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HOLOGRAPHIC PERFORMANCE OF PHOTOREFRACTIVE Bi_2TeO_5 CRYSTALS

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Bismuth tellurite – Bi_2TeO_5 is a new photorefractive material recently available for optical memory investigations. Analogue volume holograms of a two-dimensional test pattern were recorded in undoped Bi_2TeO_5 crystals by using a cw Nd:YAG laser at 532 nm. The quality, dark decay and durability during permanent reading of the image were studied and compared to those of the reference $LiNbO_3$:Fe crystals. The holograms in the two crystals were of comparable quality, and they were less vulnerable for strong laser exposure in Bi_2TeO_5 than in the $LiNbO_3$:Fe crystals by a factor of 50.

Keywords: Volume holograms; Bismuth tellurite

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1. INTRODUCTION

The widespread application of volume holographic data storage is limited by the lack of proper memory materials. The photorefractive crystals, like the $LiNbO_3$:Fe provide acceptable write sensitivity and optical quality but the durability of the recorded holograms during read out are not long enough without specific fixing. The new nonlinear optical material, bismuth tellurite (Bi_2TeO_5) was first grown in 1990 with a quality applicable for optical investigation [1]. The photorefractive properties of Bi_2TeO_5 were quickly discovered, including a long living signal component [2, 3]. Recent experiments with stable continuous wave (CW) Nd:YAG lasers (532 nm) have shown that the saturation diffraction efficiency may be as high as 44% under optimum crystal orientation and beam polarization conditions [4]. This was major progress when compared to the earlier 2% efficiency achieved with Ar-ion laser [3]. Detectable volume holograms could be written with low laser power (reference arm: 680 μW, image arm: 110 μW) but those holograms faded away in the order of 10 seconds in the first experiments [4]. Using higher (80 mW) laser intensities the holograms remained observable for hours during permanent reading, and days in the dark [5]. The aim of the present investigations is to demonstrate the quality of the hologram

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of a two-dimensional test pattern recorded in Bi_2TeO_5 crystals and its durability under permanent reading.

2. EXPERIMENTAL

Single crystals of undoped Bi_2TeO_5 were grown by the diameter controlled Czochralski technique, technical details of the crystal growth can be found in [1]. The samples for the holographic investigations were X-ray oriented, cut and polished. Specific coatings on the optical surfaces were not applied. The reference congruent $LiNbO_3$ crystals were also grown by the Czohralski technique, with Fe concentration 10^{-3} mole/mole.

A standard holographic setup was used for recording a test pattern in Bi_2TeO_5 crystals. The 532 nm beam from a Coherent VERDI V2 type CW Nd:YAG laser was divided into a sample and a probe paths. The sample beam was expanded to adopt the test image and then focused again into the crystal. The write beams were introduced to the crystal in the 90° pattern / reference beam configuration. The grating vector (the face diagonal in this configuration) directed along the [0 1 0] and the z-axis for Bi_2TeO_5 and $LiNbO_3$, respectively. The overlapping volume of the two beams was about $1 \times 1 \times 1\,mm^3$. The intensities of the reference and signal beams for hologram writing were 80 mW (2 mW after the dark test pattern) in the case of Bi_2TeO_5 and 2 mW for the high absorption $LiNbO_3$:Fe. The typical write time was 1 min. The recorded images were read out by 2 mW intensity 532 nm probe beam, and detected by a CCD camera. The decay of the written image was followed during permanent and sequential (dark) reading.

3. RESULTS AND DISCUSSION

The pattern written in Bi_2TeO_5 crystals showed sharp contours and high resolution. The occasional shadow image in the high contrast pictures is attributed to internal reflection from the crystals in the absence of an antireflective coating. The dynamic range of the CCD camera did not allow us to follow the entire hologram decay without switching the sensitivity or optical filtering. In the comparative pictures we choose to keep the original impression of the image contrasts during the whole decay process and the zero-time images show the camera overshooting response. The recorded images showed a fast decaying initial section in the dark (up to about 10 min) after which the contrast of the image has remained almost the same until 50 h, the end of the observation. This was in accordance with the previous photorefractive observations that the decay of the photorefractive signal in Bi_2TeO_5 is of multicomponent, and after a 10 min initial decaying section the remaining signal was observable for years without fixing [3].

