

Features of photorefractive gratings recorded with two – color scheme in doubly doped surface layer of a lithium niobate crystal

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The features of the photorefractive grating recording and storage in lithium niobate crystal with surface doping by iron and copper in conditions of additional incoherent short – wavelength illumination are experimentally investigated and discussed.

Keywords: lithium niobate, photorefractive grating, incoherent illumination

Introduction

Nonvolatile photorefractive gratings both in bulk and waveguide samples of some electrooptic crystals like lithium niobate (LiNbO_3) or strontium – barium niobate (SBN) are promising elements for different applications in photonics. For example, similar reflection gratings may be well suited for integrated waveguide lasers as distributed Bragg mirrors, or as narrow – band selective elements for dense division multiplexing. The one of general requirements to such gratings is their stability against the decay caused by the finite conductivity of the materials as in darkness as in conditions of their illumination with light of operating wavelength. To overcome this problem, the methods of thermal [1] and electrical fixing [2] of photorefractive gratings in both, LiNbO_3 and SBN, have been suggested and developed. Besides, the nonvolatile storage of holographic gratings using two – color scheme of their recording, e.g. the preliminary illumination of crystal samples with short – wavelength irradiation and recording light with longer wavelength, has been recently demonstrated for LiNbO_3 doped by two different impurities, like iron (Fe) and manganese (Mn) [3]. To form nonvolatile holograms, these impurities should exhibit different photoexcitation energies for electrons of which excitation and redistribution in space results in the holographic pattern recording. Besides Fe and Mn, another interesting couple of similar dopants, which significantly and in different ways influence the photorefractive properties of LiNbO_3 , is Fe and copper (Cu). It has been revealed that they result in significantly different values of the light absorption coefficients of LiNbO_3 at the same wavelength in the blue – green range of the visible [4]. Additionally, in some earlier experiments we observed the considerable decreasing of the dark conductivity for Fe – doped LiNbO_3 owing to its additional doping by Cu. Even the very low Cu concentration (as less than 0,1 % by weight) resulted in the dark conductivity decreasing of $\text{LiNbO}_3\text{:Fe}$ similar an order of magnitude [5]. The possible origin of these effects is the different positions of Cu and Fe donor centers within the band gap of a LiNbO_3 crystal.

In this research we investigate an influence of an incoherent green illumination to the recording and decay characteristics of photorefractive gratings which are formed in two – beam coupling configuration by the external coherent light beams in a LiNbO_3 wafer with surface doping by combination both of Fe and Cu.

Experimental setup

The schematic of experimental setup is shown in Fig. 1. In experiments we use the coherent irradiation of a He – Ne laser ($\lambda=0.63 \mu\text{m}$) with a total power 10 – 15 mW to record the photorefractive gratings, and incoherent green irradiation of a light – emitting diode (LED) as the gating light, which makes possible a participation of deep donors in the photorefractive process. The incidence plane of external recording red beams coincides with YZ plane of a LiNbO_3 crystal with light polarization along its Z axis. The intersection angle of red beams is about 5 degrees. The

crystal dimensions are $12 \times 1.5 \times 8 \text{ mm}^3$ along X, Y, Z axes, respectively. The green light is focused by a spherical lens with a focal length of 10 cm and directed to the XZ plane of the crystal near to its normal. The intensity of incoherent illumination at the crystal surface is near to 30 mW/cm^2 . We investigate two different conditions of the photorefractive grating recording and decay. In the one case we use the preliminary illumination of a LiNbO_3 sample with green light and following recording stage with only red beams. In another case we inspect the recording of such gratings using simultaneously as red beams as green illumination. The process of the grating decay is studied either with permanent or periodic readout of these gratings using a weak probing red beam.

