Edge-Lit Coherent Backlight for Flat-Panel Holographic Displays

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ABSTRACT

Coherent backlight is an essential component for holographic displays. In this paper, a compact design of edge-lit coherent backlight featuring two holographic optical elements for two-dimensional beam expansion is presented. In experiments, the input laser beam is magnified by a factor of 89 with a diffraction efficiency of 4.3%. More importantly, holographic images can be successfully reconstructed with this backlight.

INTRODUCTION

Holographic displays are usually associated with a set of optical elements, which need a spacious room to be mounted. Among other things, the lasers as the coherent light source are too bulky for the holographic displays to be applied in the consumer electronics. In order to meet the industry trend known as the flat-panel, a backlight with a compact form factor is desired. Although some efforts have been made on compact expanders for lasers using optical folding method or edge-illuminated holograms [1], they can only expand the beam in one dimension. In 2002, Shechter *et al.* introduced a planar beam expander with multiple gratings [2], the input narrow beam could be magnified by a factor of 25. In 2013, Xiong *et al.* [3] proposed a two-dimensional (2D) coherent backlight design using a scattered wave to read out a reflection hologram. Nevertheless, its diffraction efficiency (DE) is only 0.3%, which is too low for practical applications. In this paper, we present an edge-lit coherent backlight design with DE being improved up to 4.3%, which is one order in magnitude higher than its former design [3].

PROPOSED BACKLIGHT DESIGN

The schematic drawing of the proposed coherent backlight design is depicted in Fig. 1. It consists of two HOEs, which are essentially two linear gratings. The first HOE (H_1) is used to expand a laser beam along the vertical direction as an elongated beam, which will be further expanded along the horizontal direction by the second HOE (H_2). Therefore, 2D beam expansion is realised. The slant angles of the HOEs, i.e. α and β, determine the width and thickness of the backlight, respectively. The propagation direction of undiffracted wave should be perpendicular to the diffracted direction to reduce disturbance. All the other higher diffraction orders can be negligible if both HOEs are transmission volume holograms. For achieving high DE, Bragg mismatch [4] should be avoided by firmly fixing the angles of the reading beam, H_1, and H_2. It should be noticed that H_1 and H_2 are not equivalent to two mirrors, upon the reflection of which, the shape and size of the laser beams will keep unchanged.

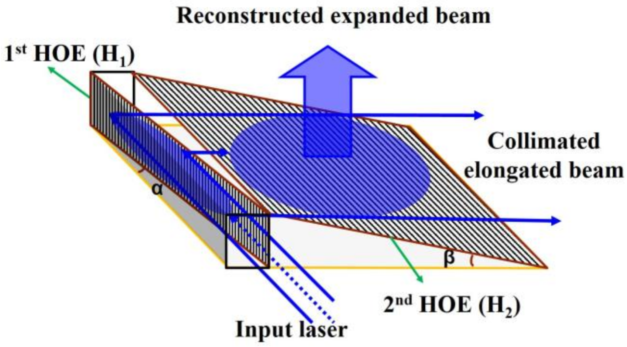
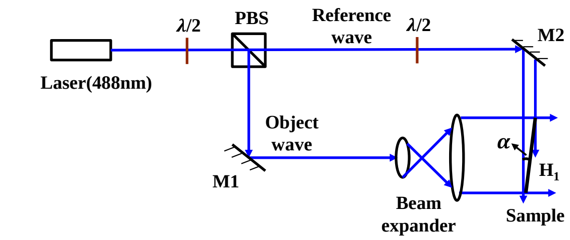


Fig. 1. Schematic drawing of the edge-lit coherent backlight.

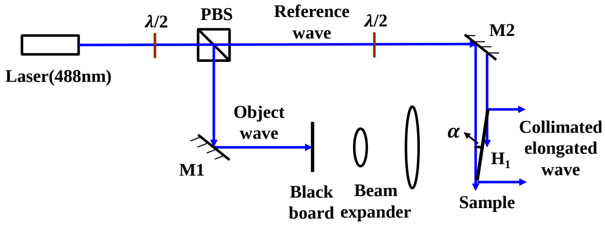
EXPERIMENTS

The material used to fabricate the foregoing HOEs is polymer dispersed liquid crystal (PDLC) [5], which comprises 50 wt%: 35.4 wt%: 13 wt%: 1 wt%: 0.6 wt% of liquid crystal 5CB (HCCH): TMPTA monomer (Aldrich): N-vinylpyrrollidone (Aldrich): N-phenylglycine (Aldrich): Rose Bengal (Aldrich). The uniform PDLC mixture is injected into an empty cell, whose cellgap is controlled by 30-μm Mylar spacers.

