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Contrast of diffuse object holograms in PVA-Acrylamide photopolymers: Real time measurements.

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ABSTRACT

New holographic recording materials based on photopolymerizable systems have contributed significantly to the recent growth of holographic applications. In this paper we experimentally analyze diffuse-object holograms recorded in a photopolymerizable material. The recording and reconstruction of holograms are in real time without a chemical process and then it is possible to know the performance of these materials when diffuse-object holograms are made and, at the same time, to measure the contrast of them. The holographic images were captured in real time every 10 s and diffraction efficiency and contrast were calculated. In these experiments the influence of the intensity and the beam ratio on these holographic characteristics was analysed. Our first results show that it is possible to obtain diffuse-object holograms with a diffraction efficiency of 8% and a contrast of 0.93.

Keywords: Diffuse-object holograms, PVA-Acrylamide photopolymers, contrast

1. INTRODUCTION

In recent years, many types of photopolymerizable systems have been developed as material for recording holograms¹. These materials have many characteristics, such as good energetic and spectral sensitivity, high resolution, high diffraction efficiency, good signal-to-noise ratio, temporal stability and processing in real time, which make them suitable for recording holograms. All these characteristics mean that such materials are very useful in applications such as: holographic optical storage, production of holographic optical elements and holographic interferometry...^{2,3}

Despite the fact that many systems of this type have been developed, very few studies are to be found relating to the measurement of the optical quality of transmission holograms of diffuse objects and noise sources that reduce the quality of these images⁴.

In this paper, we study the influence of the beam ratio and intensity on the contrast in diffuse-object holograms stored in a photopolymer and reconstructed in real time.

2. EXPERIMENTAL SET-UP

The photopolymer used in our experiment is based on acrylamides⁵. The photopolymerizable system used consisted of acrylamide as monomer, triethanolamine as radical generator and eosin yellowish as sensitizer. All the components were supported in a film of polyvinylalcohol. The photosensitive aqueous solution was prepared by adding 1.5 ml of 8g/l eosin yellowish and 8 ml of 2.5 M acrylamide and 1.5 M triethanolamine to 50 ml of polyvinylalcohol (10% by weight). The film was prepared by coating a 20 x 40 cm² glass plate with the photosensitive solution, allowing it to dry for 24 h. under normal conditions ($T \approx 21-23$ °C, $RH \approx 40-60$ %). The resulting thickness of the film was 70 ± 5 μ m.

The experimental set-up used is shown in figure 1. Both recording and reconstruction of the hologram was done with a 5W Argon laser emitting at 514 nm. The object used in these experiments was a test target storing only the zone corresponding to a frequency of 1.6 lines/mm. The virtual image provided by the hologram was captured using a CCD

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camera. In order to reconstruct the virtual image on the CCD plane, a single lens was employed. The images were captured in real time every 10 s.

Figure 1: Experimental set-up. BS: Beam Splitter, M: Mirrors, SF: Spatial Filter, L: Lens, D: Diaphragm, ES: Electronic Shutter, H: Holographic Plate.

In order to evaluate the optical quality of the holographic images we used the contrast (equation 1) and the diffraction efficiency (equation 4), defined as:

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (1)$$

where I_{max} and I_{min} are given by:

$$I_{max} = \bar{I}_1 \text{ with } I_1 = \sum_{j=1}^{128} \left\{ \sum_{p=1}^5 \sum_{i=N_{2p}}^{N_{2p+1}} I_{ij} \right\} \quad (2)$$

$$I_{min} = \bar{I}_2 \text{ with } I_2 = \sum_{j=1}^{128} \left\{ \sum_{p=0}^5 \sum_{i=N_{2p+1}}^{N_{2p+2}} I_{ij} \right\} \quad (3)$$

so that: $\sum_{p=0}^5 (N_{2p+1} + N_{2p+2}) = 128$

Where I_{ij} is the intensity of the pixel in the position i, j and N_i mark the beginning and end of each of the fringes of the test target.

Since the contrast of the object image depends on both the total incident intensity and the beam ratio, all contrast measurements have been normalised with respect to the contrast of the object given by equation 1.

And the diffraction efficiency calculated from the image captured by the CCD camera:

$$DE = \frac{I_d}{I_i} \times 100 \quad (4)$$

with:

$$I_d = \sum_{i=1}^{128} \sum_{j=1}^{128} I_{ij} \quad \text{and} \quad I_i = K \cdot I_o = K \sum_{i=1}^{128} \sum_{j=1}^{128} I_{oij}$$

where I_d is the diffracted intensity, I_i is the incident intensity, I_o is the intensity of the object beam and K the beam ratio.

