Photorefractive damage in congruent and Mg doped α-phase channeled $LiNbO_3$ waveguide.

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Abstract: We report on accurate measurements of photorefractive optical damage in congruent and Mg doped α-phase channeled $LiNbO_3$ waveguides. Whereas for undoped waveguides optical damage threshold intensities are about 200 W/cm^2, no optical damage has been found in Mg-doped waveguides up to 1 MW/cm^2. Results are discussed comparing them with data in planar waveguides and with the recent two transport model for the photorefractive effect in undoped $LiNbO_3$

Keywords-component; photorefractive effect, proton exchanged channelled waveguides, optical damag

I. INTRODUCTION

An important issue in many $LiNbO_3$ integrated optics devices is the maximum power that the device is able to safely handle on operation. In most cases the power is limited by the photorefractive (PR) optical damage which, to a greater or a lesser extension, is present in $LiNbO_3$ particularly within the visible region of the spectrum. Thus, a great effort has been devoted to characterize PR damage and to reduce it. Particular attention has been paid to waveguide configurations because the long propagation lengths and the high intensities reached increase optical damage effects. [1].

From the theoretical side, the rough explanation of the beam distortion is very simple: the light induces a refractive index decrease Δn (via charge transport and electrooptic activity in the crystal) which affects mode propagation. However, a more detailed analysis shows the complexity of the subject as it involves the microscopic origin of the charge transport and its interaction with the wavefront change via the index change Δn. In fact, very recently, a new two-center model has been proposed to explain several features that could not been predicted by the previous standard one-center model [2].

The precise control of the proton-exchange (PE) process was found essential for good non linear optical performance of the fabricated waveguides. An important step in the knowledge of the PE guides was put-on by Korkishko and coworkers with their detailed structural studies of layers exchanged under different conditions [3]. These authors revealed the occurrence of seven crystallographic phases depending on the exchange rate x of the resulting compound $H_xLi_{1-x}NbO_3$. One of these phases, the so-called α-phase, can be fabricated alone by using soft proton-exchange recipes with well controlled parameters (see section 2). The corresponding waveguides present very good non linear and electrooptical properties very similar to the $LiNbO_3$ substrates. Unfortunately, they also present moderate photorefractive damage that has been characterized in planar waveguides [4,5]. However, it is still not clear whether the results for planar guides are directly applicable to channeled waveguides which have much higher technological potential.

Hence, the aim of this work is to address accurate measurements of photorefractive optical damage of α-phase $LiNbO_3$ waveguides in channelled configuration. We will consider congruent and Mg-doped waveguides. The results will be compared with those of planar waveguides and discussed to the light of the recent two-center transport model for the photorefractive effect in undoped $LiNbO_3$.

II. EXPERIMENTAL DETAILS.

The α-phase PE waveguides were produced by immersion of the samples in a benzoic acid melt buffered with 3% lithium benzoate at 300 ºC for 48 hours within a sealed ampoule [4]. In order to obtain channelled waveguides, prior to proton-exchange a SiO_2 mask is deposited onto the crystal surface with open channels obtained by standard photolithographic techniques. Thus, we have fabricated “soft proton exchanged” waveguides as opposite to the annealed proton exchanged guides. These wavguides have passed a highly distorting proton exchange phase during fabrication and a single homogeneous structural phase cannot be assured.

A Mach-Zehnder interferometer is used for the quantitative measurement of light-induced index changes [5] in congruent and Mg-doped waveguides. Optical damage is induced by light of 532 nm wavelength and probed with red light of 633 nm wavelength. For Mg doped samples, complementary measurements have been also performed monitoring the intensity inside the waveguide just at the end of the path length as a function of the incoming light power.

III. RESULTS AND DISCUSSION.

The photorefractive index change versus the light beam intensity I inside the waveguide has been measured for two waveguides of 5 and 10 μm wide. The results are shown in Fig. 1. The values of $|\Delta n|$ are first nearly independent on I (I<100 W/cm^2) as predicted by the standard one-center model of the PR effect. From I >100 W/cm^2 $|\Delta n|$ markedly increases and finally the curve tends to saturate again because of strong optical damage. In fact, the greatest intensity which could reliably be measured (~10^3 W/cm^2 for the sample length used) is limited by this PR damage. The curve follows the typical shape reported for $\Delta n(I)$ data in α-phase congruent planar waveguides although the saturating region appears for higher intensities, (1 KW/cm^2 versus 200 W/cm^2 [5]), i.e. higher light intensities can be propagated in the channelled waveguide. The light intensity dependence is successfully explained through the two-center model [2] where, for the low intensity region, only the Fe impurity plays a role (one-center approach), but as the intensity increases a secondary center (niobium in lithium site) contributes increasing $|\Delta n|$. The final saturating region appears when $|\Delta n|$ is high enough to induce an important distortion of the mode profile and so propagation losses. Then, these data can be considered a further support for the validity of the two-center photorefractive model in undoped $LiNbO_3$ waveguides, either in planar or channel configuration. Similar $\Delta n(I)$ measurements have been carried out for Mg-doped samples and no photorefractive effect has been observed up to 1 MW/cm^2 ($\Delta n \ll 10^{-5}$). In fact, in this latter case the measurements are much more complicated because of thermal instabilities at the high-intensity range that have been taken into account.

