PROCEEDINGS OF SPIE

Holography 2005

International Conference on Holography, Optical Recording, and Processing of Information

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Editors

21–25 May 2005
Varna, Bulgaria

Organized by
Central Laboratory of Optical Storage and Processing of Information,
Bulgarian Academy of Sciences (Bulgaria)

Sponsored by
SPIE Bulgaria Chapter
European Science Foundation (France)
DEMAX Plc. (Bulgaria)
Ministry of Education and Science (Bulgaria)

Published by
SPIE—The International Society for Optical Engineering

Volume 6252

The International Society for Optical Engineering

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Author(s), "Title of Paper," in *Holography 2005: International Conference on Holography, Optical Recording, and Processing of Information*, edited by Yury Denisyuk, Ventseslav Sainov, Elena Stoykova, Proceedings of SPIE Vol. 6252 (SPIE, Bellingham, WA, 2006) Article CID Number.

ISSN 0277-786X
ISBN 0-8194-6311-6

Published by
SPIE—The International Society for Optical Engineering
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone 1 360/676-3290 (Pacific Time) · Fax 1 360/647-1445
http://www.spie.org

Printed in the United States of America.

High thickness acrylamide photopolymer for peristrophic multiplexing

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ABSTRACT

The acrylamide photolymers are considered interesting materials for holographic media. They have high difraction efficiency (ratio of the intensities of the diffracted and the incident beams), an intermediate energetic sensitivity among other materials and post-processing steps are not necessary, therefore the media is not altered. The layers of these materials, about 1 mm thick, are a suitable media for recording many diffraction gratings in the same volume of photopolymer using peristrophic multiplexing technique, with great practical importance in the field of holographic memories type WORM (write once read many). In this work we study the recording of diffraction gratings by peristrophic multiplexing with axis of rotation perpendicular to the recording media. The photopolymer is composed of acrylamide as the polymerizable monomer, triethanolamine as radical generator, yellowish eosin as sensitizer and a binder of polyvinyl alcohol. We analyze the holographic behaviour of the material during recording and reconstruction of diffraction gratings using a continuous Nd:YAG laser (532 nm) at an intensity of 5 mW/cm^2 as recording laser. The response of the material is monitored after recording with an He-Ne laser. We study the recording process of unslanted diffraction gratings of 1125 lines/mm. The difraction efficiency of each hologram is seen to decrease as the number of holograms recorded increases, due to consumption of the available dynamic range, in a constant exposure scheduling. It can be seen that the photopolymer works well with high energy levels, without excessive dispersion of light by noise gratings. In order to homogenize the difraction efficiency of each hologram we use the method proposed by Pu. This method is designed to share all or part of the avaliable dynamic range of the recording material among the holograms to be multiplexed. Using exposure schedules derived from this method we have used 3 scheduling recordings from the algorithm used. Additionaly, we use an exponential scheduling recording in order to correct the exposure times from the first iteration of the algorithm.

Keywords: photopolymer, peristrophic multiplexing, holography, acrylamide

1. INTRODUCTION

The acrylamide photolymers with a polyvinyl alcohol (PVA) binder are considered interesting materials for holographic media[1,2]. Their most important characteristics include high diffraction efficiency (ratio of the intensities of the diffracted and the incident beams), an intermediate energetic sensitivity among other materials and post-processing steps are not necessary after the hologram has been recorded, therefore the media is not altered[3]. Recently acrylamide based photopolymers have been developed in 1 mm thick solid layers, and these are ideal for use as the recording medium in studies relating to holographic information storage[4]. The layers about 1 mm thick, are a suitable media for recording many diffraction gratings in the same volume of photopolymer using peristrophic multiplexing technique, with great practical importance in the field of holographic memories type WORM[5] (write once read many).

