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Study of influence of ACPA in PVA/AA photopolymer for holographic reflection gratings

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1. Introduction

In the last decade holography has acquired great importance since holographic devices can store information throughout the volume of the material [1-2]. Your storage capacity also could be increased by storing objects with a spatial frequency as high as possible. However, it is necessary to use a material which has a high spatial resolution.

This work pretends to optimize the standard composition of the PVA/Acrylamide photopolymer, changing its composition in order to improve its spatial resolution [3-4]. To do this, a chain transfer agent, 4,4'-azobis (4-cyanopentanoic acid) (ACPA) was introduced in the photopolymer and its concentration was modified. Thus, the optimal concentration which gets obtain the maximum diffraction efficiency for high spatial frequencies was found. To quantify the improvement that occurs with the inclusion of the ACPA in the PVA/Acrylamide photopolymer, holographic reflexion gratings of 4553 lines/mm were stored. Moreover, diffraction efficiency obtained with the different concentrations of ACPA was measured to compare the obtained results.

Furthermore, the diffraction efficiency also depends on the intensity with which the gratings are stored. As maximum diffraction efficiency is intended to achieve in the gratings when they are stored in the material, different intensities of the beams were used.

2. Experimental set up

The holograms are recorded in a PVA/AA based photopolymer. The standard composition of this material contains acrylamide (AA) as the polymerizable monomer, triethanolamine (TEA) as radical generator, polyvinyl alcohol (PVA) as binder and yellowish eosin (YE) as sensitizer. Table 1 shows the concentrations of the components of this material (Composition 1). Considering the versatility of photopolymers when new components are added to its composition, a chain transfer agent (the ACPA) was decided to add to the standard composition of the used photopolymer. The main property of this photopolymer is the reduction of the polymer chain length, which in turn can improve the material response to the recorded spatial frequency. Therefore, the ACPA was added to the standard composition to improve the spatial resolution of the material. In order to optimize the composition with which gratings are obtained with maximum diffraction efficiency, two different concentrations of ACPA (0.006 M and 0.009 M) were added to the photopolymer (compositions 2 and 3). The concentrations of the components of the three compositions are shown in Table 1. The process for obtaining materials with these compositions are detailed in reference [5].

	Composition 1	Composition 2	Composition 3
Polyvinylalcohol (PVA)	8.26% m/v	8.26% m/v	8.26% m/v
Acrylamide (AA)	0.44M	0.44M	0.44M
Triethanolamine (TEA)	0.20M	0.20M	0.20M
Yellowish eosin (YE)	2.4x10-4M	2.4x10-4M	2.4x10-4M
4,4´-Azobis(4-cyanopentanoic acid) (ACPA)	-----	0.006M	0.009M

Table 1 Concentrations of the photopolymer compositions.

Figure 1 shows the experimental setup used to store holographic reflection gratings with a spatial frequency of 4553 lines/mm. Holographic reflection gratings were stored using a Nd:YV04 laser (Coherent Verdi V2) with a wavelength of 532 nm, at which the material was sensitive. A symmetric geometry was used in order to obtain gratings with interference fringes parallel to the recording material. The vertical polarized beam emitted by the laser was split into two beams with a beam-splitter. Each beam was expanded and filtered using a microscope objective and a pinhole and a series of lenses and diaphragms collimated beams with the desired diameter. The intensity of the recording beams was changed in order to obtain the maximum diffraction efficiency of the stored gratings. For this purpose, a total intensity of 6 and 12 mW/cm^2 with an intensity ratio of 1:1 was used. The two laser beams were spatially overlapped at the recording medium intersecting at an angle of 63.3º (measured in air). Using the refractive index of the material with composition 1 (n_{532}=1.515), the intersection angle in air, and the recording wavelength, the spatial period of the grating was 0.2196 μm and the spatial frequency was 4553 lines/mm [5].

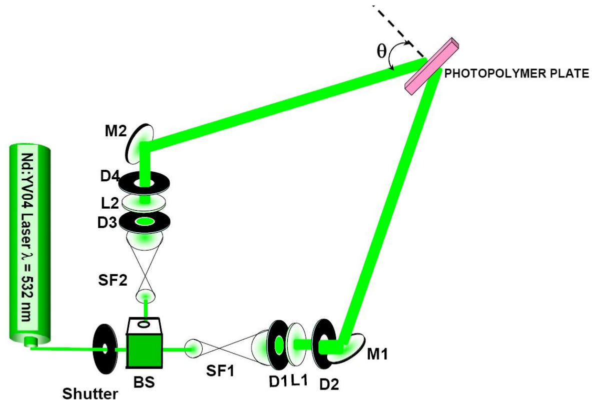

Figure 1 Experimental setup for reflection gratings: BS beam splitter, Mi mirror, Li lens, Di, diaphragm, SFi, microscope objective lens and pinhole.

In the reconstruction stage, the diffraction efficiency was measured by a double-beam spectrophotometer, which measures the transmittance of the photopolymer versus the wavelength.

After storing the gratings in the material, their transmittance was measured with the spectrophotometer following the procedure described. The gratings were reconstructed in a spectral range (610 nm – 660 nm) where absorption is negligible, so the conservation of energy principle implies that transmittance T(λ) and reflectance R(λ) are approximately complementary, i.e. T(λ)+R(λ)≈1 and thus R(λ)≈1-T(λ). Since, the spectrophotometer gives the energy transmitted, analyzing just the transmittance T(λ) will suffice. Once the transmittance is known, the diffraction efficiency is defined as the depth of this transmitted peak and can be calculated from equation (1):

$$DE = \frac{T_p - T_{pg}}{T_p} \quad (1)$$

where T_p is the transmittance of the photopolymer layer without the recorded grating and T_{pg} the transmittance of the photopolymer layer with the recorded grating [6-7].