Figures 2(a) and 2(b) illustrate the optical setups for H_1 during recording and reconstruction, respectively. In Fig. 2(a), the recording light derived from a 488-nm laser is set to s-polarization to ensure high interference efficiency as the recording angle is almost 90°. The reference beam is emitted from the laser with a diameter 0.1 cm and the area of the spot is 0.0079 cm^2. The slant angle α of H_1 is 6°, which enables the reference beam to illuminate an elongated elliptic area (0.075 cm^2) on H_1. In addition, the object beam is expanded to 1 cm in diameter by a conventional beam expander. The intensities of both recording beams are 2 mW/cm^2 on H_1, and the exposure duration is 1 minute. In Fig. 2(b), the object plane wave is blocked by a black board, and the reference beam reconstructs a collimated elongated beam, which will later interfere with another plane wave during recording of H_2.



(a)



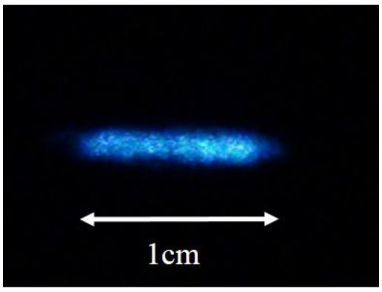
(b)

Fig. 2. Optical setups for H_1 during (a) recording and (b) reconstruction.

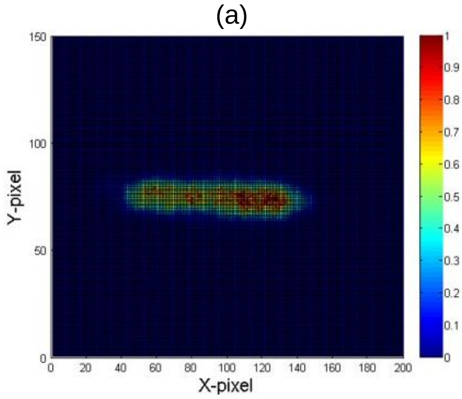
RESULTS AND DISCUSSION

1D Expansion

As shown in Fig. 3(a), the collimated elongated beam with an area of 0.075 cm^2 is reconstructed by the reading beam. The intensity of the collimated elongated beam is almost uniform, as shown in Fig. 3(b). The power of the elongated beam is measured as 0.033 mW, when the power of the reading beam is 0.158 mW. The DE of H_1 is 21%, defined as the ratio of the power of the reconstructed collimated elongated wave to that of the reading beam.



(a)

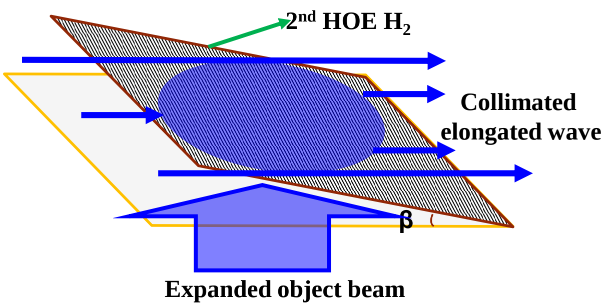


(b)

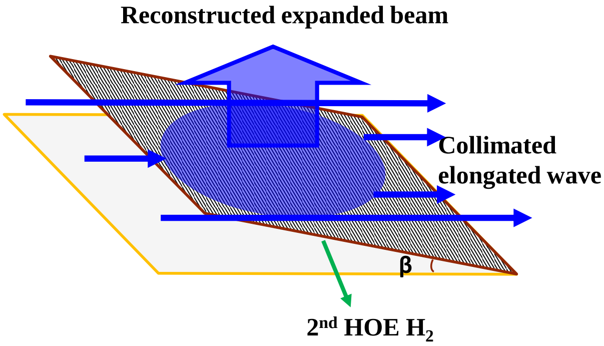
Fig. 3. (a) Image of diffracted waves of H_1, (b) normalised intensity distribution.

