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Waveguide couplers based on HPDLC for see-through applications: Initiator optimization

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ABSTRACT

Polymer nanocomposites are designed and engineered on a nanometer scale with versatile applications including optics and photonics. During the last two decades, different photopolymerizable nano-compounds were introduced and developed to modify polymer properties. In this sense, inorganic and organic nanoparticles have been introduced to increase the refractive index modulation and/or to reduce the shrinkage. Liquid crystal polymer composites have been added to the category of active photopolymer materials with an electrically switchable option.

Nowadays, in the design of smart glasses some problems remain on the table, like power consumption, the limitation of the resolution, the wide field of view, etc. The inclusion of holographic optical element has provided some possible solutions. In particular the photopolymers have been reported a good system to bring the photons produced in the image creation to the eye. Our group proposed an alternative scheme using transmission holographic elements. The fabrication architecture was tested with different photopolymers in order to optimize their chemical composition, and we proposed three schemes adapted to each material properties. In this paper we study the influence of the initiator concentration, for Holographic polymer dispersed liquid crystal photopolymer, on the refractive index modulation and on the tunable properties of these holographic optical elements.

Keywords: see-through, holography, photopolymers, waveguides

1. INTRODUCTION

Dry photopolymeric materials are holographic recording media with important characteristics such as low price, self-processing capability and a high versatility. These characteristics, among many others, offer significant advantages over conventional wet-type recording materials [1]. Their wide potential in photonics and communications have been long and extensively studied. There are interesting applications and development in diffractive optics [2-3], optical communications [4], photonic crystal [5], holographic data storage [6], sensors [7], solar concentrators [8], wearable eyeglasses [9] and waveguides [10-11]. This last application can be designed as a tool or supporting technology for more complicated displays, such as photovoltaic concentrators or see-through eyeglasses [12]. The work to obtain a thin, light, aesthetically pleasing pair of augmented reality (AR) glasses is in progress. Nowadays, in the design of smart glasses some problems remain on the table, like power consumption, the limitation of the resolution, the wide field of view, etc [13-15]. There are different steps to fix in order to fabricate a smart glass: sensing, processing, image generation, the transformation of an analogical image to a digital one, propagation through the glass to the eye and the generation of the virtual image on the retina. In the last two processes the inclusion of holographic optical element has provided some possible solutions. Photopolymers have been reported as a good system to bring the photons produced in the image creation to the eye.

For normal incidence we found that a photopolymer with dispersed liquid crystal molecules was the best option [16]. In this sense the chemical composition was optimized to record holograms with spatial frequencies of 1000 lines/mm [17]. In this paper we check the paper of the radical generator, N-phenylglicine (NPG), in this photopolymer for the application of waveguide couplers. In particular for the recording geometry proposed in [18] where Hpdlc materials present good behavior.

