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Fabrication of computer-generated phase holograms using photopolymers as holographic recording material

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ABSTRACT

Photopolymers are studied as holographic recording material for computer-generated phase filters for pattern recognition by optical correlation. The analysis was performed using a copying process with a computer-generated filter, which is produced by means of a high resolution graphic device, as a master. In this work the low spatial frequency response of the photopolymer as holographic material is studied. The copying process used in this work consists of storing the pattern contained in the master in a photopolymer used as a holographic recording material. This photopolymer does not work in real-time, it is possible to store the holographic optical element for a long time because the dye is finished during exposition and the chemical process is not necessary after exposition. We used partially coherent light, from a high pressure mercury lamp. The photopolymer used in these experiments was composed of acrylamide and triethanolamine as the coinitiator, photoinitiated with a dye, yellow exine. Components were supported by a film of poly(vinylalcohol) (PVA). The resulting thickness of the film was approximately 70 μm . Diffraction gratings and Fresnel lenses were obtained as phase holograms by index and thickness modulation, monitored with an electron microscope. First order diffraction efficiency achieved was 30%.

Keywords: Photopolymers, Holographic Recording Materials, Low Spatial Frequency, Optical Correlation Filters, Computer-Generated Holograms, Hologram Copying

1. INTRODUCTION

Holographic optical elements (HOEs) is one of the application fields in which holography has proven to be of great utility. Recently there has been increasing interest in the use of holographic HOEs for applications in optical interconnections. More precisely computer-generated holograms (CGHs) are HOEs of interest in the field of the optical processing of information. Many substrate materials have so far been proposed for fabrication of phase-only CGHs. These include silver halide, dichromated gelatin and photopolymers. The use of silver halide and dichromated gelatin involves wet chemical processing and requires careful control of processing conditions in each step to produce consistent results. In contrast, the fabrication of HOEs with photopolymers requires only simple dry processing (UV curing)^{1,2}. In addition, the continual improvements in optical performance of photopolymers in recent years has made them more attractive and popular for various applications. Another advantage is the low cost of fabrication due to the possibility of producing them on a large scale. Mass production can, however, be achieved by making copies of a master amplitude mask by contact printing. In this work the potential of photopolymer as a recording material for phase-only noninterferometric CGHs is investigated. The research in holographic recording materials has been focused on medium and high spatial frequencies and there are few papers about low spatial frequencies in photopolymers. The frequencies involved in CGHs attain a maximum of about 30 lines/mm. In this paper the low spatial frequency response of the photopolymer as holographic material is studied.

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2. EXPERIMENTAL

In order to obtain a phase computer-generated filter we use a copying process. The copying process³ consists of storing the pattern contained in the master in a photopolymer used as a holographic recording material. This photopolymer does not work in real time. We use partially coherent light from a high pressure mercury lamp, which enables us to work with more economical sources and devices, and provides stable conditions that are not as strict as those used in conventional holographic devices, and also the low coherence of the source gives better signal to noise ratio. The photopolymer has low energetic sensitivity and the absorption curve of the dye used is between 450 and 550 nm, as can be seen in figure 1.

Figure 1.- Photopolymer's transmittance versus wavelength.

First the master is designed by digital techniques. The design is saved in a PostScript file, which is printed by a Linotronic 630 printer⁴ on photographic film. This is a high resolution commercial laser writer usually used in graphic arts. A binary transmittance transparency of high contrast is produced. The fidelity of the implementation of the digital design depends on the resolution in the positioning of the printed spot of the printer and on the spot printed by the graphic device. The resolution of the Linotronic 630 is 3251 dots per inch (dpi) and the diameter of the spot is 13 μm . The combination of these two parameters limits the maximum spatial frequency that can be implemented on the transparency to approximately 30 lines/mm. The copying master is composed of different symmetrical gratings and Fresnel lenses. We mean by symmetrical gratings those with equal width in the dark and in the transparent zones.

Once the master has been produced it is copied on a holographic photopolymer. The master is placed in direct contact with the photopolymer, with the master and the photosensitive layer of the copy placed together. A collimated beam from a high-pressure mercury lamp, without interferential filter and incident to the master and copy, was used to expose the photopolymer.

The photopolymer used in these experiments was composed of acrylamide and triethanolamine as coinitiator, photoinitiated with a dye, yellow eosine. Components were supported by a film of poly(vinylalcohol) (PVA). The photosensitive aqueous solution was prepared with over 50 ml of polyvinylalcohol of 10% by weight, 2.5 ml of yellow eosine and 8 ml of a solution of acrylamide and triethanolamine. The film was prepared by coating a photosensitive solution on a 20x40 cm^2 glass (BK7) with a TLC coating provided by CAMAG allowing it to dry 24h under ambient conditions (65% R.H. and 20°C). The resulting thickness of the film was approximately 70 μm , measured with a P.I.G. 455 apparatus supplied by Neurtek. The composition used in the preparation of the photopolymer solutions is given in table I.

Table 1

Acrilamide	$4.4 \times 10^{-1} \text{ M}$
Triethanolamine	$2.0 \times 10^{-1} \text{ M}$
Yellow eoixine	$1.9 \times 10^{-5} \text{ M}$
PVA	10%

Diffraction gratings and Fresnel lenses were obtained as phase holograms. The performance of the diffraction gratings is evaluated in terms of diffraction efficiency. For the experimental measurement we have illuminated the grating with a plane wave from a He-Ne laser ($\lambda = 632.8 \text{ nm}$) entering normal to the surface of the recording material. The diffracted beam intensity is measured and the first order diffraction efficiency (η_1) is calculated as the ratio of the energy in the first diffracted order to the incident energy. An analogous definition is established for the zeroth order diffraction efficiency (η_0).

We multiply these values by 100 to represent the percentage of the incident energy which arrives at each diffraction order.

We copy each master grating with different exposures. The exposure range considered is from 50 to $500 \mu\text{J}/\text{cm}^2$.

The goal of this study, made by varying the exposure, is to obtain the highest η_1 value for each spatial frequency. Curves showing the variation of the peak diffraction efficiency with exposure are presented in figure 2. The masters we used had a spatial frequency from 4 to 25 lines/mm. As can be seen in figure 2 the diffraction efficiency obtained with a partially coherent light CGH copy has a maximum value of 30% which is similar to those obtained with coherent light; low spatial frequency gratings obtained in photopolymer are thin grating copies.

Figure 2.- Diffraction efficiency versus exposure for different spatial frequencies.

3. RESULTS AND CONCLUSIONS

The holographic results, which appear in figure 2, show that the maximum diffraction efficiency reached is for low values of exposure and for a studied range of frequencies. As can be observed, it is possible to obtain a diffraction efficiency of 30% with an energetic sensitivity of $85 \mu\text{J}/\text{cm}^2$. In figure 3 we can see a photograph by electron microscope of a Fresnel lens. It is possible to see a thickness modulation. For this reason CGHs obtained in photopolymer were phase holograms by index and thickness modulation.

We have demonstrated the feasibility of photopolymer as a recording material to obtain diffraction gratings and Fresnel

lenses as CGHs, when photopolymer does not work at real time. By using these systems, diffraction efficiencies of almost 30% can be achieved when energy is $85 \mu\text{J}/\text{cm}^2$ with a low coherent source. CGHs mass production in photopolymer is possible using this copying method.

Figure 3.- Electron Microscope Photograph of Fresnel lens.

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4. Linotronic 630 is made by Linotype-Hell Co., 425 Oser Ave. Hauppauge, NY 1178.