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Spectroscopic characterizations and optical damage resistance of $Zn:Yb:Er:LiNbO_3$ crystals

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Abstract

$Zn:Yb:Er:LiNbO_3$ crystals have been grown. The infrared transmission spectra were measured and discussed in terms of the spectroscopic characterizations and the defect structure of the $Zn:Yb:Er:LiNbO_3$ crystals. The optical damage resistance was characterized by the transmitted beam pattern distortion method. The optical damage resistance of Zn (6.0 mol%):$Yb:Er:LiNbO_3$ crystal is about two orders of magnitude higher than that of other crystal. The dependence of the optical damage resistance on the defect structure was studied.

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Keywords: $Zn:Yb:Er:LiNbO_3$; Spectroscopic characterization; Optical damage resistance

1. Introduction

The electro-optic, acousto-optic and non-linear properties of $LiNbO_3$ (LN) crystals, combined with the laser emission of trivalent erbium ions (Er^{3+}) around 1.55 μm, together with the possibility of producing low-loss waveguides, have led to choose this material in order to develop monolithic integrated devices [1-3]. Also, the energy transfer between Yb^{3+} and Er^{3+} in $LiNbO_3$ crystals has been recently characterized under CW and pulsed excitation [4,5], and it has been found that this transfer is highly efficient [6].

It is known that pure $LiNbO_3$, as well as $Er:LiNbO_3$ and $Yb:Er:LiNbO_3$, presents a low threshold for photorefractive damage [7]. When

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$LiNbO_3$ devices are used at high laser intensity, their performance is severely limited by the optical damage effect, which induces birefringence change and distorts the laser beams [8]. Some damage-resistant impurities have been discovered, including divalent (Mg^{2+} [9], Zn^{2+} [10]) and trivalent (In^{3+} [11,12], and Sc^{3+} [13]) impurities, which lead to a strong decrease in the photo damage of $LiNbO_3$ and have been receiving a lot of interest.

In this paper, doping over a range of Zn concentration is used to enhance the optical damage resistance of Zn:Yb:Er:$LiNbO_3$ crystals. The dependence of optical damage resistance on the concentration of ZnO is discussed. The IR transmission spectra of the Zn:Yb:Er:$LiNbO_3$ crystals were measured to investigate the structure of the crystals.

2. Experimental

2.1. Crystal preparation

The congruent $LiNbO_3$ crystals with 0.5 mol% of Er_2O_3, 1.0 mol% of Yb_2O_3, and various concentrations (0, 3.0, and 6.0 mol%) of ZnO were grown by Czochralski method. For comparison, Er:$LiNbO_3$ crystal was also grown. The raw materials used for crystal growth are Li_2CO_3 (4N purity), Nb_2O_5 (4N purity), ZnO (4N purity), Yb_2O_3 (4N purity) and Er_2O_3 (spectral purity). The melt composition for several crystals is shown in Table 1. To prepare the doped $LiNbO_3$ polycrystalline materials, the thoroughly-mixed raw materials were put into a platinum (Pt) crucible, and calcined at 750 and 1150 °C for 2 h, respectively. The crystals were grown under the optimum conditions: temperature gradient of 430–50 °C/cm, rotation rate of 12–20 rpm, and growth rate of 1.0–1.5 mm/h. After growth, the crystals were cooled to room temperature at a rate of 150 °C/h. All of the crystals were clear and transparent.

The crystals were placed in a furnace where the temperature gradient is below 5 °C/cm for polarizing. After being held at a temperature of 1200 °C for 8 h, the crystals were polarized with 5 mA/cm^2 current density. During the cooling process, the temperature was decreased rapidly from 1000 to 800 °C to avoid "dissolve-off" phenomenon from appearing. Test samples were cut from the middle of the crystals and polished to optical grade smoothness. The size of the samples is listed in Table 1.

2.2. Measurements

The infrared transmission spectra of the crystals were obtained with a Nicolet Avatar-370 FT-IR spectrometer in the 3000–4000 cm^{-1} range at room temperature.

The transmitted beam pattern distortion method [14] was used to study the optical damage resistance of the Zn:Yb:Er:$LiNbO_3$ crystals. Fig. 1 shows the experimental setup. Light from an Ar^+-ion laser (488.0 nm) was focused by means of a convex lens of focal length, f, onto a crystal sample placed in the focal plane. The laser beam is polarized parallel to the c-axis of the crystal. The diameter of the focused laser beam is related to the incident beam diameter, d, determined by the diaphragm, and yields the focused laser beam area given in Eq. (2) for S.

$$D = \frac{2f\lambda}{\pi d}, \tag{1}$$

Table 1
Composition of raw materials of the Zn:Yb:Er:$LiNbO_3$ crystals and the size of the samples

Crystal	No.1	No.2	No.3	No.4
[ZnO] (mol%)	0	0	3.0	6.0
[Er_2O_3] (mol%)	0.5	0.5	0.5	0.5
[Yb_2O_3] (mol%)	0	1.0	1.0	1.0
Crystal size (mm^2)	$\phi35 \times 50$	$\phi30 \times 40$	$\phi30 \times 40$	$\phi30 \times 40$
Wafer size (mm^3)	$10 \times 10 \times 3$	$10 \times 10 \times 3$	$10 \times 10 \times 3$	$10 \times 10 \times 3$