

Self-induced phase gratings due to the inhomogeneous structure of acrylamide photopolymer systems used as holographic recording materials

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We report the observation of self-induced gratings or noise gratings in an acrylamide photopolymer for use in real time holography. The possibilities of this noise source as an optimization technique for this type of material 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. © 1995 American Institute of Physics.

Photopolymers can be considered holographic recording 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 nonvolatile storage.¹ 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.²⁻⁴ 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.⁵

Among the different sources of noise in holography, self-induced gratings (also called 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 the signal-to-noise ratio. Even though these scatter gratings have been seen in PMMA⁶ and other photopolymers,⁷ and in photorefractive crystals,⁸ they have really only been analyzed extensively for photographic emulsions,⁹ and information about these grating structures in photopolymers is quite scarce. In this letter we show, by means of angular transmittance data, that noise gratings are formed at recording. We hope to contribute information regarding the appearance of noise gratings in acrylamide photopolymers which are materials whose response is in real time and need no developing.

Holographic photopolymer systems basically consist of one monomer or a mixture of monomers, and a photoinitiator. The system selected for analyzing the noise gratings was formed by mixing two aqueous solutions. The polymerizable system (solution A) was made up of acrylamide, 7 M; zinc acrylate, 1 M; and *N, N'*-methylenebis-acrylamide, 0.7 M. The photoinitiator system (solution B) was made up of Methylene Blue, 3.6×10^{-4} M, Rose Bengal, 6.0×10^{-5} M; and *p*-toluensulfonic 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. In Fig. 1 we show the absorption spectra before and after exposure as a function of wavelength. For materials that work in real time, it is the transmittance function which measures the appearance of noise gratings given that the presence of this noise source manifests itself when transmitted light decreases due to diffraction.⁹

In this study, self-induced phase gratings were recorded with single beam exposures and replayed using the setup shown in Fig. 2. A single collimated beam polarized perpen-

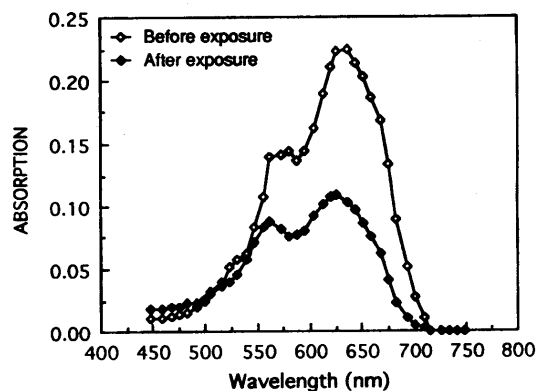


FIG. 1. Absorption spectra as a function of the wavelength before and after exposing a 45 ± 5 μm thick sample.

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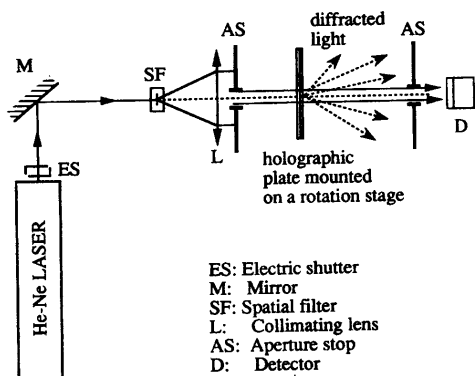


FIG. 2. Experimental setup for recording noise gratings into acrylamide photopolymer layers.

pendicular 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 3 shows a typical time dependent transmittance curve for the photopolymerizable system used when the reconstruction beam is similar to the recording one (the same polarization state and incident angle) and using an intensity level of $135 \mu\text{W}/\text{cm}^2$. 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 trans-

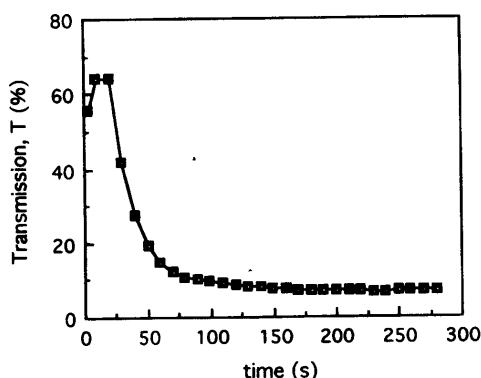


FIG. 3. Experimental measurement of the transmitted beam intensity vs exposure time, for a hologram recorded with a single beam exposure in an acrylamide photopolymer (the replay wavelength was 633 nm).

