EPJ Web of Conferences **287**, 09046 (2023) https://doi.org/10.1051/epjconf/202328709046
EOSAM 2023

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Manufacturing reflection holographic couplers for see-through applications recorded in photopolymers without prisms: an experimental validation

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Abstract. In the present work, the viability of a novel recording geometry to produce reflection holographic couplers is analyzed. Recalling the idea of previous works, photopolymers are used as the recording material, as they are well-suited for the intended see-through application. Moreover, Kogelnik's theory fundamentals give us the proper background to examine the proposed design, where no prisms or microlenses arrays are used. Aiming to support the analysis, we provide experimental evidence that the produced gratings exhibit the correct properties to work as a coupler.

1 Introduction

Photopolymers have widely been used, among many other applications, to produce Holographic Optical Elements (HOEs) in recent years, mainly to its tuneable capacities, high efficiency and low cost. Its usage to be part of see-through devices has also been studied and proved in different works [1, 2], as they are one of the most promising solutions for the in-couplers and out-couplers elements.

In this case, the majority of the recording holographic geometries are based on reflection holograms using prisms and microlens arrays [3], and they provide higher values of the Field of View (FOV) compared with the transmission ones, a key factor in see-through devices.

The use of prisms and index matching permits impinging angles very oblique, to achieve diffraction angles higher than the critical angle inside the substrate. Nevertheless, this is readily achievable in a laboratory setting, it poses much larger challenges in mass production, mainly because of the need to avoid an air gap, and is not suitable for any kind of non-contact master-copying automated production method.

The novelty of this work is about presenting an examination of the recording conditions to design the appropriate gratings without using prisms and an experimental evidence about the viability of this approach.

2 Theoretical Background

The main parameters of the grating are closely related to the recording geometry. Denoting as $\boldsymbol{k}_o$ and $\boldsymbol{k}_r$ the wave vectors of the object and reference beams, we can compute the grating vector, $\boldsymbol{K}$, as:

$$\boldsymbol{K} = \boldsymbol{k}_o - \boldsymbol{k}_r. \tag{1}$$

That being so, with Λ as the grating spacing and φ as the slant angle of the grating vector given by (1), the Bragg's condition during the reconstruction step yields the angle of incidence θ'_B for which the maximum diffraction occurs, given the reconstruction wavelength λ_c and the average refractive index n_0:

$$\cos(\theta'_B - \varphi) = \frac{\lambda_c}{2n_0\Lambda}. \tag{2}$$

Moreover, under Kogelnik's framework [4], we can compute the angle of the diffracted beam, as its associated wave vector $\boldsymbol{\sigma}$ is related to the transmitted wave vector $\boldsymbol{\rho}$ and the grating vector through:

$$\boldsymbol{\sigma} = \boldsymbol{\rho} - \boldsymbol{K}. \tag{3}$$

Combining the former relations we can design a specific geometry from the desired Bragg condition and the angle of the diffracted beam. If we can impose that the former is greater than the critical angle of the substrate, the hologram can work as a holographic coupler [5].

This is why we have chosen the specific geometry depicted in Fig.1, using $\lambda_0 = 532$ nm as the recording wavelength and 30° and 60° as the recording angles in air.

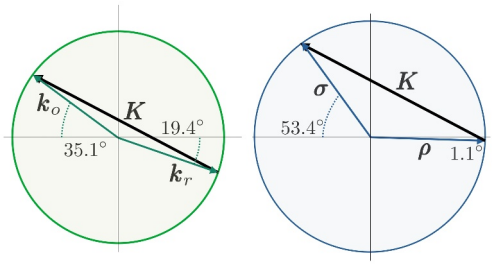

Figure 1. Ewald's spheres for the selected geometry. The recording structure (green) is built upon the recording angles in the material: 19.4° and 35.1°. The equivalent assembly for the reconstruction step (blue) yields angles of 1.1° and 53.4°. The average refractive index is $n_0 = 1.505$, so the critical angle is $\theta_c = 41.6°$.

With $\lambda_c = 488$ nm, values obtained from (2) and (3) show that the diffracted beam propagates under the Total Internal Reflection (TIR) principle, as Fig. 1 illustrates. Using different wavelengths in the recording and reconstruction processes permits to accomplish this condition without using prisms.