3. Results

Reflection gratings were stored with a spatial frequency of 4553 lines/mm using the experimental setup in figure 1. This was done to check whether ACPA works for high spatial frequencies.

Gratings were recorded with different intensity beams and different ACPA concentrations and the diffraction efficiency was measured by a double-beam spectrophotometer as it is explained in previous section.

Figures 2 and 3 show the transmittance of the gratings stored with two different intensity beams: 6 mW/cm^2 (figure 2) and 12 mW/cm^2 (figure 3). Moreover, a chain transfer agent (the ACPA) was decided to add to the standard composition of the used photopolymer in order to improve the diffraction efficiency for high spatial frequency gratings. So in each figure three different graphs are shown: transmittance obtained with the composition 1 in table 1 (standard polymer without ACPA) is represented with black circles; transmittance obtained with the composition 2 in table 1 (polymer with an ACPA concentration of

0.006M) is represented with red squares; and transmittance obtained with the composition 3 in table 1 (polymer with an ACPA concentration of 0.009M) is represented with blue triangles. With the transmittance values in the two figures, the DE is calculated from equation (1).

Using the transmittance results in figure 2 (gratings stored with a total intensity beams of 6 mW/cm^2) and equation (1), DE was 3% for the grating stored in the standard photopolymer. In the photopolymer with an ACPA concentration of 0.006M, DE obtained was 6.1%. And in the photopolymer with an ACPA concentration of 0.009 M, DE obtained was 5.75%. As can be seen, when ACPA is introduced in the standard photopolymer, its DE is duplicated.

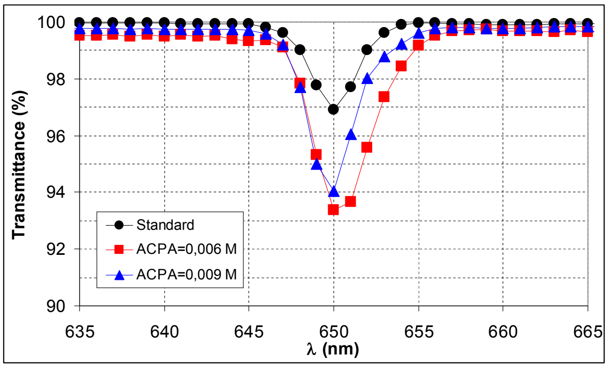

Figure 2 Transmittance as a function of wavelength for reflection gratings stored with a spatial frequency of 4553 lines/mm in the photopolymers of the Table 1 with a total intensity beam of 6 mW/cm^2.

From the transmittance data in figure 3 (gratings stored with a total intensity beams of 12 mW/cm^2), DE obtained from the grating stored in the standard photopolymer was 4.5%; DE obtained with an ACPA concentration of 0.006 M was 8%; and DE obtained with an ACPA concentration of 0.009 M was 8.3%. So in this case the DE nearly is also duplicated.

Comparing the data in figures 2 and 3 we can see that in both figures ACPA increases the DE compared with photopolymer without ACPA. Moreover higher recording intensity beams produce an increment of the DE in gratings stored with the same composition.

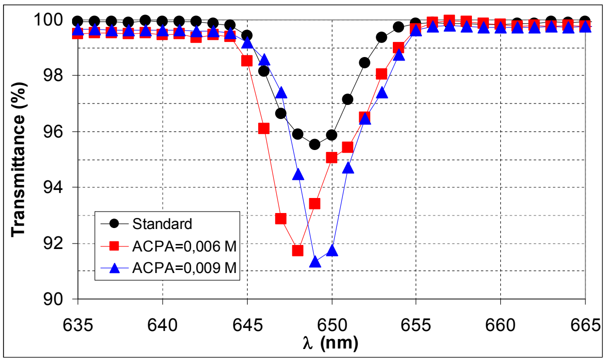

Figure 3 Transmittance as a function of wavelength for reflection gratings stored with a spatial frequency of 4553 lines/mm in the photopolymers of the Table 1 with a total intensity beam of 12 mW/cm^2.

4. Conclusions

This study has demonstrated the validity of using chain transfer agents, specifically ACPA, to increase the spatial resolution of photopolymers. ACPA improved the spatial resolution of the material since reflection gratings stored with a spatial frequency of 4553 lines/mm in compositions 2 (C_{ACPA}=0.006 M) and 3 (C_{ACPA}=0.009 M) had a higher DE (6.1% and 5.75% respectively) than those stored in composition 1 without ACPA (3%) when the gratings are stored with the same intensity beams (6 mW/cm^2). Moreover when the gratings are stored with a higher recording intensity beams (12 mW/cm^2), DE is also increased to 4.5% in composition 1 without ACPA, to 8% in composition 2 and to 8.3% in composition 3.

From these results it may be concluded that the photopolymer without ACPA has greater difficulty in resolving gratings with high frequencies (4553 lines/mm) which results in a low DE. Incorporating ACPA in the composition of the photopolymer increases the resolution of the material yielding a higher DE. Therefore, ACPA improves the resolution of the material.

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