MULTIPLEXED STORAGE OF PERMANENT AND REAL-TIME HOLOGRAMS IN PHOTOREFRACTIVE BSO

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In this paper we present a technique for storing holograms in crystals of bismuth silicon oxide (BSO) that combines reversible photochromic effects with the more usual real-time photorefractive characteristics. Photochromic effects have been observed before in these sillenite cyrstals [1] but have generally been considered as a problem rather than as a possible mechanism for holographic storage. As the normal photorefractive (PR) behaviour is unaffected, however, simultaneous spatial multiplexing of both photorefractive (real-time) and photochromic (permanent) holograms is possible in the same crystal volume.

We have demonstrated a number of applications here ranging from image synthesis to holographic interferometry. These operations are mostly based on the inherently separate nature of these two holographic gratings which can lead to relative phase shifts between the two simultaneously scattered fields by shifting the real-time grating with respect to the permanent one, using optical techniques. Furthermore, the permanent holograms also show unexpected dynamic behaviour in which a fast increase in diffraction efficiency is observed upon illumination by a beam at the highly absorbed blue wavelengths. This effect can be used for all-optical switching.

Recording Characteristics

In fig. 1, beams 1 and 3 interfere to record a hologram in the BSO crystal. The real-time and permanent holograms were written using an argon ion laser operating at 488 nm in multilongitudinal mode, and at typical intensities for beams 1 and 3 of $I_1 = I_3 = 1.4$ W cm^{-2}. To investigate the formation of the permanent holograms , recording was performed at several Bragg angles ($\theta = 1° - 15°$) and the combined diffraction efficiency (η_T) of the real-time and permanent gratings was monitored by using a Bragg matched He-Ne beam 5 at 633 nm (∿ 5 mW).

To demonstrate the various image processing applications, the full angle between the two writing beams was set at $2\theta = 27°$ and transparencies placed at Q were imaged onto the BSO crystal by lens L1. Readout of the stored hologram was performed by beam 2 which was counterpropagating to beam 1 (DFWM). The isotropically diffracted beam 4 is the phase conjugate (PC) replica of the signal beam 3 used for recording. The PC image was monitored by a vidicon camera with the aid of lens L2.

Hologram exposure times were in the range of 5 minutes to more than 300 minutes. The exposed region of the crystal took on a light brown colouration, darker than the usual yellow colour of BSO. Similar absorption effects have been observed in [1] and have been attributed to the existence of Cr and Mn impurities or natural defects formed during crystal growth. To verify the

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reversible nature of the permanent recording, the BSO crystal was indirectly heated in silicone oil. At 150°C all the photochromic discolouration was erased in a time of about 1 hour.

Fig. 2 shows a typical recording of the temporal development of a permanent hologram for a Bragg angle of $\theta = 1.25°$. Curve (a) shows the total diffraction efficiency, η_T, of the combination of permanent and real-time gratings recorded simultaneously in the same crystal volume. Curve (c) depicts the diffraction efficiency of the permanent hologram alone, η_p. This was achieved by blocking beams 1 and 3 at regular intervals and sampling the permanent hologram for a period of ∿ 4 sec.. A steady increase in the difference of diffraction efficiencies between permanent, (c), and permanent/real-time, (a), is observed. An unexpected effect is the increase of the diffraction efficiency of the permanent hologram upon illumination by only one of the writing beams at 488 nm, curve (b). This diffraction efficiency increase is plotted in fig. 3 as a function of the intensity of the blue enhancing beam. We observe that only ∿ 2 mW cm^{-2} is enough to produce a six-fold increase in the diffraction efficiency, η_p.

Wavefront Reconstruction and Wavefront Interferometry

The reconstructed PC replica of an object (e.g. fig. 5(a)), or plain Gaussian beam, may be expressed as $E_p(x,y) = |A_p(x,y)| \exp[i\phi_p(x,y)]$. Since the normal PR behaviour is unaffected, a real-time grating can be recorded in the same crystal volume with the same or a different object placed at Q. The real-time PC is of the form $E_{rt}(x,y) = |A_{rt}(x,y)| \exp[i\phi_{rt}(x,y)]$. The significant feature of this scheme is that the readout beam 2 is simultaneously scattered off two distinct gratings, having identical carrier grating wavevectors, with comparable diffraction efficiencies. The interference of these two waves leads to an intensity pattern:

$$I_{OUT} \sim |A_p|^2 + |A_{rt}|^2 + 2|A_p|\,|A_{rt}| \cos[\phi_p - \phi_{rt}].$$

As an example of this, using two Gaussian beams of different divergence for the permanent and real-time recording respectively, Fresnel-type zone plate patterns were obtained, fig. 4. This scheme can be used in optical testing applications where not only do we have real-time wavefront interferometry but also all the advantages of phase conjugate optical imaging.