3 Experimental set-up

Fig. 2 shows the holographic set-up used in the lab to produce the gratings with the recording geometry described in the preceding section.

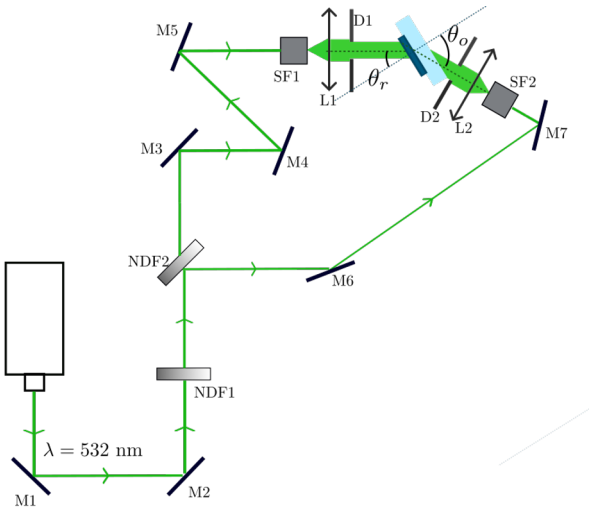

Figure 2. Set-up. M: mirror, NDF: neutral density filter, SF: spatial filter, L: lens, D: diaphragm.

The laser beam is split into two secondary beams, whose diameter is increased to 1 cm using a spatial filter and a collimating lens. The mirror M4 ensures the optical length is the same for both arms, that reach the sample with an intensity ratio given by:

$$I_o \cos\theta_o = I_r \cos\theta_r, \tag{4}$$

where the subscripts stand for the object and the reference beams, respectively.

4 Experimental validation

As a first step to study the viability of the proposed geometry, we present here the results obtained using the commercial photopolymer Bayfol HX-200 [6].

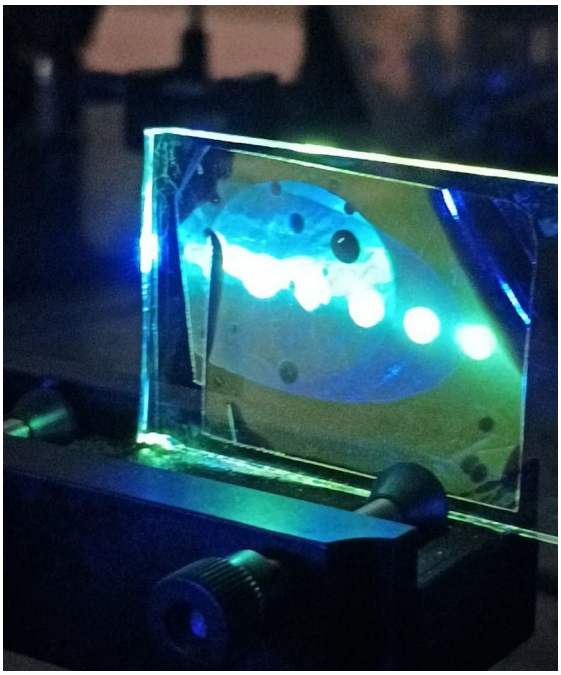

Figure 3. Reflection grating, recorded with the geometry in Fig.1, acting as in-coupler under blue-light reconstruction.

Fig.3 is taken during the reconstruction step using blue light. The hologram's size is about $1x1$ cm, which turn out to be the effective area of the coupler.

In the same image, it can be seen that the diffracted beam is trapped within the glass thanks to TIR. Hence, the grating acts as a reflection holographic in-coupler.

5 Conclusions

A new recording geometry has been proposed to produce holographic reflection gratings in photopolymers, devoted to work as couplers in a see-through device. The inspection of the theoretical background has led us to a specific configuration where prisms are not needed, thanks to the ratio of the recording and the reconstruction wavelength being different than the unity.

The proper functioning of the designed gratings has been proven and validated in the lab. This evidence allows us to look forward to further experimental investigation, either by using a different photopolymer (like the HPDLC, with tuneable capacities after the recording process [7]) or by studying the imaging properties of the system as a whole.

Acknowledgments

Work supported by the "Generalitat Valenciana" (Spain) project PROMETEO/2021/006 and "Ministerio de Ciencia e Innovación" of Spain (project PID2021-123124OB-I00)

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