D-N_A)$ is the bulk photovoltaic electric field. As is usual, q is the elementary charge, N_A is the density of acceptors, N_D is the density of donors, $N^+= N_A(N_D-N_A)/N_D$ is called the effective trap density, Λ is the grating spacing, ε is the dielectric constant of material, ε_0 is the vacuum permittivity, K_B is the Boltzmann constant, T is the absolute temperature, p is an equivalent photovoltaic constant, γ_R is the recombination constant, μ is the charge mobility, and s is the cross section for photoexcitation. Each parameter of the right-hand side of equation for E_{PH} is usually considered a constant.

3. Results

A large dependence of photorefractive effect on c-axis orientation for Mg: $LiNbO_3$ has been observed. Despite that Mg content is above threshold, the photorefractive response of this host persists if the c-axis is perpendicular to the incidence plane of beams in the two-wave mixing setup, whereas an optical-damage resistance greatly increases if Mg content is below threshold. Accordingly, this suggests that, besides photorefractive applications, Mg: $LiNbO_3$ can be used in anharmonic-oscillator-type nonlinear optical phenomena, in which the photorefractive response can be inhibited due to its anisotropic photorefraction only by selecting a suitable crystal orientation. Lastly, it has been proposed one model which takes into account a dependence of photovoltaic electric field on grating spacing, and an estimation of bulk photovoltaic field has also been carried out.

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5. References

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