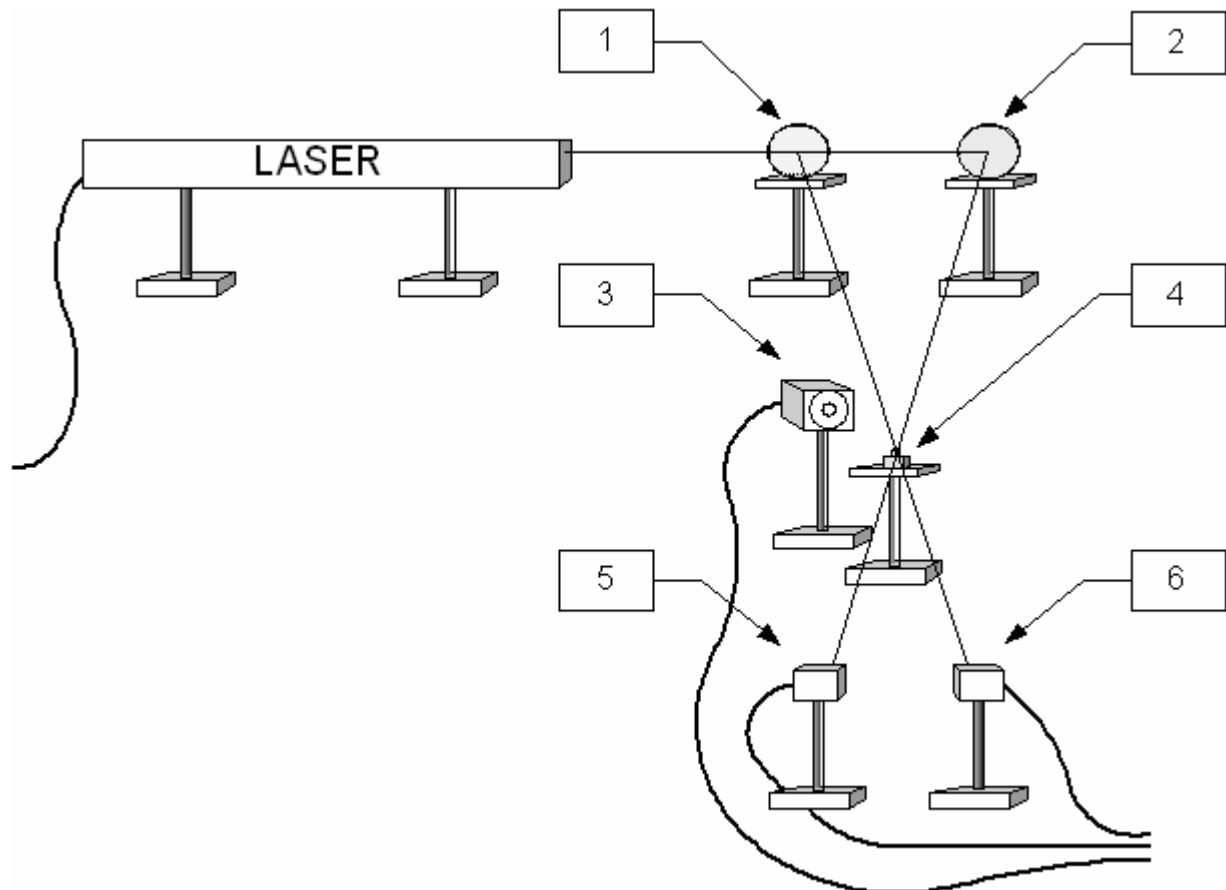


Fig. 1. Experimental setup. 1, beam splitter; 2, mirror; 3, LED; 4, LiNbO_3 sample; 5 and 6, photodiodes.

Doubly – doped LiNbO_3 sample

The crystal sample investigated is a Y cut LiNbO_3 wafer with its XZ surface doped by Fe and by a combination of Fe and Cu in the part of the whole surface. The thermal diffusion of Fe is performed at a diffusion temperature of 950°C and for Cu it makes 900°C . The diffusion time is 10 hours for Fe and 6 hours for Cu. The initial thickness of metal films formed by vacuum evaporation is $\sim 40.0 \text{ nm}$. It should be noted that Fe diffusion results in the increasing of both, as extraordinary as ordinary refractive indices of LiNbO_3 , e.g. it forms in LiNbO_3 a planar optical waveguide. We use this property to estimate the thickness of Fe – doped crystal layer and an average concentration of Fe within it. We also can estimate the Cu distribution within the crystal by comparison of the effective refractive indices of TE modes within waveguide areas with only Fe doping and with

doping by Fe and Cu. In the sample discussed the thicknesses of boundary layers doped with Fe and Cu are estimated as ~ 6 and ~ 30 μm , respectively. The waveguide supports up to 8 TE modes along the X direction at $\lambda=633$ nm. Parameters of refractive index profiles are reconstructed from the measured TE mode indices through a numerical solution procedure for the corresponding wave equation using a Runge – Kutta method. We find that the perturbation of the initial Fe – caused refractive index profile of the waveguide due to the Cu diffusion is insignificant (slight decreasing of the extraordinary refractive index is observed with respect to the Fe – doped region).