In order to take full advantage of the storage capacity of the recording medium, various multiplexing[5] techniques are used enabling multiple holograms to be recorded in a given volume of photopolymer. Depending on its thickness and

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Holography 2005: Intl. Conf. on Holography, Optical Recording, and Processing of Information, Yury Denisyuk, Ventseslav Sainov, Elena Stoykova, Eds., Proceedings of SPIE Vol. 6252, 62520U, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.677014

composition, each photopolymer is capable of reaching a particular dynamic range[6], that is, it enables a certain number of holograms to be recorded with constant maximum diffraction efficiency for each hologram.
In this work we study the influence of recording diffraction gratings by peristrophic multiplexing in the acrylamide photopolymer characteristics. We analyze the holographic behaviour of an acrylamide photopolymer with hydrophilic binder in layers around 1 mm thickness. The photopolymer is composed of acrylamide as the polymerizable monomer, triethanolamine as radical generator, yellowish eosin as sensitizer and a binder of PVA[4]. We analyze the holographic behaviour of the material during recording of diffraction gratings using a continuous Nd:YAG laser (532 nm) at an intensity of 5 mW/cm^2 as recording laser. The response of the material is monitored after recording with an He-Ne laser. We study the recording process of diffraction gratings of 1125 lines/mm, in 720, 880 μm photopolymer thick layers with PVA Mw=130000 binder.

We use the peristrophic multiplexing technique with the axis of rotation perpendicular to the recording media to store holograms, with low individual diffraction efficiency (DE), in a previously developed acrylamide photopolymer approximately 1mm thick[3]. The DE of each hologram is seen to decrease as the number of holograms recorded increases, due to consumption of the available dynamic range in a constant exposure scheduling.

The photopolymer works well with high energy levels, without excessive dispersion of light by noise gratings. In order to homogenize the DE value of each hologram we use the meted proposed by Pu[8]. This method is designed to share all or part of the avaliable dynamic range of the recording material among the holograms to be multiplexed.

Using exposure schedules derived from this method we have used 3 scheduling recordings from the algorithm used. Additionaly, we use an exponential scheduling recording in order to correct the exposure times from the first iteration of the algorithm.

2. EXPERIMENTAL

2.1 Preparation of the material

In recording materials based on PVA/acrylamide (AA), a solution of PVA in water forms the matrix and this is used to prepare the solution of monomer (AA) and photopolymerization initiator system: yellowish eosin (YE), triethanolamine (TEA). The PVA was supplied by Fluka, AA and TEA by Sigma and YE by Panreac.

We prepare the solutions using a conventional magnetic stirrer, under red light and in laboratory conditions (T= 21 °C, relative humidity RH= 48%). In Table 1 are the concentrations of the components of optimized[4] photopolymer solution wich is deposited in order to obtain solid layers of recording media. The solutions are deposited by gravity, in polystyrene or polymethylmethacrylate circular molds to avoid strain and distortion in the material during the water evaporation process, and left in the dark to allow the water to evaporate, while recording the laboratory conditions (T, relative humidity) during the process. When part of the water has evaporated, the "dry" material is removed from the mold, cut into squares and adhered, without the need for adhesive, to the surface of glass plates measuring 6.5×6.5 cm^2. The plates are then ready for exposure, which takes place immediately. The thickness of the material is measured using a conventional micrometer.

Table 1. Concentrations of the components of optimized photopolymer solution

Components	Concentration	
Polyvinyl alcohol M_w=130000	13.30%	w/v
Triethanolamine	0.15	M
Acrylamide	0.34	M
Yellowish eosin	9.00×10^{-5}	M

2.2 Holographic set-up

To study the behavior of the photopolymer as a holographic recording material, we obtained unslanted diffraction gratings using a holographic set-up. The experimental device is shown in Figure 1. A Nd:YAG laser with 532 nm was used to store diffraction gratings by means of continuous laser exposure. The laser beam was split into two secondary beams with an intensity ratio of 1:1. The diameters of these beams were increased to 1.5 cm with an expander, while spatial filtering was ensured. The object and reference beams were recombined at the sample at an angle θ=17.4° with an appropriate set of mirrors, and the spatial frequency obtained was 1125 lines/mm. The working intensity at 532 nm

was 5 mW/cm^2. The diffracted and transmitted intensity were monitored in real time with a He-Ne laser positioned at Bragg's angle (θ'=20.8°) tuned to 633 nm, where the material is not sensitive. In order to obtain transmission and diffraction efficiency as a function of the angle at reconstruction we placed the plates on a rotating stage. The transmission and diffraction efficiency (TE and DE respectively) were calculated as the ratio of the transmitted and diffracted beam, respectively, to the incident power.

