Photorefractive nonlinear propagation of single beams in undoped $LiNbO_3$: Self-defocusing and beam break-up

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Abstract: Beam propagation in photorefractive $LiNbO_3$ planar waveguides has been studied at different beam intensities and propagation lengths. Self-defocusing and beam break-up have been observed and explained using BPM simulations under a two-center band transport model.

OCIS codes: 190.4390 Nonlinear optics, integrated optics; 190.5940 Self-action effects; 230.7390 Waveguides,

1. Introduction

It is well known that the photorefractive nonlinearity of $LiNbO_3$ causes beam distortion (optical damage) during propagation of single beams of moderate or high light intensity. This effect is a major drawback for photonic applications such as second harmonic generation or laser oscillation [1]. Although this distortion consists roughly in a self defocusing effect, the detailed investigation and full understanding of this phenomenon is still incomplete. In this work we develop a beam propagation simulation under a recently reported photorefractive 2-center model for undoped $LiNbO_3$ [2] and check the model predictions with some experiments.

2. BPM Calculations

The beam propagation method (BPM) uses a finite element algorithm. A planar wave-guiding geometry has been chosen in order to restrict self-defocusing to the guide plane, making easier simulations and measurements as well as their comparison. Specifically, we consider a Z-cut planar guide in which beam propagates along the Y-axis. The photorefractive nonlinearity has been described using a two-center model (Fe and Nb_{Li}), instead of the standard one centre approach that fails in modelling the main optical damage features as recently reported [2,3]. The rate and transport equations for the two centres that can be found elsewhere [2], allows obtaining the light-induced photorefractive index change as a function of the beam intensity for each material slab along the propagation direction. Material parameters used in the simulation correspond to α-phase $LiNbO_3$ waveguides.

In fig.1, we represent the evolution of the beam intensity (1a) and photorefractive index change $\Delta n(x)$ (1b) profiles as a function of the propagation distance up to a 4 mm length inside the waveguide. The input beam has initially an 80 microns width Gaussian profile and a maximum intensity of 700 W/cm^2. However, it distorts along propagation showing a decreasing peak intensity accompanied with a broadening profile that reaches roughly an increase of a factor 2. In turn, the $\Delta n(x)$ has a well-shape whose depth decreases with the propagation length and which shows some two-step structure. In fact the smaller step of ~ 10^{-5} just at both sides is due to the Fe-centre whereas the second much higher decrease up to $2x10^{-4}$ is due to the second Nb_{Li} centre and it is the main origin of optical damage distortion.

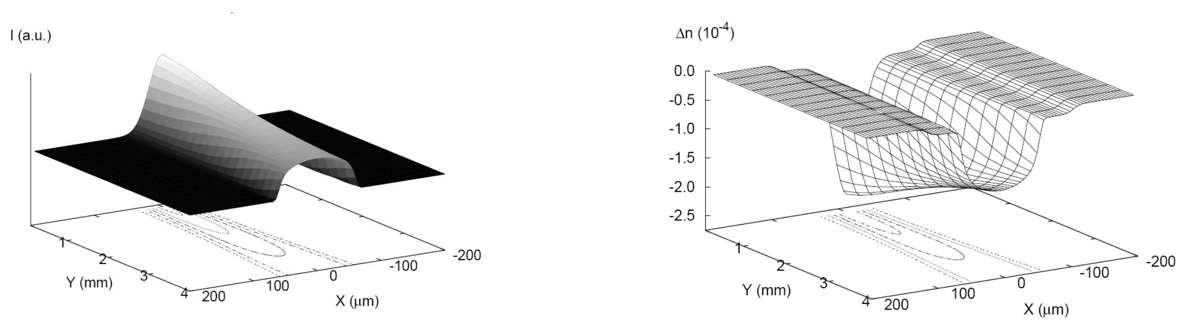

Figure 1: Simulations of the beam intensity (a) and the refractive index change (b) profiles along a length of 4 mm in a planar waveguide for a light intensity of 700 W/cm^2

3. Experiment

To check the beam propagation predictions the decoupled beam intensity profile after propagation along 4 mm in a planar z-cut α-phase $LiNbO_3$ waveguide has been recorded using a beam profiler placed at 8 cm from the guide. The observed normalized intensity profiles (solid line) are presented in figure 2 together with the corresponding simulations (dashed lines) for four increasing intensities: I_1= 10 W/cm^2 (a), I_2= 100 W/cm^2 (b), I_3=300 W/cm^2 and I_4=700 W/cm^2. For I_1 there is no appreciable distortion because this intensity is close but below the so-called optical damage threshold I_{th} [4] whereas for I_2 one can already see some broadening due to self-defocusing by the light-induced photorefractive index well. At higher intensities an unexpected beam break-up appears that is due to the phase profile imprinted in the beam by the photorefractive index change (see fig. 1b). It is worthwhile remarking the good accordance between theory and experiment regarding both the beam broadening and the profile structure that shows beam break-up with a number of peaks or filaments that increases with the light intensity. In fact, for still higher intensities a higher number of filaments have been observed either in theory and experiment.