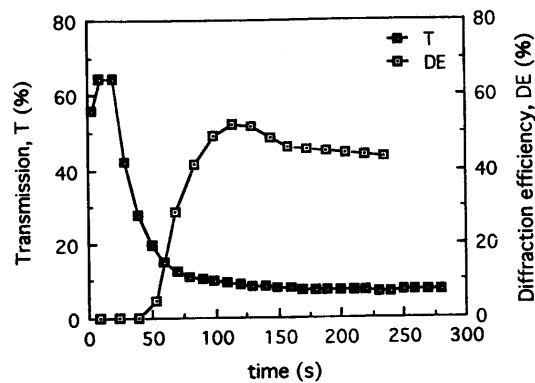


FIG. 4. Experimental measurement, as a function of exposure time, of the transmitted beam intensity (T) for a hologram recorded with a single beam exposure, and the diffraction efficiency (DE) for a 1000 lines/mm planar transmission diffraction grating.

mitted light. After a long period of time, transmittance again levels out and reaches the nonlinear zone of the material.¹¹ If we compare the diffraction efficiency curves for 1000 lines/mm holographic diffraction gratings recorded with an intensity level of $135 \mu\text{W}/\text{cm}^2$ to the transmittance curves which we show in Fig. 4, we can see that there is a perfect match. This figure shows 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 which we can use to analyze and optimize the photopolymers as was done for photographic emulsions.¹²

Figure 5 shows the angular transmittance data for an exposure energy of $375 \text{ mJ}/\text{cm}^2$. The plate was fixed by using a uniform postexposure accomplished with a flashlight and it was replayed with a perpendicularly polarized reconstruction beam. In this figure, the pronounced drop in transmission is caused by the presence of noise gratings.⁹ This figure further confirms that noise gratings exist in the photopolymer layer. As we can see in Fig. 5, the effects of the

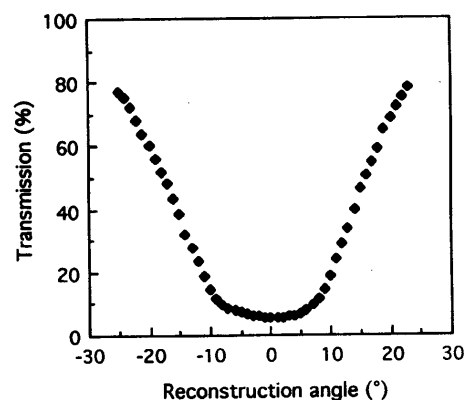


FIG. 5. Experimental measurement of the transmitted beam intensity vs replay angle, for a hologram recorded with a single beam exposure in an acrylamide photopolymer (the replay wavelength was 633 nm).

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 ($\sim 30^\circ$). This angular bandwidth is higher than the angular bandwidth obtained, for example, for bleached emulsions ($\sim 8^\circ$).⁹ This is due to the thickness of photopolymer layer used ($\sim 45 \mu\text{m}$) which is higher than the typical thickness of a photographic emulsion ($\sim 6 \mu\text{m}$) making it possible to record more noise gratings.

In another experiment we observed that if we reconstructed the holographic plate with a parallel-polarized reconstruction beam, we obtained a considerably smaller dip in transmission.¹³ Finally, we experimentally observed the scattered light of holograms (recorded with a single beam of light) in a plane parallel to the plate and situated at a distance of 30 cm from the plate. From these observations we conclude that the preferred scattering direction in this observation plane was perpendicular to the polarization direction when the directions of polarization for the recording and readout beams were the same. However, when the polarizations of the recording and reconstruction beams were perpendicular, the preferred scattering direction was parallel to the direction of polarization of the replay beam, which was perpendicular to the direction of polarization of the recording beam. These experimental results were previously predicted theoretically¹³ and they confirm the model developed in Ref. 13 to explain the polarization influence on the efficiency of noise gratings.

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.¹⁴

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