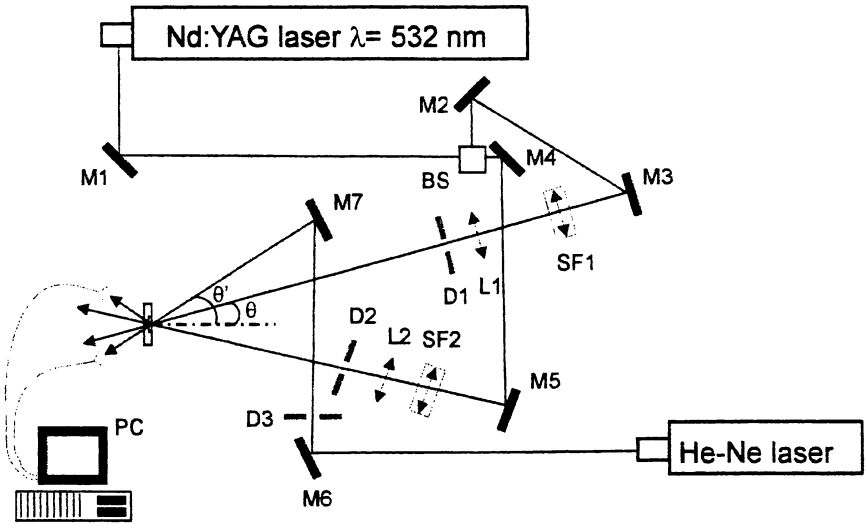

Fig. 1. Experimental set-up: BS, beamsplitter, Mi, mirror, SFi, spatial filter, Li, lens, Di, diaphragm, PC, data recorder.

2.3 Peristrophic multiplexing

In order to analyze the photopolymer characteristics on several holograms recording, we have used the peristrophic multiplexing technique, with rotation axis perpendicular to media layer. we put the layer on automatic rotation stage in order to record the angular response of diffraction layers and we use an manual rotation stage additionally with the automatic rotation stage for the rotation with rotation axis perpendicular to media layer. At the end of register, we are able to reconstruc the holograms by angular scan.

3. RESULTS

3.1 Consumption of the photopolymer's dynamic range

17 holograms with 10 s of exposure time are registered in 880 μm thick photopolymer layer at 5 mW/cm^2 of recording beams total intensity and an angular separation of 10 degrees. Figure 2 shows the reconstruction carried out immediately after recording, the x axis is the accumulated energy after each exposure. A reduction in the DEmax of each hologram is seen as the number of holograms recorded increases due to consumption of dynamic range. Figure 2 shows the values of DE, TE and DE plus TE as a function of the accumulated energy tow which the photopolymer is exposed. When the number of holograms recorded using a constant exposure scheduling increases, the individual DE decreases. This photopolymer is seen to respond well to high energy levels, since the sum of DE and TE remains in the range of 78-91%, thus indicating low losses due to absorption and dispersion of light. This is especially noticeable towards the end of the recording, when losses due to dispersion of light usually increase due to the accumulation of noise gratings formed as a result of the large amount of energy to which the photopolymer is exposed.

