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Optimization of a holographic memory setup using an LCD and a PVA-based photopolymer

Elena Fernández[a,*], Manuel Ortuño[b], Sergi Gallego[b], Andrés Márquez[b], Celia García[a], Rosa Fuentes[a], Augusto Beléndez[b], Inmaculada Pascual[a]

[a]Dpt. Óptica, Farmacología y Anatomía, Universidad de Alicante, Apartado 99, E-03080 Alicante, Spain
[b]Dpt. de Física, Ingeniería de Sistemas y Teoría de la Señal, Universidad de Alicante, Apartado 99, E-03080 Alicante, Spain

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Abstract

Holographic data pages were stored in a polyvinyl alcohol (PVA)/acrylamide (AA) photopolymer. This material is formed of AA photopolymers which are considered interesting materials for recording holographic memories. A liquid crystal device was used to modify the object beam and store the data pages in the material. During the storage process, some parameters like exposure time, beam ratio and reading beam intensity were controlled to obtain high image quality after the reconstruction process. The bit error rate (BER) was calculated fitting the histograms of the images to determine what parameters improve the quality of the images.
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1. Introduction

Two-dimensional memory technologies like CD-ROMs and DVDs have arrived to their limits of capacity, and the world needs new technological systems to keep more information. Thus holographic data storage (three-dimensional technology) is becoming the new optical memory technology. These new technologies allow an important number of bits to be stored in a recording material with more capacity, more density and faster readout rates than two-dimensional technology [1,2]. Some companies such as Aprilis [3] or InPhase [4] have already created the first prototypes of holographic optical storage systems capable of storing from 200 Gbyte to 1.6 Tbyte.

Photopolymers are considered interesting materials for recording holographic memories because they have a high refractive index modulation [5], large dynamic range [1,6,7], good light sensitivity, real-time image development, high optical quality and low cost. In addition to this, their properties like energetic sensitivity or spectral sensitivity can be easily changed by modifying their composition [5,8].

In this study, we focus on the optimization of a holographic memory setup using a liquid crystal display (LCD) and a polyvinyl alcohol (PVA)–acrylamide (AA) photopolymer.

Twisted-nematic liquid crystal displays (TN-LCDs) have been studied for application to spatial light modulators (SLMs) used to modify in real time the amplitude or phase of a light beam [9]. This LCD can be used to design programmable optical elements, such as lenses and data pages or in holographic data storage. In

*Corresponding author.
E-mail address: Elena.Fernandez@ua.es (E. Fernández).

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particular in holographic data storage, LCDs allow data pages to be recorded in real time in the holographic recording material.

To obtain a storage holographic system we have characterized a holographic material. In this work, a PVA/AA photopolymer material has been used to store the holograms [5]. In particular, layers about 80 μm of this material have been used to store the holograms.

Different objects with white and black pixels were used to simulate data page bits (ones and zeros). During the storage process, these data pages are stored in the photopolymer. When the hologram has been stored, it is illuminated in the reconstruction stage by the same plane wave as in the recording process in order to prevent the appearance of aberrations in the reconstructed image. Using an optical system, the stored information is imaged onto a Cohu 4710 Series Monochrome charge coupled device (CCD) camera connected to a personal computer, where the images are analyzed and processed.

When the data page is stored, certain parameters influence the image quality. Parameters corresponding to the holographic setup may introduce some noise, which we can try to reduce but it may not be possible to control. These parameters are, for example, the SLM, the CCD camera, the optical components, homogeneity of the beam, etc. However, there are some external parameters that may be changed in order to improve the quality of the images obtained. These parameters are, for example, the reading beam intensity, the reference to object beam intensity ratio, the exposure time, the size of the bits on the LCD, etc.

In this work, we evaluated the performance of the setup as a function of these parameters in order to obtain a greater image quality.

Once the images have been obtained, a criterion has to be used to assess the quality of the different images and to compare them with the original object. In order to evaluate the image quality, its histogram is used to calculate the bit error rate (BER) [10] and determine the contrast between white and black pixels. BER values of each image are calculated to decide what parameters provide the best image quality (greater contrast and less noise).

2. Preparation of the material

The holograms are recorded in a photopolymer composed of AA as the polymerizable monomer, triethanolamine (TEA) as radical generator, *N*,*N*′methylene-bis-acrylamide (BMA) as crosslinker, yellowish eosin (YE) as sensitizer and a binder of PVA. Introduction of BMA in the composition improves the energetic sensitivity and diffraction efficiency of the material and, in addition, gives a greater stability to the stored grating, thereby preventing it from disappearing with time.

Table 1. Concentrations of the photopolymer composition

	Composition
Polyvinylalcohol	6.6% w/v
Acrylamide	0.33 M
Triethanolamine	0.17 M
Yellowish eosin	2.4×10^{-4} M
N,*N*′methylene-bis-acrylamide	0.027 M

Table 1 shows the component concentrations of the photopolymer composition used to obtain layers about 80 μm thick.

A solution of PVA in water forms the matrix and this is used to prepare the mixture of AA, BMA and photopolymerization initiator system composed of TEA and YE. The mixture is made under red light, deposited by gravity on a $22 \times 40\,cm^2$ glass plate and left in the dark for 1 day to allow the water to evaporate in conditions of temperature, *T*, between 20 and 25 °C, and relative humidity, RH, between 40% and 60%. These conditions of drying time, temperature and relative humidity are optimized to obtain the maximum diffraction efficiency of the gratings.

3. Holographic setup

Holographic data pages were recorded using the output from a diode-pumped frequency-doubled Nd: YVO_4 laser (Coherent Verdi V2) which was split into two beams and then spatially filtered, using a microscope objective lens and a pinhole, and collimated to yield a plane-wave source of light at 532 nm. The diameter of these beams was 1.5 cm. The two laser beams were spatially overlapped at the recording medium intersection at an angle of 17.4° (measured in air).

One of the beams was the object beam and the other was the reference beam. In the object beam the LCD was placed between two polarizers, one to each side of the LCD. The set of LCD and polarizers was used as an SLM. In addition, a lens was placed before the first polarizer to do the Fourier transform (FT) of the data page. The other beam, the reference beam, was a plane wave that interferes with the object beam at the surface of the material.

In the reconstruction stage, the stored hologram that contains the information of the data page was illuminated with the reference beam, but at a very low intensity so as not to deform the hologram because the material is sensitive at this wavelength. Another lens was placed behind the photopolymer to do the inverse FT of the diffracted beam on the surface of the CCD.

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