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2. EXPERIMENTAL SETUP

In previous works the material analyzed [9], HPDLC, presents a weak reaction when an electric field was applied. The monomer used was dipentaerythritol penta-/hexaacrylate (DPHPA), with a refractive index $n = 1.490$. We used the nematic liquid crystal QYPDLC-036 (LC036) from Qingdao QY Liquid Crystal Co., Ltd (LC). It is a mixture of 4-cyanobiphenyls with alkyl chains of different lengths. It has an ordinary refractive index n0 = 1.520 and a difference between extraordinary and ordinary index $\Delta n = 0.250$ [9]. The liquid crystal concentration was set at 28 wt%, for solution 0, see table I, as the starting point for component optimization and remained practically unchanged during this process, N-phenylglicine (NPG) as radical generator, octanoic acid (OA) as cosolvent [7] and ethyl eosin (YEt) as dye. N-methyl-2- pyrrolidonev (NMP) was used to control overmodulation during hologram recording [7]. The prepolymer solution was made by mixing the components under red light to which the material is not sensitive. The solution was sonicated in an ultrasonic bath, deposited between glass plates 1 mm thick, separated using glass microspheres as spacers. The microspheres were provided by Whitehouse Scientific with a thickness between 20 and 30 μm. Firstly we introduce the Yet with the NMP to solve all the dye in the NMP. Secondly, we add NVP or/and NMP to the solution and keep mixing 5 minutes with the magnetic stirrer bar spinning. On the third place we introduce OA and keep stirring for 3 minutes, then we add to the solution NPG under red light because now the solution reacts to the green and blue wavelengths. When the solution is again homogeneous, we add the LC036. One the solution transparent, under red light, again we introduce the main monomer DPHPA. Due to the high viscosity of this monomer the solution should be stirred with a stick to obtain a transparent mixture again. From the chemical solution 1 studied in previous papers [4], we have checked the influenced o the NPG, the radical generator. In solution 2 we have increased 4 times its presence in the solution and in solution 3, we have increased 8 times. Analyzing the obtained results, we have tested solution 4 where the concentration is half of the original, solution 1. It is important to remain that the concentration of NPG concentration es extremely small in comparison with other components, only the dye Yet, has a comparable little value.

Table 1. Chemical solutions analyzed.

Component	Solution 1	Solution 2	Solution 3	Solution 4
YEt (g)	0.001	0.001	0.001	0.001
NMP (μL)	469	469	469	469
OA (μL)	144	144	144	144
NPG (g)	0.010	0.040	0.080	0.005
LC036 (μL)	450	450	450	450
DPHPA (g)	1.1	1.1	1.1	1.1

The task of the diffraction grating is to couple the energy of the incident beam, whose propagation vector is denoted by $\boldsymbol{\rho}$, to the diffracted beam, whose propagation vector is denoted by $\boldsymbol{\sigma}$**.** The diffracted beam must be deflected so that the angle formed with respect to the normal of the glass substrate must be higher than the critical angle, θc, (for the interface glass-air) to accomplish total internal reflection. The recording and read out schemes inside the material are represented in Figure 1 using Ewald's sphere.

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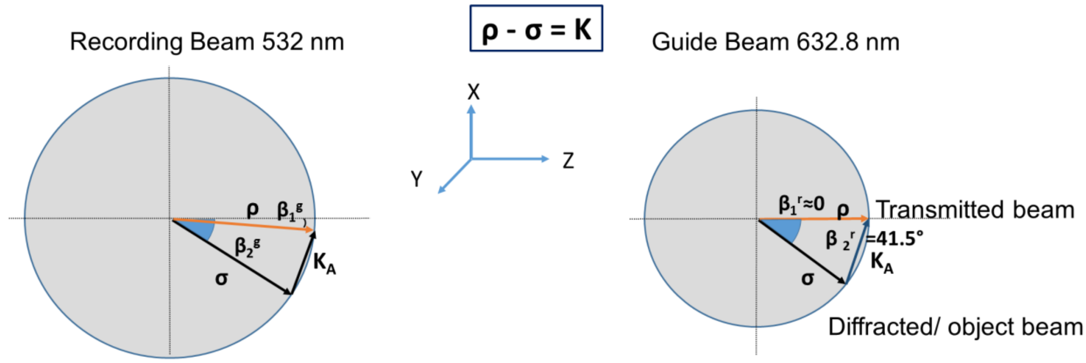

Figure 1. Ewald's sphere and recording (left) and read out (right) geometries waveguide coupled element designed for normal incidence of red light.