3.2 Optimization of the recording process

In order to homogenize the individual DE values and make better use of the dynamic range of the photopolymer, the method proposed by Pu[8] is used. From the curve obtained in the case of constant exposure (Figure 2) we obtain the curve/graph for A, cumulative grating strength up to hologram n (Figure 3), given by equation (1).

$$A = \sum_{i=1}^{n} \eta_i^{1/2} \tag{1}$$

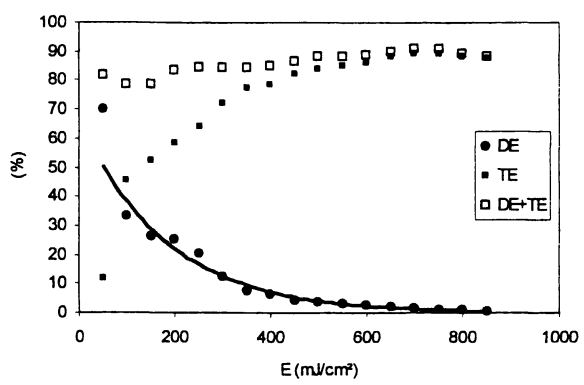

Fig. 2. Recording of 17 holograms with constant exposure by peristrophic multiplexing.

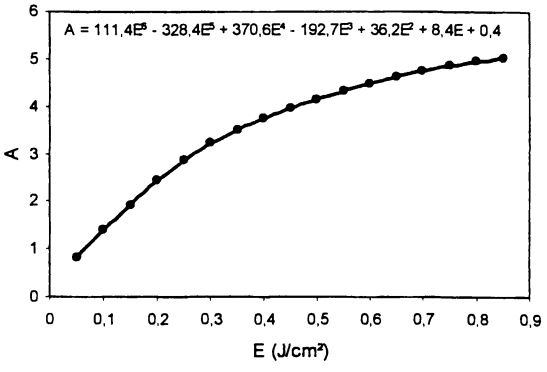

Fig. 3. Cumulative grating strength in constant exposure recording

The experimental points are fitted using a grade 6 polynomial as shown in Figure 3. E is the cumulative exposure energy. By taking the derivative of equation in Figure 3, the grating strengh growth rate as a function of exposure energy is obtained. In order to obtain equal grating strength holograms it es necessary allocate the entire dynamic range of the photopolymer equally among the holograms. From the graph in Figure 3 we obtain A_{sat} , which is the saturation grating strength. The parameter A_{sat} when diffraction gratings are recorded is equivalent to M/#, which refers to the dynamic range of the photopolymer. From the recording at constant exposure we obtain A_{sat}= 5.
The exposure schedule in terms of exposure time becomes:

$$\frac{A_{sat}}{IMt_n} = a_1 + 2a_2\sum_{i=1}^{n-1}E_i + 3a_3\left(\sum_{i=1}^{n-1}E_i\right)^2 + 4a_4\left(\sum_{i=1}^{n-1}E_i\right)^3 + 5a_5\left(\sum_{i=1}^{n-1}E_i\right)^4 + 6a_6\left(\sum_{i=1}^{n-1}E_i\right)^5 \quad (2)$$

E_i is the amount of energy the photopolymer received in order to record the i'th hologram, M=17 the number of stored holograms, a_1 through a_6 are the parameters obtained from fitting Figure 3.Figure 4 shows the exposure times obtained from the algorithm given by equation (2) for 3 iterations. After each iteration a new recording is done in a new layer of photopolymer with the values of exposure time obtained. Figure 5 shows the values of DE obtained for each hologram in the different steps, with the times obtained in each iteration (Figure 4). It can be seen that in the first iteration the algorithm reduces the exposure times assigned to holograms 1-13 to less than the 10 s used in constant exposure scheduling, whereas it increases the time to more than 10 s for holograms 14-17. In this way, an attempt is made to reduce the DE of the first holograms and therefore the last holograms can increase their DE.

