PROCEEDINGS
SPIE—The International Society for Optical Engineering

Holographic Materials II

T. John Trout
Chair/Editor

31 January 1996
San Jose, California

SPIE P PROCEEDINGS SERIES

Volume 2688

NOISE GRATINGS RECORDED WITH SINGLE-BEAM EXPOSURES IN LIQUID HOLOGRAPHIC PHOTOPOLYMERS

A. Fimia, A. Beléndez† and L. Carretero

Laboratorio de Optica, Departamento Interunversitario de Optica, Universidad de Alicante, Apdo. 99, Alicante E-03080, Spain.

(†) *Departamento de Ingeniería de Sistemas y Comunicaciones, Universidad de Alicante, Apartado 99, Alicante E-03080, Spain.*

e-mail: fimia@vm.cpd.ua.es

ABSTRACT

Photopolymers can be considered viable holographic material because of their many attractive features. Among these we could mention their ability to self-develop, the fact dry processing can be used with them, their good stability and thick emulsion layers, their haigh sensitivity, diffraction efficiency and resolution, and finally their non-volatile storage. Among the different sources of noise in holography, noise gratings are due to scattering from inhomogeneities in the recording material and have an important spurious effect on volume holography. Their effect at reconstruction is to bring about a reduction in diffraction efficiency and signal-to-noise ratio. Even though these scatter gratings have been seen in PMMA and other photopolymers, and in photorefractive crystals, they have really only been analyzed extensively for photographic emulsions, and information about these grating structures in photopolymers is quite scarce. In this communication we present the observation of noise gratings in an acrylamide photopolymer for use in real time holography. The possibilities of this noise source as a optimization technique for this type of materials are pointed out. Noise gratings in these polymer films were created upon exposure to a He-Ne laser collimated beam at 633 nm without any subsequent processing step. The influence of intensity on recording noise gratings and angular selectivity are reported showing its influence on the recording of this type of noise source in real time holographic materials.

KEY WORDS: Holography, holographic recording materials, photopolymers, noise sources, noise gratings.

1. INTRODUCTION

The future extensive applications of holography depends, to a great extent, on the performance and survivability of the employed holographic recording materials[1]. Photopolymers can be considered viable holographic materials because of their many attractive features. Among these we could mention their ability to self-develop, the fact dry processing can be used with them, their good stability and thick emulsion layers, their high sensitivity, diffraction efficiency and resolution, and finally their non-volatile storage[2]. Photopolymers have been developed for conventional imaging systems and holographic optical elements. These materials have potential applications in other optical devices such as high-density storage and optical data processing. Photopolymers have traditionally been analyzed as holographic recording materials by measuring their diffraction efficiency in relation to the index modulation obtained when using them, their spatial response and their energetic and spectral sensitivities[3-5]. However, even though they are considered good recording materials for the storage of information and for the production of holographic optical elements, little information has been offered on the image quality that these recording materials produce[6].

Among the different sources of noise in holography, noise gratings are due to scattering from inhomogeneities in the recording material and have an important spurious effect on volume holography[7]. Their effect at reconstruction is to bring about a reduction in diffraction efficiency and the signal-to-noise ratio. In this communication we show, by means of angular transmittance data, that noise gratings are formed at recording when an acrylamide photopolymer system is used as holographic recording material.

2. PHOTOPOLYMER SYSTEM

Holographic photopolymer systems basically consist of one monomer or a mixture of monomers, and a photoinitiator. Upon irradiation, active species, radicals or ions, are produced which initiate the polymerization chain reaction, with selective conversion of monomer into polymer in the irradiated areas. In this way it is possible to obtain refractive index modulations, the base of the data storage in holography. In Table I we show the chemical composition of the system we use. This system is based on that previously described by Sugawara *et al.*[8] Basically it is made up of two aqueous solutions, the monomer system used in A and a group of sensitizers in B. It is wirthwhile to point out use of a second sensitizer, Rose Bengal, whose function is fundamental to the elimination of the inhibition period[9,10].

Table I

Solution A	
Acrylamide	7 M
Zinc acrylate	1 M
N, N'-methylenebis-acrylamide	0.7 M
Solution B	
Methylene Blue	3.6×10^{-4} M
Rose Bengal	6.0×10^{-5} M
P-toluensulfunic acid	1.7×10^{-2} M

The to-be-irradiated solution was made by mixing four volumes of solution A with one volume of solution B. This mixture was then placed between two glass plates separated by a 45 ± 5 μm uniformly thick spacer.

