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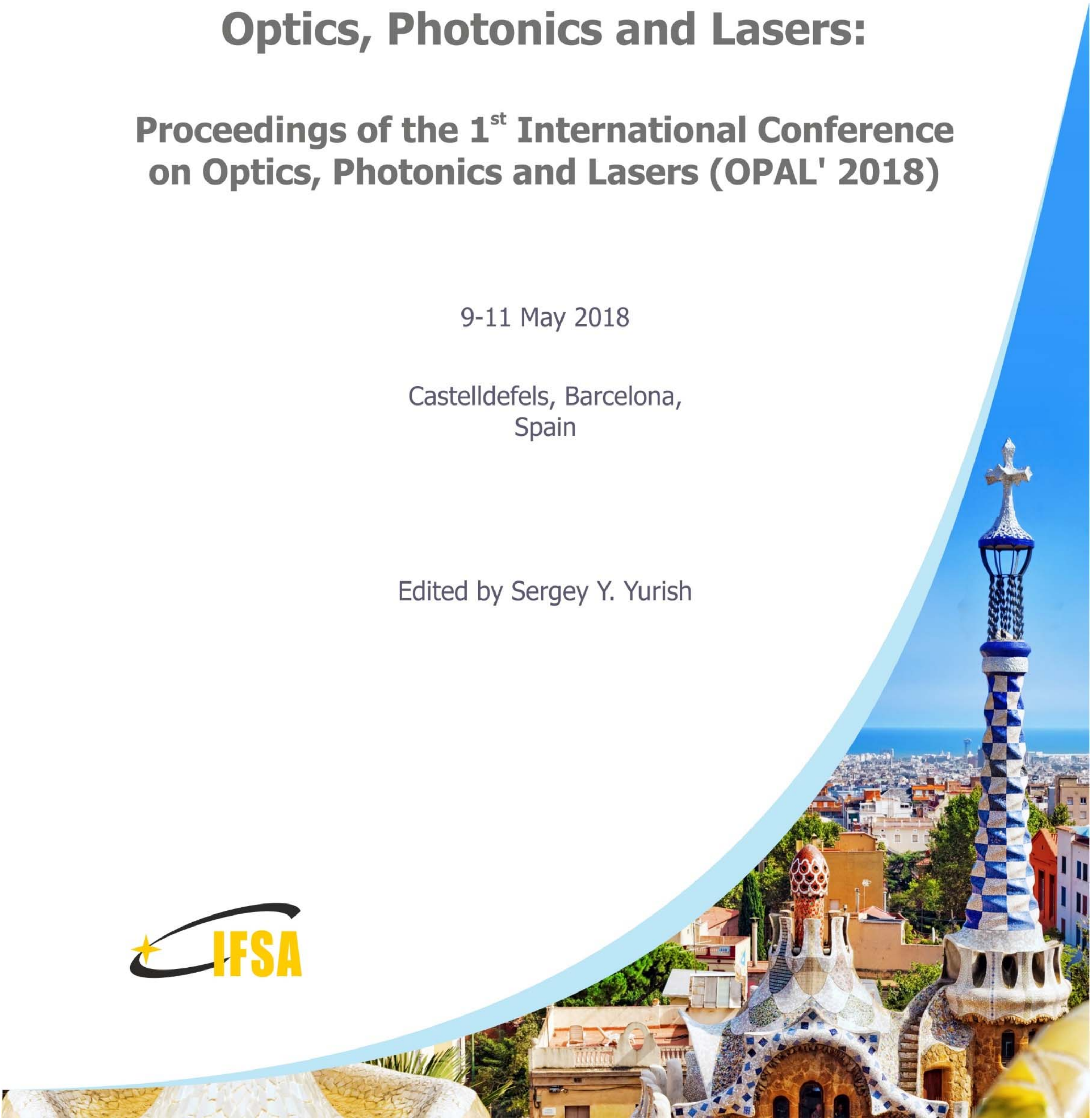

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Complex Diffractive Optical Elements Stored in Photopolymers