Using the times of the first iteration, the range of values of DE is reduce (DE=0-50%), which implies a better use of the dynamic range of the photopolymer (A_{sat}= 6.14 compared with 5.00 in the case of constant exposure). In iteration 2 the algorithm reduces the times assigned to all the holograms (Figure 4) and more homogeneous values of DE (0-6%) are obtained, although the value Asat=2.56 is lower than for constant time exposure. This is due to the fact that the exposure times are very short, bearing in mind the energetic sensitivity of the photopolymer. In iteration 3 the times proposed are very similar for the first holograms and are shorter for the last ones, so the algorithm attempts to homogenize the DE values to the lowest level (the one obtained for the first holograms after iteration 2). Based on the best result obtained with the algorithm (iteration 1), which achieves the most homogeneous DE values while maximizing the value of A_{sat}, an additional improvement is proposed consisting in calculating only iteration 1 and slightly modifying the values obtained for t using an exponential curve that reduces the times for the first holograms (so as to conserve the dynamic range), increases the time allotted to the middle holograms (so that a higher DE is obtained than with the times of iteration 1) and reduces the times for the last holograms. The continuous line in Figure 4 represents the exponential scheduling given by the equation:

$$t_i = 2.7\exp(0.096i) \quad (3)$$

where t_i is the time allotted to hologram i. The result obtained with this scheduling is shown in the curve step 4 in Figure 5. Greater homogenization of the DE values (1.34-22.91%) is obtained than with the scheduling of the first iteration (0-50%), although the dynamic range achieved is somewhat smaller A_{sat}=5.61.

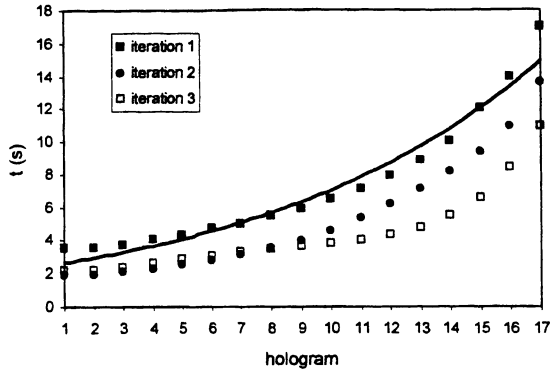

Fig. 5. DE of each hologram after the 4 recordings performed. Iteration 1-3 with the times given by the algorithm in the 3 iterations. Step 4 with the times from equation (3).

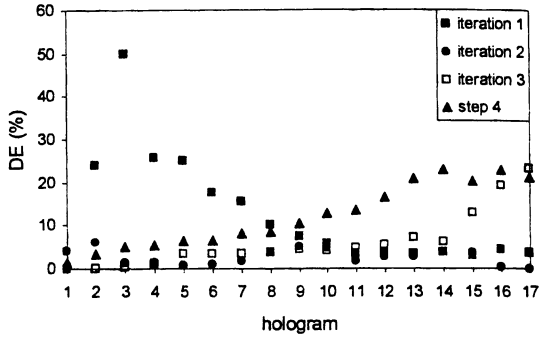

Fig. 4. Optimization of the exposure times in 3 iterations. The continuous curve represents an exponential scheduling that gives rise to the curve "step 4" in Figure 5.

CONCLUSION

With the photopolymer used in this study there is only a low level of noise throughout the recording process using peristrophic multiplexing with rotation axis perpendicular to the medium. The values of DE are seen to decrease as the number of holograms recorded at constant exposure increases, and a value of saturation grating strength A_{sat}= 5.00 is achieved. The algorithm proposed by Pu, in the first iteration, enables the values of DE to be more homogenised, and a better use to be made of the dynamic range, obtaining a value of A_{sat}=6.14. Successive iterations tend to reduce the exposure times necessary to homogenize the DE values, so all the available dynamic range is not used (A_{sat}=2.56). Bearing in mind that this photopolymer responds well to high energy levels, with a low level of noise, a small correction in the times obtained with the first iteration, using an exponential scheduling, enables a better homogenization of the DE values to be achieved, using a greater proportion of the photopolymer's available dynamic range (A_{sat}=5.61).

ACKNOWLEDGMENT

This work was supported by Ministerio de Educación y Ciencia, Spain, under projects MAT2004-04881-C02-01 and MAT2004-04881-C02-02.

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