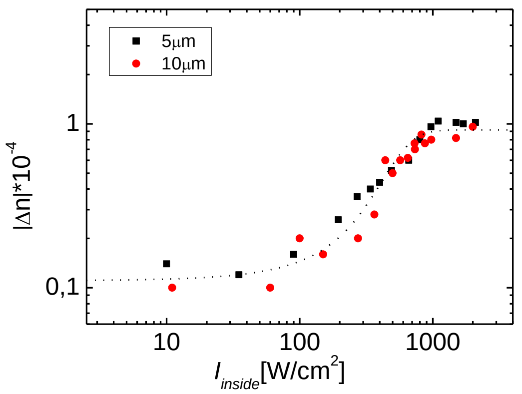

Fig.1 *Logarithmic plot of the photorefractive index change Δn_e versus the light intensity I inside the waveguide. The dotted line is only to guide the eyes.*

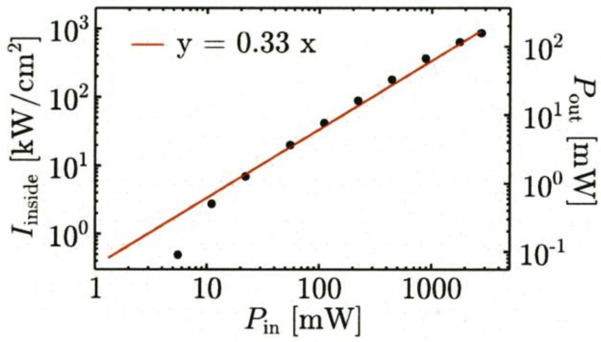

Fig.2 *Logarithmic plot of light intensity inside the waveguide just before emerging from it, I_{inside}, versus de incoming power P_{in} for a Mg-doped sample . The fit is a straight line through the origin.*

A further confirmation of the absence of PR damage has been obtained measuring the light intensity I_{inside} at the end of the waveguide propagation length as a function of the incoming light power P_{in}. A linear dependence up to I_{inside}~1 MW has been obtained demonstrating the absence of PR damage in this intensity range.

In summary photorefractive optical damage of α-phase PE channeled waveguides has been accurately measured finding an intensity response similar in accordance with the recently reported two-center charge transport model [2]. For congruent waveguides the photorefractive effect becomes relevant at light intensities about 400-500 W/ cm^2 slightly higher than in planar guides whereas no optical damage has been found in Mg-doped waveguides up to remarkably higher intensities of 1 MW/cm^2**.**

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REFERENCES

[1] D. Kip and M. Wesner, "Photrefractive waveguides," in Phtorefractive Materials and their applications I: Fundamental phenomena (Springer Berlín, 2006)

[2] J. Villarroel, J. Carnicero, F. Ludtke ,M. Carrascosa, A. García-Cabañes ,J. M. Cabrera, A. Alcazar y B. Ramiro; "Analysis of photorefractive optical damage in lithium niobate: Aplication to planar waveguides"; Opt. Express **18**, 20852-20861 (2010)

[3] Y. N. Korkishko, V. A. Fedorov, "Structural phase diagram of $H_xLi_{1-x}NbO_3$ waveguides: the correlation between optical and structural properties", IEEE J. Selected Topics in Quant. Electr. **2**(2), 187 (1996).

[4] O. Caballero-Calero, A. Alcázar, A. García-Cabañes, J. M. Cabrera and M. Carrascosa, "Optical damage in x-cut proton exchanged $LiNbO_3$ planar waveguides," J. Appl. Phys. **100**, 093103 (2006).

[5] F. Luedtke, J. Villarroel, A. García-Cabañes, K. Buse, and M. Carrascosa, "Correlation between photorefractive index changes and optical damage thresholds in z-cut proton-exchanged-$LiNbO_3$ waveguides," Opt. Express **17**, 658 (2009).