Nonvolatile hologram storage in $In:Fe:Mn:LiNbO_3$

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Abstract. We describe the performance of two-center hologram storage in $In:Fe:Mn:LiNbO_3$. The doping content of MnO and the oxidation state that yield the maximum nonvolatile diffraction efficiency in $In:Fe:Mn:LiNbO_3$ (0.080 wt % Fe_2O_3, 3 mol % In^{3+}) are discussed.
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Subject terms: two-center recording; light-induced scattering; $In:Fe:Mn:LiNbO_3$.

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1 Introduction

Volume holographic storage has been investigated extensively due to its potential for large storage capacity, high data rate, and short access time.[1,2] Once information has been stored in a volume hologram medium, it can be retrieved and can serve as a library for pattern recognition or other processing.[3,4] However, erasure of the optical grating during reading has been one of the major problems for practical application of volume holographic storage. Several techniques, including thermal fixing,[5] electrical fixing,[6] two-step recording,[7] and two-center recording,[8] have been developed to solve this problem. Among them, two-center recording does not require heating or external electric fields and permits recording with a high dynamic range.[9,10] To reduce the influence of light-induced scattering, $LiNbO_3$ doped with damage-resistant dopant is grown for holographic storage.[11] Zhen et al. have studied the threshold effect of In_2O_3 on the resistance to optical damage in $Fe:Mn:LiNbO_3$ (0.030 wt % Fe_2O_3, 0.1 wt% MnO).[12] According to their paper, the doping content is not suitable for high nonvolatile diffraction efficiency. According to the study by Momtahan and Adibi,[10] the optimal ratio of the doping content of MnO to that of Fe_2O_3 for high nonvolatile diffraction efficiency is about 1:10 for two-center recording in $Fe:Mn:LiNbO_3$. In the work described in this paper, In_2O_3 was doped in $Fe:Mn:LiNbO_3$ (0.080 wt % Fe_2O_3, 0.008 to 0.014 wt % MnO), and hologram storage for high nonvolatile diffraction efficiency was studied.

1.1 *Light-Induced Scattering in* $In:Fe:Mn:LiNbO_3$

We take $In:Fe:Mn:LiNbO_3$ (0.080 wt % Fe_2O_3, 0.012 wt % MnO) doped with 0.5, 1, 2, 3, and 4 mol % In^{3+} to measure light-induced scattering. According to Ref. 13, $Fe:Mn:LiNbO_3$ for two-center recording should be oxidized moderately to ensure that Fe traps are empty and Mn traps partially filled. So these five samples are annealed together to make them have no obvious absorption at 477 nm but a moderate absorption coefficient about 3 to

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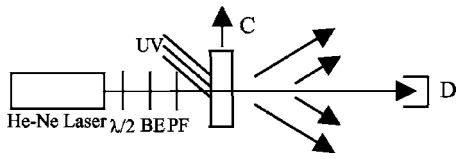

Fig. 1 Experiment setup for measuring light-induced scattering. BE: beam expander; PF: polarizing film; D: detector.

4 cm^{-1} at 420 nm. The beam from a 100-mW He-Ne laser and unpolarized UV light at 404 nm from a 100-W mercury lamp were used in all this work.

As shown in Fig. 1, the extended He-Ne laser beam of extraordinary polarization propagates perpendicular to the In:Fe:Mn:$LiNbO_3$ plate with a thickness of 4 mm, and the UV light sensitizes the material. The ratio of their intensities is set to be 20. We use a $\lambda/2$ wave plate and polarizing film to modulate the incident intensity of the He-Ne laser beam. The effective diameter of the detector is 3 mm, the same as that of the He-Ne laser beam. The transmitted light intensities at $t=0$ (I_0) and $t=3000$ s (I_t) for different incident intensities are shown in Fig. 2. When the doping content of In^{3+} is less than the threshold content (3 mol %), there is a maximum incident intensity such that the light-induced scattering can be suppressed effectively. Furthermore, once the doping content is above the threshold value, light-induced scattering will not be observed even at a high incident intensity.