Image Synthesis and Logic Operations

It is likely that a $\pi/2$ phase shift occurs between the PR and the permanent hologram since the latter corresponds to an absorption grating unshifted with respect to the intensity interference pattern, while, in the diffusion only regime applicable for BSO, a $\pi/2$ phase shift exists for the PR grating. The PR grating can be shifted in real-time with respect to the permanent one, for example optically, by externally imposing phase shifts on one of the writing beams. The two gratings may also be shifted by different amounts by applying an electric field on the crystal. Thus, by controlling the relative phase between the two gratings, image synthesis operations such as addition or subtraction can be achieved.

Fig. 5 shows the results of several operations achieved. Fig. 5(a) shows the reconstructed PC of an object (part of a test chart) obtained by permanent recording and Fig. 5(b) shows the real-time PC's of other objects used. The operations of coherent addition (Fig. 5(c)) and image subtraction (Fig. 5(d)) between these images is also demonstrated. Similarly, in the digital case, the logic operations of exclusive - OR (XOR) and OR can be achieved. Another possible operation using this scheme is two-dimensional differentiation.

Optical Switching

The diffraction efficiency enhancement effect upon illumination of the permanent hologram by an additional beam at 488 nm can be utilized in optical switching/modulation applications. The process has a very fast intensity dependent response time in the millisecond time scale. The insert of Fig. 3 shows a typical oscilloscope trace of the diffracted He-Ne beam modulated by a $\sim$ 100 mW beam at 488 nm. The two states for blue beam ON and OFF are identified.

Conclusions

The recording of permanent absorption holographic gratings due to photochromic effects does not appear to affect (generally) the usual underlying photorefractive behaviour. The multiplexing of permanent and real-time holograms within the same crystal volume has revealed a number of applications in image synthesis, interferometry, optical logic and switching. The origin of the effects observed is not well understood and we are currently investigating the various mechanisms responsible.

References

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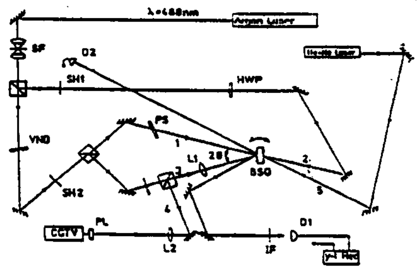

Fig. 1 Experimental arrangement used to investigate the formation of the permanent holograms and to demonstrate image synthesis and interferometric applications.

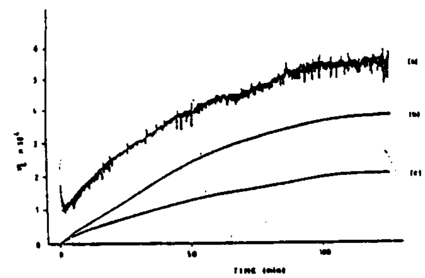

Fig. 2 Temporal development of a permanent hologram. Recording of the diffraction efficiencies η_T(a), η_p(c) and the enhanced diffraction efficiency (b).

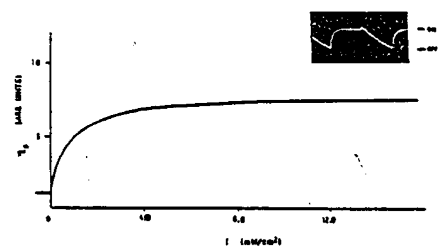

Fig. 3 Diffraction efficiency of the permanent hologram as a function of an enhancing beam at 488 nm. The insert shows a typical oscilloscope trace of the diffracted beam.

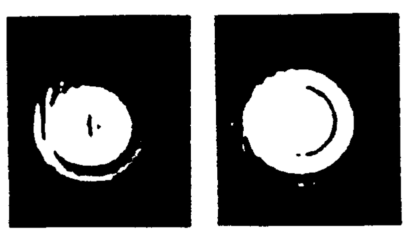

Fig. 4 Interference patterns obtained on simultaneous PC reconstruction of a permanent and a real-time hologram using two Gaussian beams of different divergence for recording.

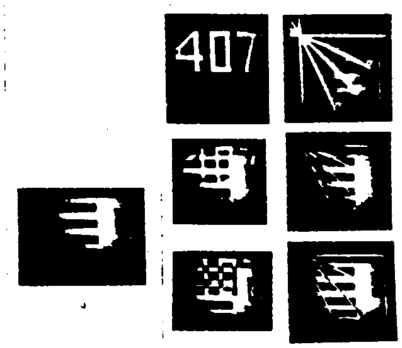

Fig. 5 Examples of image synthesis operations. (a) Image reconstructed by a permanent hologram. (b) Images reconstructed by real-time holograms. (c) Their coherent addition and (d) their subtraction.