Experimental results

As the clear evidence of the strong Cu influence to the photorefractive characteristics of LiNbO_3 we previously test the decay of photorefractive gratings formed by the same guided modes within waveguide parts with only Fe doping and with Fe and Cu content. The significant difference in the dark conductivity of a crystal for these parts is illustrated by Fig. 2 with time dependences of the diffraction efficiency for the gratings formed within the waveguide by TE_1 modes. The photoconductivity of the material does not contribute in this experiment as the periodic readout of the decaying grating by weak light beam is used. The diffraction efficiency of the waveguide gratings in both parts is practically the same for the same power of recording light beams.

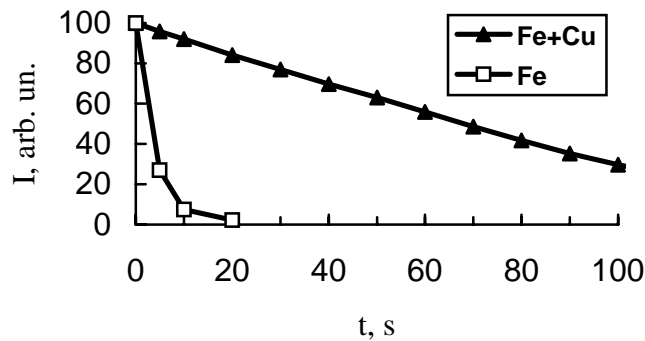


Fig. 2. The relative intensity of readout beam during decay of photorefractive gratings formed by TE_1 modes within Fe- and Fe:Cu – doped areas of the waveguide.

In the experiments with recording of photorefractive gratings by external light beams in surface – doped LiNbO_3 we also find the significant distinctions of this process for areas with single and double doping. For example, we practically do not observe the grating formation in the area with only Fe doping. At the same experimental conditions the diffraction efficiency of photorefractive gratings formed in the doubly – doped area may achieve values of up to 10%. In part it may be explained by the distinction of the depths of Fe- and Fe:Cu – doped crystal layers. The same undoped crystal also shows very low photorefractive sensitivity for the red light.

The grating recording in the doubly – doped area by red beams with its preliminary illumination by incoherent green light for 5 – 15 minutes shows the slight distinctions between diffraction efficiencies of these gratings with respect to similar formed without such incoherent illumination. Incoherent gating light may increase this diffraction efficiency for the same recording time and light intensity. The time decay of such gratings shows slower decreasing of the grating amplitude for the case of previous incoherent illumination. It is illustrated by the results in Fig. 3 for time evolution of the diffraction efficiency of photorefractive gratings formed with previous crystal illumination with green light for 5 minutes and without it. In this experiment we use the permanent readout of gratings by red beam with its power near 0.1 mW.

The regime of simultaneous incoherent illumination of a crystal and recording of photorefractive grating by coherent red light demonstrates the significant influence of the illumination characteristics to diffraction efficiency of the grating formed. As we observe, the diffraction efficiency, e.g. the grating amplitude in some conditions may be considerably increased even at green light intensity near to 1 mW/cm^2 .

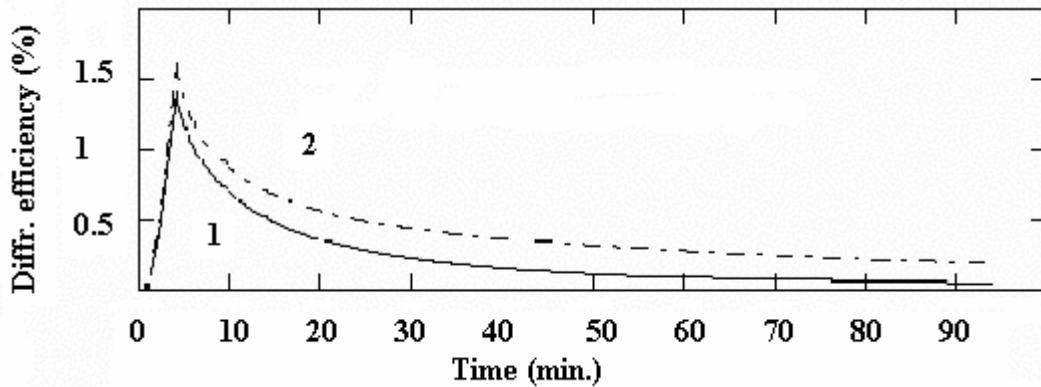


Fig. 3. Time evolution of the diffraction efficiency of photorefractive gratings while their recording and decay. Gratings are formed:
1, by only red beams; 2, with previous incoherent illumination.

These results may be useful for design of photonics elements as with stable grating elements as with stable channel waveguide structures formed in planar waveguides by spatial optical solitons. All the experimental results and the features of the photorefractive grating recording and decay in the two – color scheme will be discussed in more details in the report.

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