2D Expansion

We use the collimated elongated wave generated by H_1 as the reference beam, and a circularly expanded beam from a conventional beam expander as an object beam, to record H_2, as shown in Fig. 4(a). Because the interbeam angle is 90°, both waves are set to s-polarization to maximize the interference. The slant angle β of H_2 is 6°, and the collimated elongated wave illuminates a circular area (0.7 cm^2) on H_2. The object plane wave is expanded to 1 cm in diameter. The intensities of both recording waves are 1 mW/cm^2, and the exposure duration is 2 minutes.



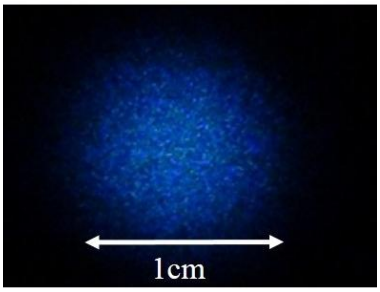
(a)



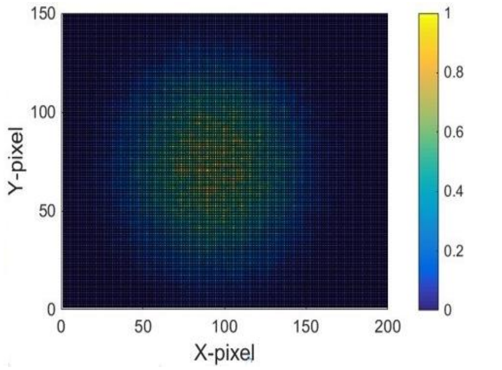
(b)

Fig. 4. Optical setup for H_2 during (a) recording and (b) reconstruction.

Figure 5(a) shows the reconstructed expanded beam with a power 0.0068 mW, when the power of the reading beam is 0.158 mW. Figure 5(b) is the normalised intensity distribution. The definition of the total DE is the ratio of the power after leaving H_2 to the power incident on H_1. The DE is measured as 4.3%.



(a)



(b)

Fig. 5. (a) Image of diffracted waves of H_2, (b) normalised intensity distribution.

Hologram Reconstruction

As shown in Fig. 6, we use conventional beam expander and the proposed edge-lit backlight, respectively, to generate the expanded collimated beams, which are then incident onto a spatial light modulator (SLM) to read out the holographic 3D images. In Figs. 6(a) and 6(b), one can see that when the camera focuses on letter A/B, then letter B/A will be out of focus, appearing blurred. As seen in Figs. 6(c) and 6(d), there is a little distortion in the holographic images formed by the reconstructed expanded beam.

CONCLUSIONS

An edge-lit coherent backlight featuring two HOEs has been demonstrated. With this backlight, a laser beam can be magnified by a factor of 89, from the original beam size of 0.0079 cm^2 to the expanded beam size of 0.7 cm^2. The DE of each grating is 21% and thus the total DE of the backlight is 4.3%. In addition, holographic images rendered on a SLM have be successfully reconstructed using this backlight. Hopefully, this type of coherent backlight would lay a foundation for the flat-panel holographic displays.

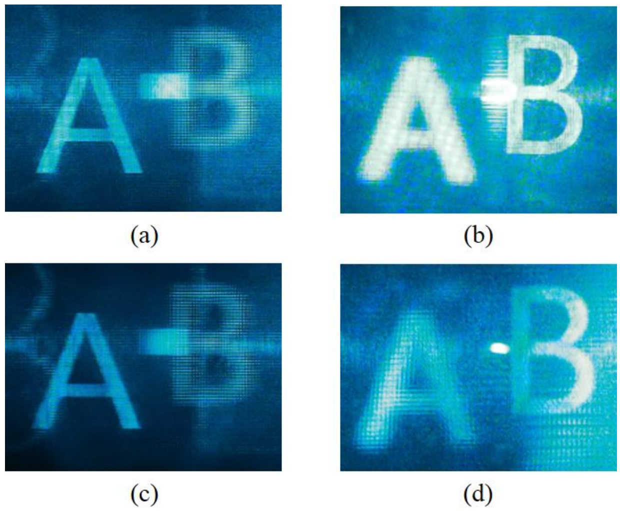


Fig. 6. Reconstructed holographic images by using the conventional beam expander when focusing on (a) 'A' or (b) 'B'; and by using the proposed edge-lit backlight when focusing on (c) 'A' or (d) 'B'.

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