2 Two-Center Hologram Recording in In:Fe:Mn:$LiNbO_3$ with Different Doping Contents of In^{3+}

For two-center recording, two different dopants are used to provide shallower (Fe) and deeper (Mn) traps in photorefractive crystals with UV light (shorter wavelength) for sensitization and coherent light (longer wavelength) for recording. Firstly, the crystal is exposed to UV light to transfer electrons from deep traps to shallow traps through the conduction band. Then, in the hologram recording phase, the crystal is exposed to UV light and recording beam simultaneously. Thus the information carried by the recording beam could be recorded in the shallow and the deep traps. When exposed to only homogeneous recording light, the electrons would move from the shallow traps back into the deep traps. As a result, the hologram is fixed in deep traps, and it is insensitive to the recording light.

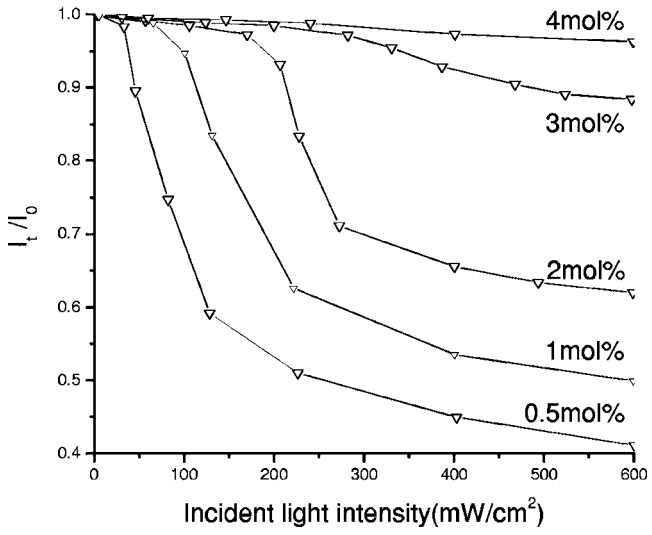

Fig. 2 Relation between I_t/I_0 and incident intensity of He-Ne laser beam for In:Fe:Mn:$LiNbO_3$ (0.080 wt % Fe_2O_3, 0.012 wt % MnO) with different doping contents of In^{3+}.

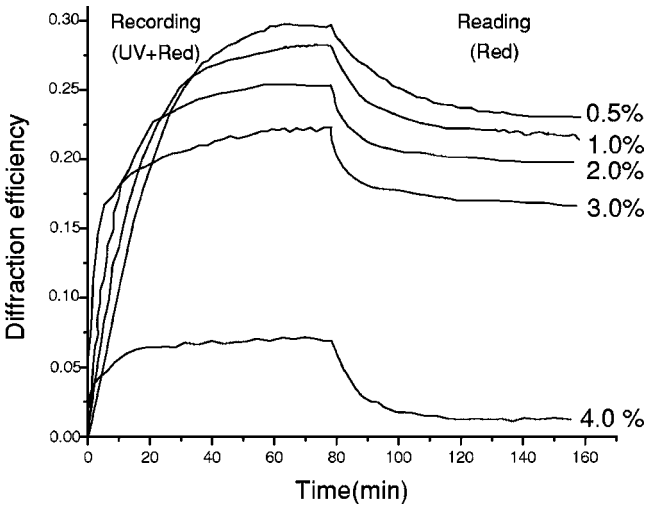

Fig. 3 Recording and readout curve for In:Fe:Mn:$LiNbO_3$ (0.080 wt % Fe_2O_3, 0.012 wt % MnO) doped with different doping content of In^{3+}.

