

## Analysis of diffractive optical elements generated onto photopolymer materials using a liquid crystal display

A. Márquez<sup>1,3</sup>, S. Gallego<sup>1,3</sup>, M. Riquelme<sup>1</sup>, M. Ortuño<sup>1,3</sup>, M. L. Álvarez<sup>1,3</sup>, A. Beléndez<sup>1,3</sup>, I. Pascual<sup>2,3</sup>

<sup>1</sup>Dpt. de Física, Ing. de Sistemas y Teoría de la Señal, Univ. de Alicante, Spain

<sup>2</sup>Dpt. de Óptica, Farmacología y Anatomía, Univ. de Alicante, Spain

<sup>3</sup>I.U. Física Aplicada a las Ciencias y las Tecnologías, Univ. de Alicante, Spain

email: [Andres.Marquez@ua.es](mailto:Andres.Marquez@ua.es)

### Summary

We produce phase-only diffractive optical elements (DOE) onto photopolymer. To this goal we use a liquid crystal display (LCD), displaying the DOE amplitude master, which is imaged onto the photopolymer. Various challenges need to be overcome such as accurate combined control of LCD and photopolymer and proper imaging of the master onto the photopolymer plane, which will be presented in the paper.

### Introduction

Liquid crystal displays are widely used as spatial light modulators (SLMs) in many applications. In diffractive optics, LCDs are used to display programmable DOEs [1]. However, in many cases, passive DOEs are actually needed and a number of microoptics fabrication technologies [2], are available to produce these passive DOEs. In this sense, we explore the use of a LCD to display the master DOE to be recorded [3]. The introduction of the LCD enhances the flexibility of the recording architecture since it allows changing the element to be recorded simply by changing the function addressed to the LCD. The recording material we consider is photopolymer, which is a phase material, increasing the light efficiency of the DOEs produced. In particular we consider polyvinyl alcohol (PVA) based photopolymers. Both the composition and the thickness need to be optimized for the application to DOEs. In the composition we include a cross-linker monomer [N,N\_-methylenebisacrylamide (BMA)], which produces higher values of refractive index modulation and more stable gratings [4].

### Discussion

Several steps need to be considered so as to produce DOEs onto the photopolymer. First, a combined photopolymer-LCD exposure schedule needs to be calibrated so as to imprint the necessary phase-shift onto the photopolymer. This is challenging since small variations in the environmental conditions and in the preparation of the photopolymer induce loss of repeatability. Second, the recording setup needs to be carefully analyzed. It allows us to filter the pixilation of the LCD and demagnify the DOE master onto the photopolymer to increase the spatial frequencies. This may produce deviations from the calibration values. It may also produce some other effects such as smoothing of the features of the master DOE. Thirdly, proper study of the stability properties of the photopolymer needs also to be considered. The latter is being accomplished through a number of works in the group [5][6]. Some results related with the first and second steps will be given in the next figures.

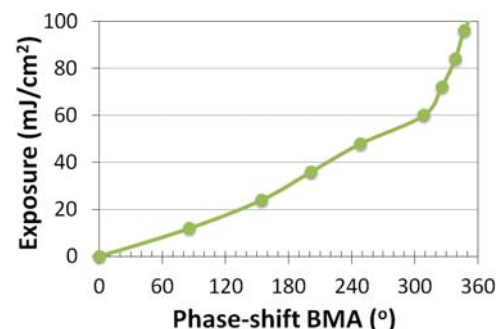


Fig. 1. Exposure vs. phase-shift for the photopolymer.  $\lambda=633$  nm

In Fig. 1 we show the results for a calibration of exposure versus phase-shift for the photopolymer layer, intended to produce multilevel phase-only DOEs. We observe that to reach a  $360^\circ$  phase depth we need an exposure of about  $110 \text{ mJ/cm}^2$ . The phase-shift calibration corresponds to a zero frequency limit characterization [5], in which the diffusion processes in the material do not play any role in the index modulation formation. Diffusion processes will actually take a role when recording DOEs, thus the phase-shift calibration in Figure 1 can be considered as a reasonable starting point but not as an exact calibration.

The experimental setup images the master DOE displayed on the LCD onto the photopolymer. In Fig. 2a and 2b we show respectively the image captured with a CCD camera on the plane of the photopolymer and a vertical cut of the image. The master DOE is a blazed grating with 32 pixels period ( $131 \mu\text{m}/\text{period}$ ), which is imaged with unit magnification. We observe in Fig. 2b the intensity profile of the imaged blazed grating where we observe that the profile is quite linear with the pixel count but becomes steeper for higher intensity values. This is exactly in accordance with the calibration exhibited in Fig. 1, which shows that to obtain higher phase-shift values larger exposure steepness is necessary. We note in Fig. 2b that no visible smoothing has occurred through the imaging system. In some other work we demonstrated the ability of the proposal to generate diffractive lenses onto the photopolymer.

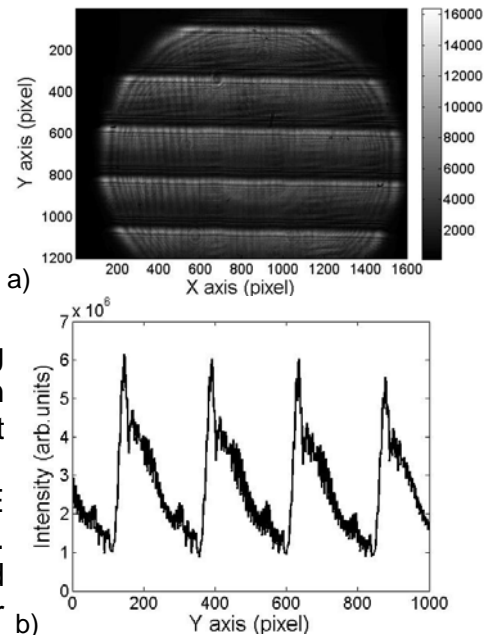


Fig. 2. a) Intensity image and b) profile, in photopolymer plane from a blazed grating on the LCD.

## Conclusions

We have shown some of the steps dealing with the generation of multilevel DOEs onto the photopolymer, specifically blazed gratings, focusing on the calibration and imaging steps. Good results have been obtained.

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