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Summary: Photopolymers have been used mainly for holographic recording applications. Nowadays, the improvements made in diffusion models, simulating phase image stored in these materials, enable a wide range of complex diffractive optical elements (DOEs) to be fabricated. Concurrently, the miniaturization of spatial light modulators makes it possible to generate both symmetric and non-symmetric DOEs. We show the procedure to record different complex diffractive elements, and we study the viability to fabricate them based on photopolymers. In particular we evaluate the recording of achromatic lenses, axicons and fork gratings interesting to obtain optical vortices. To achieve this goal, we use a three-dimensional diffusion model, previously experimentally validated with the recording of diffractive lenses.

Keywords: Holographic recording materials, Photopolymers, Diffractive elements, Optical axicons.

1. Introduction

Photopolymer recording materials are highly versatile in terms of their composition, reliability and properties. These characteristics make them one of the best recording media for holographic storage applications and an ideal candidate for the fabrication of photonic devices, such as two-dimensional structures, waveguides, or diffractive optical elements (DOEs) [1-3].

One of the photopolymers widely used in optics is based on polyvinyl alcohol/acrylamide (PVA/AA), and interesting results were obtained when this material was used to produce blazed gratings or spherical lenses [4]. In this work, we study the viability to fabricate complex DOEs based on photopolymers. In particular we evaluate the recording of achromatic lenses [5], axicons and fork gratings [3] interesting to obtain optical vortices. To achieve this goal, we use a three-dimensional diffusion model previously experimentally validated with the recording of diffractive lenses in a PVA/Acrylamide photopolymer [4].

1.1. Diffusion Model

In the case of spherical lenses, another dimension (related to the 'y' variable) must be added to the standard diffusion models [4]. Then the differential equations can be written as follows:

$$\begin{aligned}\frac{\partial M(x,y,z,t)}{\partial t} &= \frac{\partial}{\partial z}D_m(t)\frac{\partial M(x,y,z,t)}{\partial z} + \frac{\partial}{\partial y}D_m(t)\frac{\partial M(x,y,z,t)}{\partial y} \\ &+ \frac{\partial}{\partial x}D_m(t)\frac{\partial M(x,y,z,t)}{\partial x} - F_R(x,z,t)M(x,z,t),\end{aligned} \tag{1}$$

$$\frac{\partial P(x,y,z,t)}{\partial t} = F_R(x,y,z,t)M(x,y,z,t). \tag{2}$$

The polymerization rate depends on the reaction kinetics and the recording intensity; this dependence can be described by the following equation:

$$F_R(x,y,z,t) = k_R(x,y,z,t)I(x,y)^{\gamma}e^{-\alpha(t)\gamma z}, \tag{3}$$

where I is the recording intensity, k is the polymerization velocity, γ indicates the relationship between intensity and polymerization rate, 0.96 for our system, and α is the coefficient of light attenuation. The initial value of α [$\alpha\,(t=0)=\alpha_0$] can be obtained if the transmittance and the physical thickness of the layer are known.

The recording intensity distribution from the spatial light modulator in the amplitude regime is projected onto the material and produces the corresponding phase element. For spherical lens, for example, the phase depends on the quadratic value of the distance between the point and the lens centrum, but the desired intensity profile is smoothed by the experimental set up [4].

Once we obtain the monomer and polymer concentrations, we can use the refractive index values to calculate the refractive index distribution during the recording process. The refractive index distribution can be measured using the Lorenz-Lorenz Eq. as follows:

$$\frac{n^2-1}{n^2+2} = \frac{n_m^2-1}{n_m^2+2}M + \frac{n_p^2-1}{n_p^2+2}P + \frac{n_b^2-1}{n_b^2+2}\left(1-M_0\right). \tag{4}$$

2. Results and Discussion

In order to obtain an amplitude image projected onto material the LCoS must work in amplitude mode. To obtain this, we have previously characterized the screen display, which is placed between two polarizers to control the polarization of the incident and output light [4].