3. EXPERIMENTAL RESULTS

In this study, self-induced phase gratings were recorded with single beam exposures and replayed using the set-up shown in Figure 1. A single collimated beam polarized perpendicular to the plane of the figure was incident normal to the surface of the plate. The recording wavelength was 633 nm from a He-Ne laser. By using a detector, we measured the transmittance of the plate in real time when the hologram was replayed at a uniform exposure. Given that noise gratings do appear, this transmittance decreases until it reaches a minimum value due to the fact that the light is diffused in directions other than the transmitted one. The measurement of the shape of the angular response at this point of high exposure confirms the existence of noise gratings.

Figure 2 shows typical energy dependent transmittance curves. These curves were obtained using a reconstruction beam similar to the recording one (the same polarization state and incidente angle). The experimental measurements have been corrected by using the Fresnel equations in order to take into account the reflections at the surfaces of the glass plates and on the surfaces of the photopolymer layer. As can be seen in this figure, transmittance increases during the first few seconds due to the bleaching of the dye. This zone corresponds to the inhibition time that is due to the presence of oxygen in the sample[10]. After a certain level of exposure is reached, transmittance falls quickly, given that noise gratings are being stored. This implies a redistribution of the transmitted light. After a long period of time, transmittance levels out again and reaches the non-linear zone of the material[11].

Figure 3 shows typical energy dependent diffraction efficiency curves for 1000 lines/mm holographic diffraction gratings recorded with different intensity levels. In Figure 4 we compare these diffraction efficiency curves to the corresponding transmittance curves for single beam exposures, and we can see that there is a perfect match. These figures show the curves that correspond to transmittance and diffraction efficiency as a function of exposure time, thereby establishing the agreement between the storage of gratings and noise gratings. Thus we find analogy between the storage of a planar holographic grating and noise gratings. Therefore we can establish a correlation between both curves that we can use to analyze and optimize the photopolymers as was done for photographic emulsions[12].