To study the recording process, hologram recording and readout are done in the crystals. The He-Ne laser beam is split into two beams of equal intensity, and these two beams, of extraordinary polarization, are made to intersect symmetrically inside the crystals with a separation angle of 30 deg in the air to ensure the grating vector is parallel to the crystal's c axis. To eliminate the influence of light-induced scattering when the doping content of In^{3+} is less than the threshold value, the two recording beams are both weakened to 40 mW/cm^2, and the effective receiving diameter of the detector is twice that of the recording-beam spot (3 mm). The recording material is preexposed to UV light of 4 mW/cm^2 for 2 h. As shown in Fig. 3, with increasing doping content, the sensitivity rises but the saturation and nonvolatile diffraction efficiency decrease. When it is above 3 mol %, the diffraction efficiency falls rapidly.

For In:Fe:Mn:$LiNbO_3$ whose doping content of In^{3+} is less than the threshold value, In^{3+} takes priority in replacing antisite Nb (Nb_{Li}^{4+}), which plays the role of an electron trap, whereas Fe and Mn ions occupy normal Li sites first.[14,15] With increasing doping content of In^{3+}, the concentration of electron traps (Nb_{Li}^{4+}) decreases. This leads to increases of the photoconduction and mobility of the excited charge carrier. So the response speed rises, and the light-induced scattering is suppressed. But because the Fe and Mn ions, which are dominant factors for photoconduction, are not appreciably affected, the system is still suitable for hologram recording. With further increase of the doping content of In^{3+}, a few of the Fe and Mn ions on the Li sites are repelled to the Nb sites by In^{3+}. Once the doping content of In^{3+} is above 3 mol %, most of the Fe and Mn ions will be

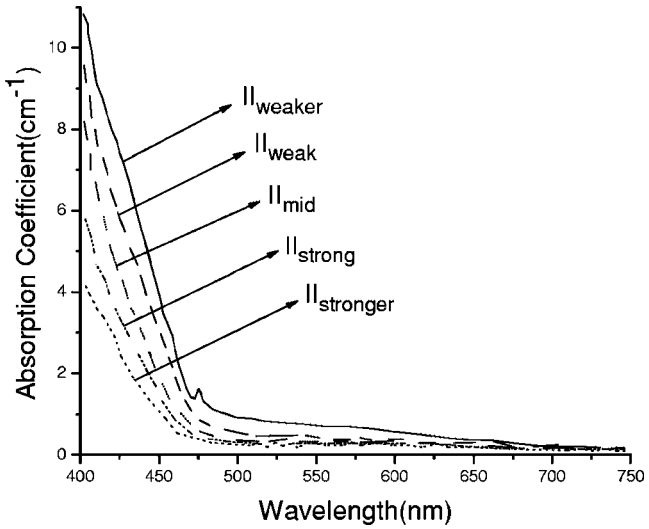

Fig. 4 Absorption spectra of five In:Fe:Mn:$LiNbO_3$ (3 mol % In^{3+}, 0.080 wt % Fe_2O_3, 0.012 wt % MnO) samples from the same boule with different oxidation states.

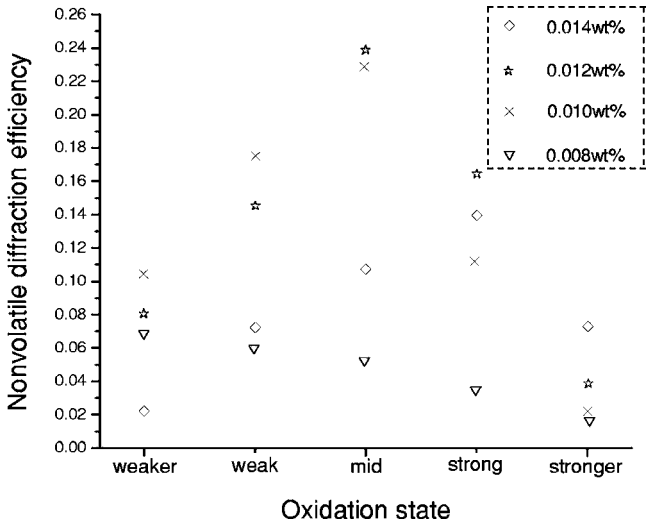

Fig. 5 Nonvolatile diffraction efficiency after saturated recording in In:Fe:Mn:$LiNbO_3$ (3 mol % In^{3+}, 0.080 wt % Fe_2O_3) with varied doping of MnO with different oxidation states.