The experimental device is an asymmetric transmission holographic setup; it is represented in Figure 2. A Nd:YAG laser tuned at a wavelength of 532 nm was used to record diffraction gratings by means of continuous laser exposure. The laser beam was split into two secondary beams with an intensity ratio of 2.5:1. Due to the cross section of the up arm is in this scale higher than the down one. The diameter of these beams was increased to 1 cm using a spatial filter and collimating lens, while spatial filtering was ensured. The working intensity at 532 nm was 2.5 mW/cm^2 and 1.0 mW/cm^2 for up and down arms. Slanted gratings of 1700 lines/mm were recorded; to do this, the reference beam formed an angle to the normal of −4.8 º, whereas the object beam formed an angle of 68º. We monitored in real time the diffraction grating using red light (λ = 633 nm which the dyes do not absorb) using close to normal incidence (0.3º). After recording, the sample was rotated to record the angular response around the first Bragg condition.
It should be noted that the diffraction efficiency (DE) from a waveguide structure used in our experiment cannot be directly measured because the diffracted beam is trapped inside the glass substrate of the sample at a diffraction angle larger than the critical angle at the boundary between the glass substrate and the air. The diffraction beam goes out from the edge of the glass substrate. For this reason, we evaluated the TE defined as the ratio of the transmitted power to the incident one, of our holographic optical elements (HOE), without Fresnel correction at s polarization. We found that the sum of TE and DE in our experiment was close to 0.9. In this way angular responses of the waveguide were measured using transmitted beam, to avoid the movement of the detector to capture the diffracted beam. We rotate the sample in order to obtain the angular response and then we can fit the TE as a function of the outside angle to obtain the value of the effective optical thickness (d), the refractive index modulation (Δn), and the absorption and scattering coefficient (α).

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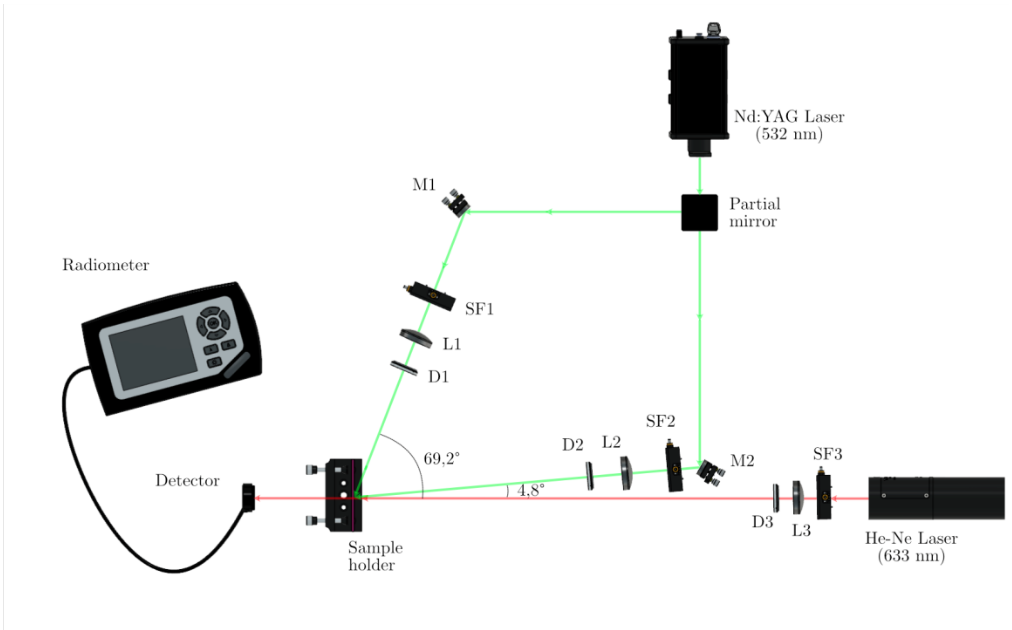

Figure 2.- Experimental setup. BS: Beamsplitter; Mi: mirror, SFi: spatial filter; Li: lens diaphragm; Oi: optical power meter; PC: data recorder.; Di:

3. RESULTS AND DISCUSSION

The recording of the waveguide couplers was performed under similar condition in the lab. This is important to note due to the important dependence of the solution behavior with the temperature, 22ºC. The external aspect of the solution changes significantly with the variation of the NPG. NPG is a dark powder, and the final aspect of the solution shows a strong dependence on the NPG concentration. That means an important dependence of the transmittance with the NPG. Nevertheless, when the holographic behavior is analyzed, we obtained similar results for solutions 1, 2 or 3. It can be seen in figure 3. In this figure we depicted the transmitted light, the diffracted is guided throw the waveguide, as a function of recording time. Only, maybe, for solution 3 we can appreciate a faster reaction of the material with light, but the refractive index modulation of saturation is the same for these different materials. The layers analyzed have a thickness around 25±3µm. It is a suppressive result and indicates that we have remained NPG in our initial solution 1. Therefore, we have reduced the NPG concentration, solution 4, then it can be seen, how this reduction has influence on the velocity of the hologram formation and also on the final refractive index modulation.

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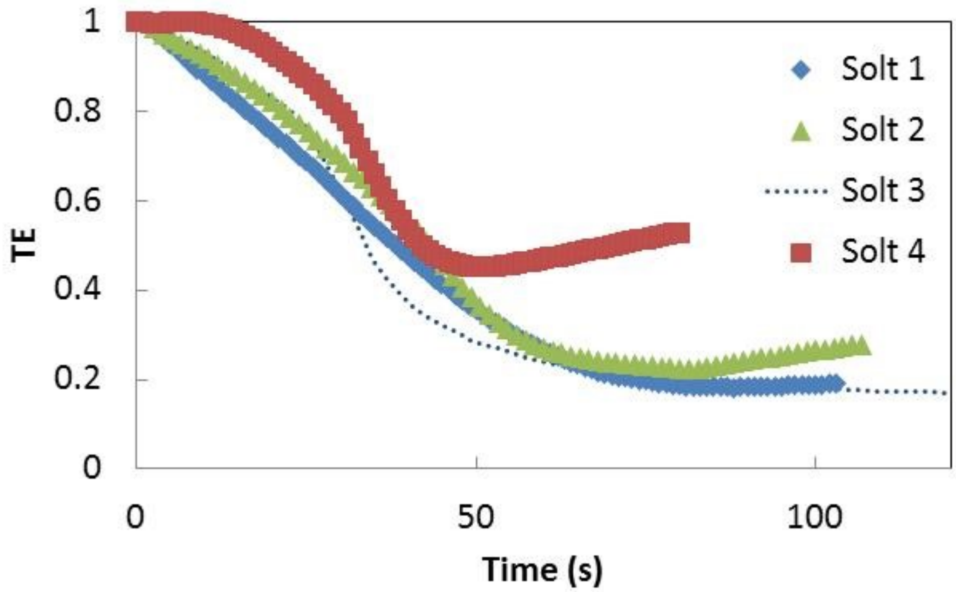

Figure 3.- Transmitted efficiency as a function of the exposure time for the different chemical compositions analyzed for layer with thickness between 22 and 27 μm.

This kind of elements can be used for see-through applications as we shown in figure 4. Due to the different wavelength used in the holograms recording, 532 nm, and the wavelength used in the reconstruction process, 632 nm, the diffracted light is trapped by total refraction inside the glass substrate to the second coupler, output, this is inversed respect to the input, then the imaged guided can be seen by the user of this see-through system.