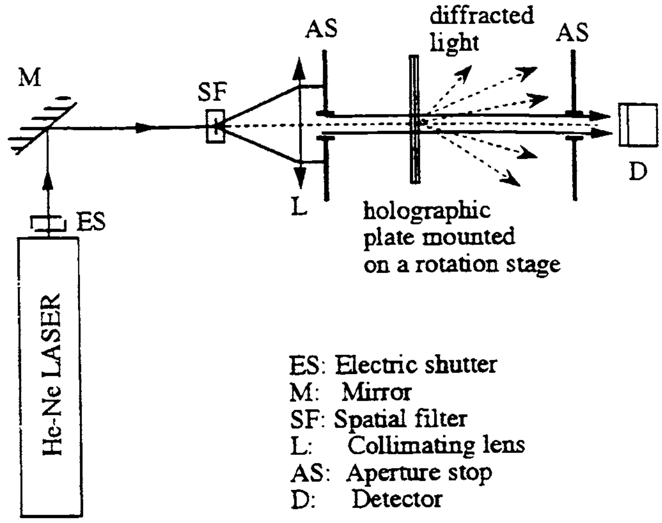

Figure 1

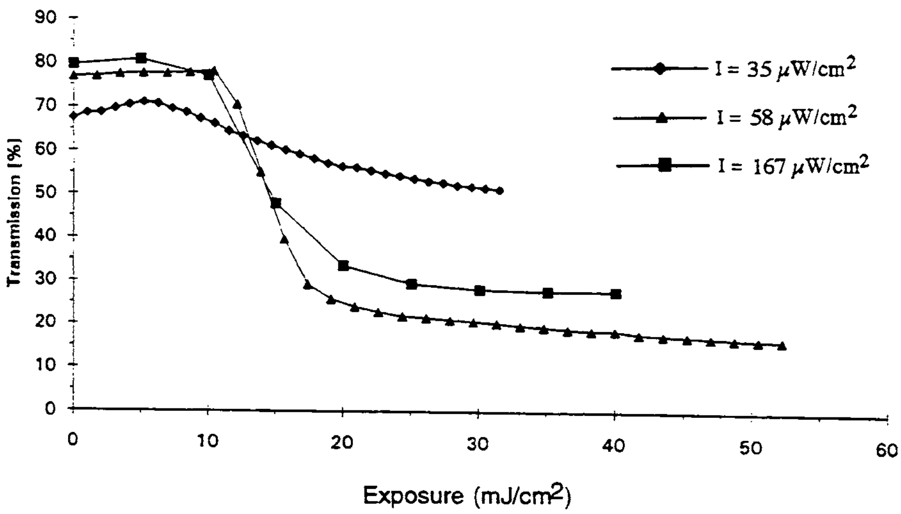

Figure 2

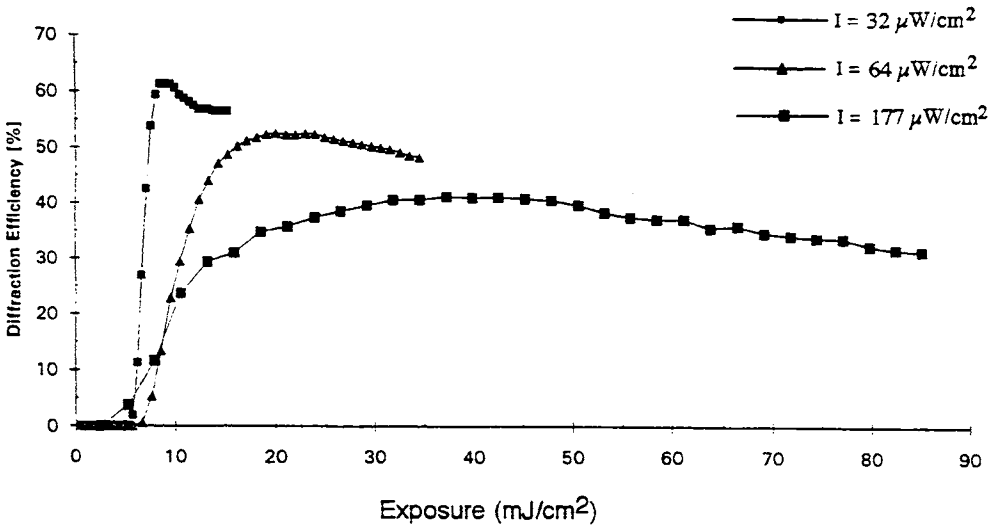

Figure 3

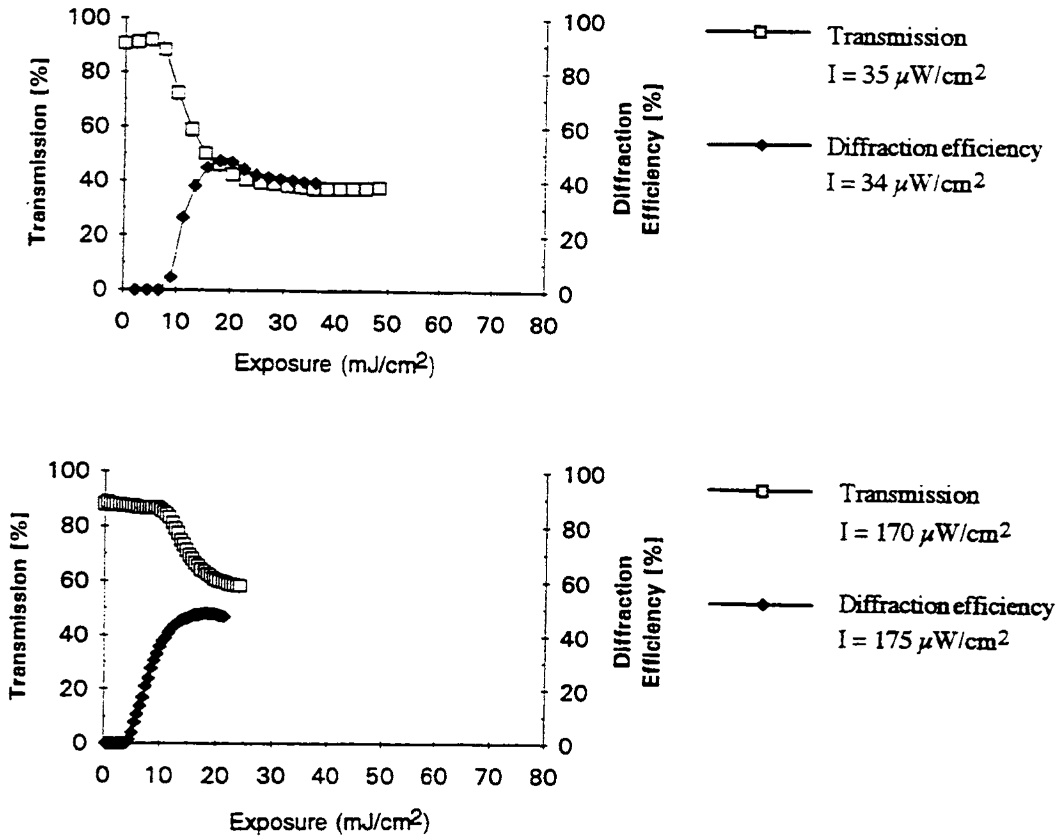

Figure 4

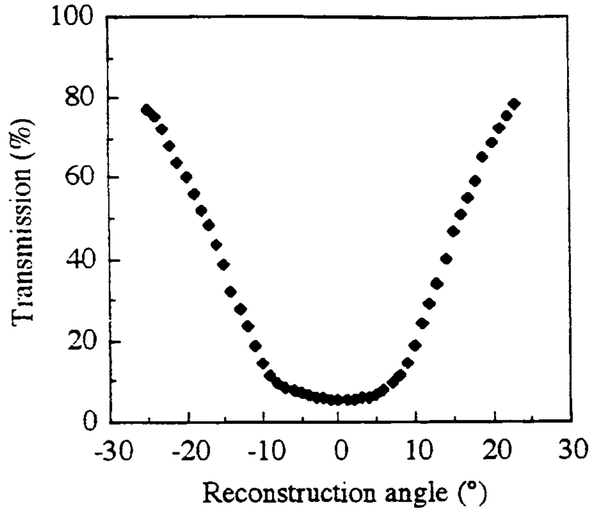

Figure 5

Figure 5 shows the angular transmittance data for an exposure energy of 375 mJ/cm^2. The plate was fixed by using a uniform postexposure accomplished with a flash light and it was replayed with a perpendiculary polarized reconstruction beam. In this figure the pronounced drop in transmission is caused by the presence of noise gratings[7]. This figure further confirms that noise gratings exist in the photopolymer layer. As we can see in Figure 5, the effects of the noise gratings are quite significant and transmittance is practically null for reconstruction angles around the recording angle (0°), which implies that almost all of the incident light is diffracted by the noise gratings recording on the material. Another important aspect that can be observed is that the angular bandwidth of the transmittance curve is very high (~30°). This angular bandwidth is higher than the angular bandwidth obtained, for example, for bleached emulsions (~8°)[7]. This is due to the thickness of photopolymer layer used (~45 μm) which is higher than the typical thickness of a photographic emulsion (~6 μm) making it possible to record more noise gratings.

4. SUMMARY

In summary, the presence of spurious gratings in acrylamide photopolymers, generated by scattering at recording, has been observed in the response of the holograms, which proves the presence of inhomogeneities in these materials. Their appearance and storage in these materials can be used as a methodology for the optimization of these recording materials. The appearance of this noise source in photopolymers might be one more indication of the good image quality that