Some of the DOE elements introduced in our experimental set-up are presented in Figs. 1 and 2. Fig. 1 shows one of the achromatic lens described in ref. [5] by Yzuel et al. and Fig. 2 shows the intensity distribution of a typical axicon. One possibility to obtain an optical vortex is using the fork gratings described in [3].

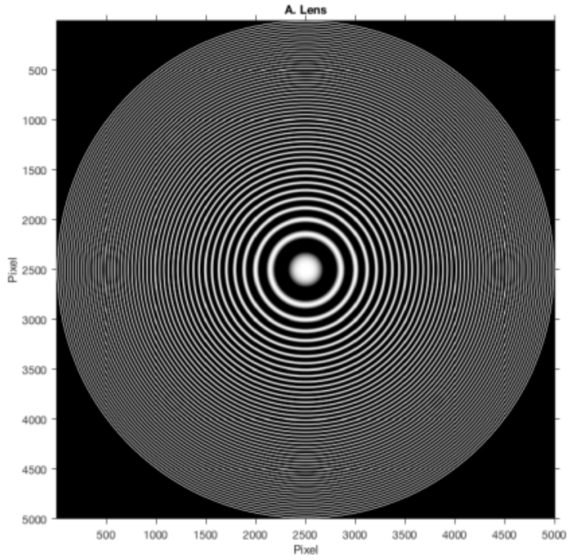

Fig. 1. Achromatic lens introduced in the LCoS.

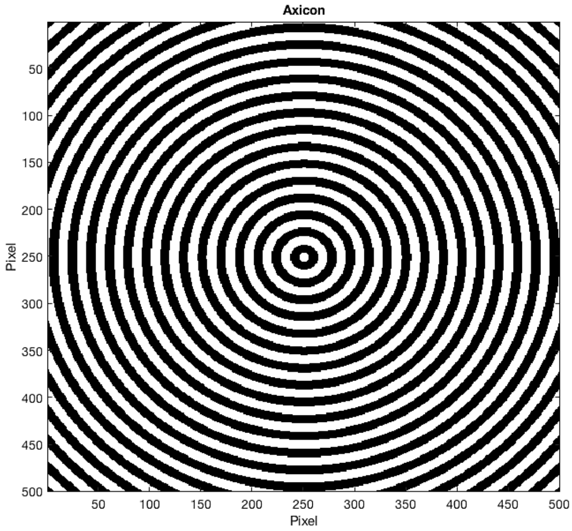

Fig. 2. Amplitude distribution for the axicon introduced in the LCoS.

Once we have introduced these DOEs in our LCoS, they can be projected onto the recording material as an intensity distribution. We can model the recording of the phase object using the 3-dimensional diffusion model. In Fig. 3, we show the expected intensity distribution in Fraunhofer domain for a fork grating with spatial period of 288 μm. As it can be seen, there are two important intensity peaks and between them the intensity achieves the value of zero. These are good results in order to, for example, designing systems to trap particles with light.

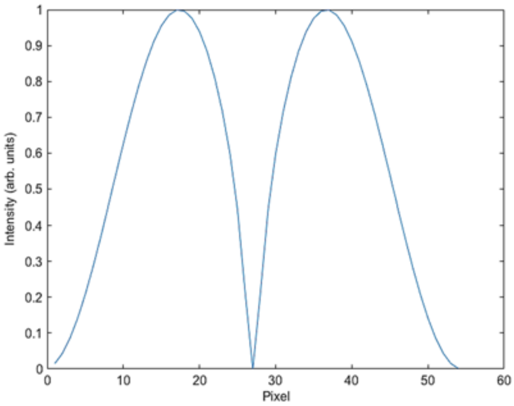

Fig. 3. Intensity distribution at the central point simulated by the diffusion model.

4. Conclusions

We have shown a system to record complex and asymmetric DOEs in PVA/AA photopolymer. We have explained how to model the recording of these elements and demonstrated that good results with optical vortices and axicons can be expected even with the experimental limitation to obtain recording sharp profiles.

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