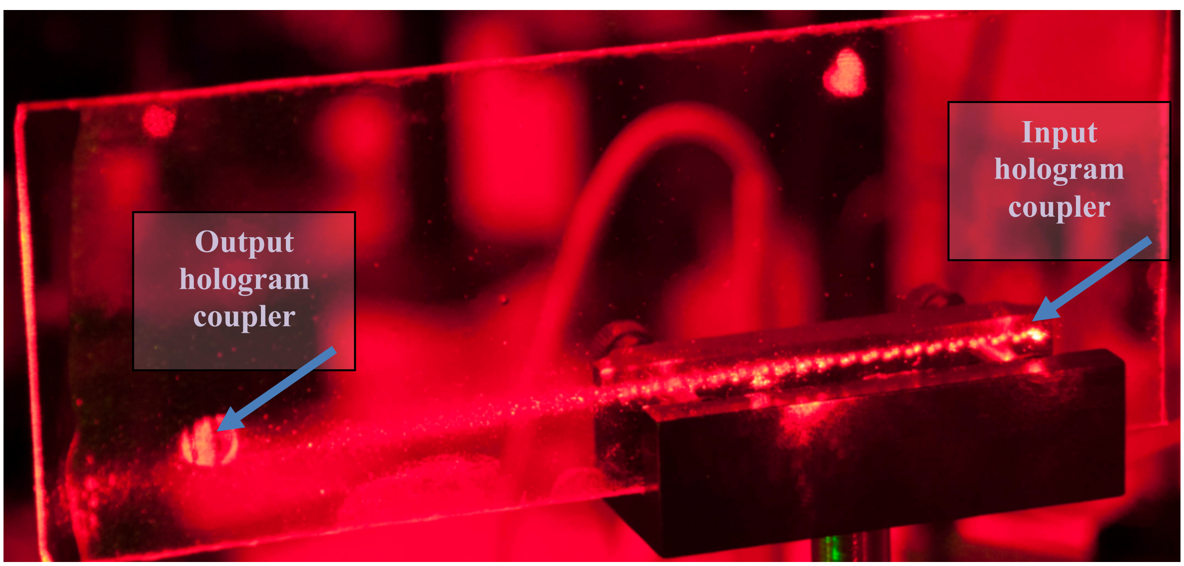

Figure. 4 waveguide couplers for see through applications working with he-Ne laser.

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Other possibility for this kind of wave couplers is the use to trap and guide solar light. In this application, the short wavelengths are transmitted and the long wavelengths, red, are guided to the photovoltaic cell, for example. It can be seen in figure 5, where a angular response of this kind of elements are represented, together with the behavior under solar light. As it can be seen, in figure 5, almost 100% of the light can be guided for a specific incidence angle and wavelength.

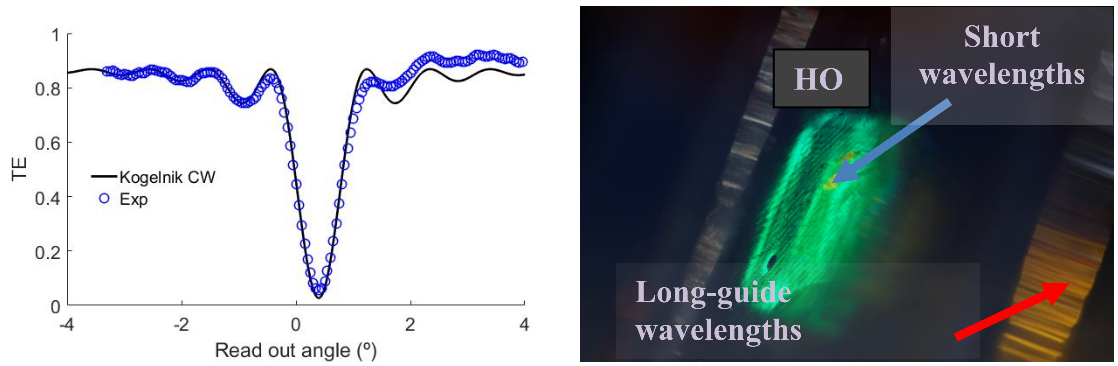

Fig. 5 Angular response of a overmodulated waveguide recorded using solution 1 with a sample with thickness of 54 μm. Under solar light behavior.

4. CONCLUSIONS

We have analyzed and presented the dependence on the radical generator, NPG, of this HPDLC photopolymer for this kind of waveguide couplers based on transmission slanted holographic gratings. The have demonstrated the existence of a limit value for NPG concentration, under this value the solution present worse behavior and when it is increase, we have not detected any significant variation. The also have shown two different application of this kind of elements, one with monochromatic light, and also with solar light.

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