these materials have, as was shown for other recording media such as photographic emulsions, in which the image quality of the holograms of diffuse objects improved significantly when the noise gratings appeared[13]. Finally, the inclusion of noise gratings as a source of noise in holograms recorded in acrylamide photopolymer systems and the influence of these gratings on the final holographic characteristics of these holograms present new perspectives for the analysis of noise in holography and at the same time allow us to obtain more information about the behaviour of photochemical process involved in these recording materials.

5. ACKNOWLEDGMENTS

This work was supported by the "Comisión Interministerial de Ciencia y Tecnología" (Project MAT93-0369), Spain.

6. REFERENCES

1.- R. A. Lessard and G. Manivannan, *Proc. SPIE* **2405**, 2 (1995).
2.- U. Rhee, H. J. Caulfield, J. Shamir, C. S. Vikram and M. M. Mirsalehi, *Opt. Eng.* **32**, 1839 (1993).
3.- B. L. Booth, *J. Appl. Photo. Eng.* **3**, 24 (1967).
4.- W. J. Tomlinson, E. A. Chandross, H. P. Weber, and G. D. Aumiller, *Appl. Opt.* **15**, 534 (1976).
5.- W. S. Colburn and K. A. Haines, *Appl. Opt.* **10**, 1636 (1971).
6.- R. T. Ingwall and M. Troll, *Opt. Eng.* **28**, 586 (1989).
7.- R. R. A. Syms and L. Solymar, *Appl. Phys. B* **30**, 177 (1982).
8.- S. Sugawara, K. Murase and T. Kitayama, *Appl. Opt.* **14**, 378 (1975).

9.- A. Fimia, N. López, F. Mateos, R. Sastre, J. Pineda and F. Amat-Guerri, *Proc. SPIE* **1732**, 105 (1992).
10.- A. Fimia, N. López, F. Mateos, R. Sastre, J. Pineda and F. Amat-Guerri, *J. Mod. Opt.* **40**, 699 (1993)
11.- A. Fimia, F. Mateos, R. Sastre, J. Pineda and F. Amat-Guerri, *J. Mod. Opt.* **41**, 1867 (1994)
12.- L. Carretero, A. Beléndez and A. Fimia, *J. Mod. Opt.* **40**, 7 (1993)
13.- A. Fimia, L. Carretero, R. Fuentes and A. Beléndez, *Opt. Eng*. **34**, 1104 (1995).