repelled to the Nb sites to generate Fe_{Nb} and Mn_{Nb}, which cannot capture electrons effectively. This leads to a drastic reduction of the recombination coefficients of Fe^{3+} and Mn^{2+}. Thus the photorefractive effect is greatly weakened. At the same time, the increase of free electrons results in a substantial increase in photoconduction. So the diffraction efficiency reaches saturation in a shorter time.

3 Effect of Mn Ion Content and Annealing

In view of Fig. 1 and Fig. 2, we take In:Fe:Mn:$LiNbO_3$ doped with 3 mol % In^{3+} for our further study. In order to investigate the influence of doping content, we prepared four kinds of $LiNbO_3$ samples, doped with 0.080 wt % Fe_2O_3 but different MnO contents of 0.014, 0.012, 0.01, and 0.008 wt %. They are denoted as I, II, III, and IV, respectively. The medium was cut into plates with thickness 4 mm and *c* axis parallel to the surface.

For each one of the four kinds of In:Fe:Mn:$LiNbO_3$ samples, five crystals from the same boule were annealed to get different oxidation states, denoted with subscripts weak, weaker, mid, strong, and stronger. For oxidation processing, these four kinds of In:Fe:Mn:$LiNbO_3$ were treated together, and so they all yielded similar samples of five oxidation states. Figure 4 shows the absorption spectra of samples of type II with different oxidation states; those of other three types of samples are only slightly different. For II_{weaker}, which is oxidized most weakly, a small absorption peak appears at 477 nm. This indicates that Fe traps begin to be filled after all Mn traps have been filled.

Hologram recording and readout were accomplished in all these 4×5 crystals as in Fig. 3, except that the intensities of the two recording beams were both 150 mW/cm^2, and that of the UV light was 15 mW/cm^2. We compare the nonvolatile diffraction efficiency after saturated recording. As shown in Fig. 5, the maximum value appears in the mid oxidation state when the doping of MnO is between 0.012 and 0.010 wt %. With stronger oxidation, the crystal with more doping of MnO has better nonvolatile diffraction efficiency. In contrast less doping of MnO does better when the oxidation state of the crystal is weaker. For comparison, with the optimal parameters for two-center recording in Fe:Mn:$LiNbO_3$ reported in Ref. 10, the ratio of doping content of MnO to that of Fe_2O_3 is about 1:10, and 95% of the Mn traps are filled; here the ratio of about 1:7 and stronger oxidation are favorable for two-center recording in In:Fe:Mn:$LiNbO_3$ (3 mol % In^{3+}). In addition to the influence of the large decrease in the concentration of Nb_{Li}^{4+} (which serves as electron traps) in In:Fe:Mn:$LiNbO_3$ (3 mol % In^{3+}), we consider this difference to have arisen because a small fraction of Mn ions on Li sites have been repelled to Nb sites by In^{3+} even when the doping content of In^{3+} has not exceeded the threshold value.

4 Conclusion

We have studied two-center hologram recording in In:Fe:Mn:$LiNbO_3$. It was demonstrated that the doping of In^{3+} could suppress the light-induced scattering effectively. When the ratio of the doping content of MnO to that of Fe_2O_3 is about 1:7 and under the stronger oxidation for In:Fe:Mn:$LiNbO_3$ (0.080 wt % Fe_2O_3, 3 mol % In^{3+}), maximum nonvolatile diffraction efficiency is obtained, in contrast with the reported 1:10 and 95%-filled Mn traps for Fe:Mn:$LiNbO_3$.

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