The early investigations and recent tests have shown that the long lifetime photorefractive signal component in Bi_2TeO_5 is rather resistant for both red (638 nm He—Ne) or green (514.5 Ar and 532 nm Nd:YAG) homogeneous laser exposure used in the read out process [3, 4]. The properties of the volume holograms written by 80 mW reference and 2 mW image beam intensities confirm those observations. Figure 1 shows the decay of the recorded image under permanent reading by 2 mW incident laser power. In the first few minutes the weakening of the image was fast then it slowed down. After 8 hours the image was still easily readable. Under the same reading conditions, the image in the reference $LiNbO_3$ sample decayed within 10 minutes (bottom image line in Fig. 1). The exposure during the sequential reading of the individual picture was less than 2 s for each shot, and the 8 h permanent

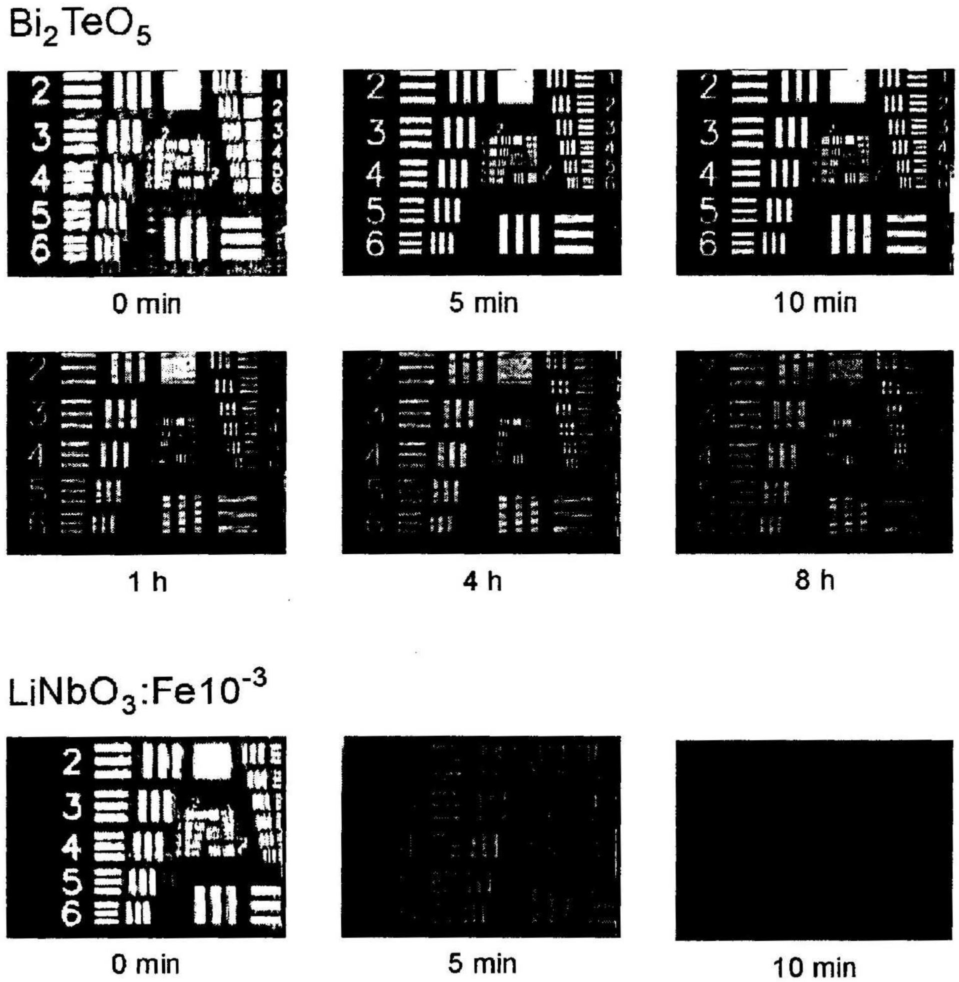

FIGURE 1 Decay of the holograms written in Bi_2TeO_5 and $LiNbO_3$:Fe crystals under permanent reading with 2 mW 532 nm laser beam.

reading corresponds to more than 10,000 subsequent read out without totally erasing the hologram.

Applicable volume holographic memory materials should obey multiple requirements. Namely, high photorefractive sensitivity for fast recording with low laser intensities, resistance against laser exposure after the hologram recorded for nonvolatile read out or multiplexing, outstanding optical properties for high quality analogue and low error rate digital holograms, in addition to the proper chemical, mechanical and thermal stability. The photorefractive sensitivity can be designed by proper doping the crystals [*e.g.* 6]. This is not employed yet for Bi_2TeO_5, and we expect progress with various dopants. The optical quality of the Bi_2TeO_5 crystals is under permanent improvement, and the chemical, mechanical and thermal stability of the material are accetable.

The durability of the hologram (photorefractive signal) without fixing is a unique property of the Bi_2TeO_5 crystals. The origin of this "self-fixing" character is not entirely understood. A reasonable model is the oxygen displacement in the photorefractive space charge field [3]. The large number of open oxygen positions in the crystal structure (17%) supports this model.

4. CONCLUSION

After the earlier quantitative photorefractive tests [4], the performance of the Bi_2TeO_5 crystals was demonstrated in analogue holographic recording. The photorefractive sensitivity of the undoped crystal is moderate but the durability of the recorded holograms for read out exposure is better than that of the traditional memory materials without fixing. The quality of the holographically recorded test pattern is acceptable. Consequently, Bi_2TeO_5 looks to be a prospective crystal for volume holographic storage, after optimizing its properties.

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