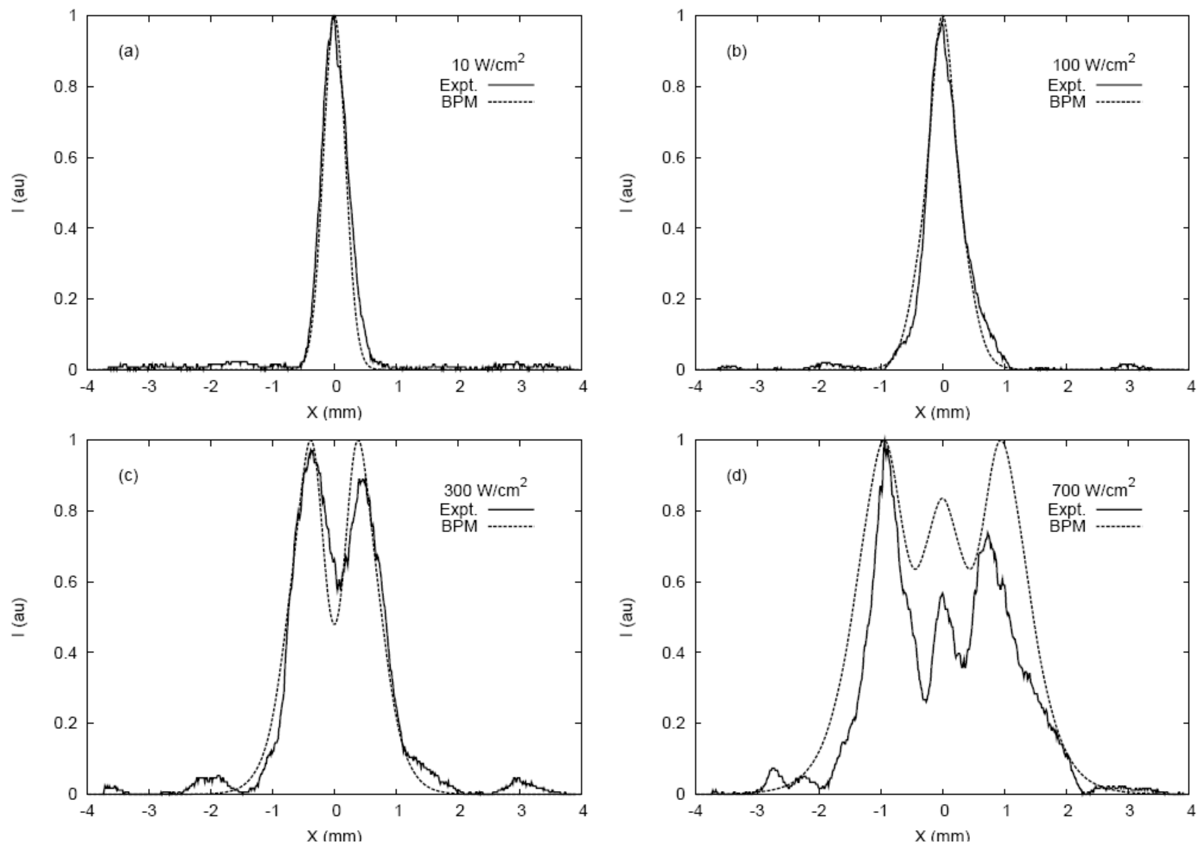

Figure 2: Comparison between the recorded light intensity profile and the corresponding BPM simulation after 4 cm-propagation in the guide and 8cm in the air at (a) 10 W/cm^2, (b) 100 W/cm^2, (c) 300 W/cm^2 and (d) 700 W/cm^2. In each figure the beam intensities have been normalized to the unity.

4. Summary and conclusions

A two center band transport model combined with a beam propagation method has been applied to simulate beam propagation below and above the optical damage threshold intensity. The simulations predict a variety of behaviors (self defocusing and beam break-up) as the light intensity increases. Moreover these effects have been also observed in experiments at the same light intensities than those predicted by theory giving a further support to the two centre photorefractive model.

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