3. RESULTS AND DISCUSSION

3.1 Influence of the intensity on the optical quality of the holographic images

In order to analyse the influence of the intensity on the optical quality of the holographic images we represent the contrast as a function of the exposure for different total incident intensities, $I = [0.6, 1.2, 2.4, 4.8]$ mW/cm² and for a constant beam ratio, $K = 5$.

In figure 2.a it can be seen that when the intensity is increased, the maximum contrast increases and the gradient of the first part of the graph is greater. In other words, the velocity of polymerization increases and the hologram is formed in less time. Figure 2.b shows the contrast as a function of efficiency. When the intensity is low, $I = 0.6$ mW/cm², the contrast and the diffraction efficiency are very low. With this intensity the material hardly responds and the hologram is not stored correctly. On increasing the intensity the contrast and the diffraction efficiency reached are greater. Starting from $I = 1.2$ mW/cm² the maximum contrast values are reached for the same diffraction efficiency value, but with higher diffraction efficiency values the contrast decreases. This means that the noise is stored more slowly than the signal and, although the diffraction efficiency increases, the quality of the stored image is worse.

These results are presented in figure 2.c, which shows the maximum contrast values and their corresponding diffraction efficiency values and the maximum diffraction efficiency value for each of the work intensities.

In figure 3 the images obtained for $I = 2.4$ mW/cm² are shown as an example. The first image corresponds to the image of the object and the rest represent the temporal evolution of the hologram stored in the photopolymer. As can be seen in the final images, not only the signal is stored but also the noise.

Figure 2a

Figure 2b

Figure 2c

Figure 2: a) Normalised contrast as a function of time for $K = 5$ and $I = [0.6, 1.2, 2.4, 4.8]$ mW/cm². b) Normalised contrast as a function of efficiency for $K = 5$ and $I = [0.6, 1.2, 2.4, 4.8]$ mW/cm². c) Maximum normalised contrast, efficiency and maximum efficiency as a function of intensity for $K = 5$.

Images for $K=5$ and $I=2.4$ mW/cm²

Figure 3: Temporal evolution of the images corresponding to the stored holograms for $I = 2.4$ mW/cm².

3.2 Influence of the beam ratio on the optical quality of the holographic images

In a second experiment the influence of the beam ratio on the quality of the holographic image has been studied. To this end, the beam ratio has been varied, $K = [3, 5, 10, 20]$ for a constant intensity, $I = 1.2 \text{ mW/cm}^2$.

In figure 4.a the variation of the normalised contrast versus the exposure is represented. It can be seen that on increasing the beam ratio the maximum contrasts reached increase, obtaining the best results for $K = 20$ with a contrast of 0.93. As regards the energetic sensitivity, we can say that this decreases when the beam ratio increases.

If we represent the contrast versus the diffraction efficiency (figure 4.b), it is observed that on decreasing the beam ratio the contrast values reached are lower, but the diffraction efficiency values reached are higher. This is more clearly observed in figure 4.c, which shows the maximum contrasts reached and the corresponding efficiency value for the different beam ratios.

We can conclude from these figures that for this intensity the highest contrast is obtained for $K = 20$ with a value of 0.93 and a diffraction efficiency of 8%.

Figure 4a

Figure 4b

Figure 4c

Figure 4: a) Normalised signal-to-noise ratio as a function of time for $I = 1.2 \text{ mW/cm}^2$ and $K = [3, 5, 10, 20]$. b) Normalised signal-to-noise ratio as a function of efficiency for $I = 1.2 \text{ mW/cm}^2$ and $K = [3, 5, 10, 20]$. c) Maximum normalised contrast and efficiency as a function of K for $I = 1.2 \text{ mW/cm}^2$.

4. CONCLUSIONS

The experimental results shown in this paper indicate that the contrast depends on the intensity and the beam ratio. The contrast increases when the beam ratio and the intensity increase. The best results were obtained for a beam ratio of 20 and an intensity of 1.2 mW/cm^2 , with a contrast of 0.93 and a diffraction efficiency of 8%.

Another question is the response of the material, which needs a minimum of intensity in order for the hologram to be stored. For $I = 0.6 \text{ mW/cm}^2$ we can say that only the CCD noise is stored. The holographic images are stored starting from $I = 1.2 \text{ mW/cm}^2$. On the other hand, the information storage is quicker when the work intensity increases.

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