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Design and analysis of processing parameters of hololenses for wavelength selective light filters

Abhijit Ghosh[a,*], R. Ranjan[b], A.K. Nirala[a], H.L. Yadav[b]

[a] Biomedical Optics Lab, Department of Applied Physics, ISM, Dhanbad 826004, Jharkhand, India
[b] Photonics Lab, Department of Physics, NIT, Jamshedpur 831014, Jharkhand, India

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ABSTRACT

In this communication the spectral characteristics based on diffraction efficiencies of hololenses in reconstructions at Bragg's angles for a wide range of wavelengths is presented. By properly optimizing design parameters of hololenses, their spectral characteristics can be controlled in the desired wavelength range. Creation of UV, visible and IR light filters have been presented in this manuscript through simulation and to validate the theoretical predictions, an experimental curve has been plotted with available wavelength sources and is found to be in good agreement.

1. Introduction

Holography is a 3-dimensional recording and reconstruction technique, in which not only amplitude distribution but also phase distribution can be recorded in a photosensitive material. Holograms can function as optical elements such as lenses, mirrors, beam splitters, gratings, zone plates, achromates, beam combiners and so on. Hologram of a point source, generated by recording interference of plane wave fronts and spherical wave fronts shows the behavior of lens action and hence can be treated as a hololens [1]. Classical lenses perform their required functions through refraction, whereas hololenses work on the phenomenon of diffraction.

The possibility of producing thick phase holographic transmission gratings with specified spectral characteristics has been reported [2,3]. Volume holographic gratings written in the crystal, glass and polymer are quite promising for wavelength selective light filters [4–8]. Due to wavelength selective properties and less angular sensitivity, reflection holograms are used as filters [9,10]. In reflection hologram quality of the out going beam degrades due to multiple reflection at fringe planes in the material and reflection losses but in case of transmission hologram, beam is allowed to pass through it without influencing in its quality. Hololenses have wavelength selective properties and thus they may qualify as a class of light filter. In this paper diffraction efficiency for different spectral distribution of a holographic light filter in reconstruction at Bragg's angle for UV, visible and IR ranges have been reported through simulation and experimentally it is verified through available wavelength sources. A brief description has been provided at the appropriate place of the manuscript in order to show the usefulness of such light filters in the field of Photovoltaics, PEC Hydrogen production, day lighting and other various fields where compensation of the spectral sensitivity of different photo sensors is highly required.

Now a days Dichromated gelatin [11–14], Photopolymers [15,16], Photo refractive materials ($LiNbO_3$) [17], PQ/PMMA [18,19] are being used extensively for recording holographic light filters, however due to ease of availability and cost effectiveness of source and recording materials, we have recorded holographic light filter on commercially available high resolution silver halide plate PFG-01 [20].

2. Theoretical background

In order to analyze the spectral characteristics of volume phase transmission holograms, we use the coupled-wave theory [21] which gives analytical equations for the diffraction efficiency assuming refractive index variation to be sinusoidal. When the wavelength of the reconstructing beam satisfies Bragg's law the diffraction efficiency is given by

$$\eta = \frac{\sin^2\{(\xi^2+\upsilon^2)^{1/2}\}}{1+(\xi^2/\upsilon^2)} \qquad (1)$$

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* Corresponding author.
E-mail addresses: abhi.photonics@gmail.com (A. Ghosh), rajeevranjan.depttphysics.nitjsr@gmail.com (R. Ranjan), aknirala@yahoo.com (A.K. Nirala), hly_physics@rediffmail.com (H.L. Yadav).

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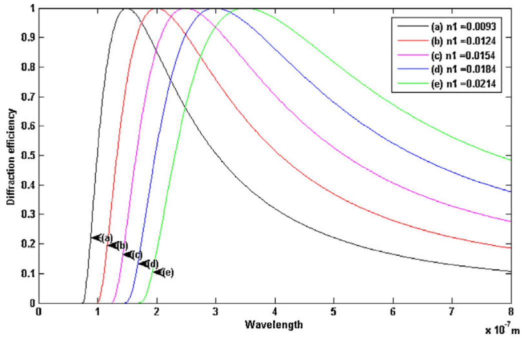

Fig. 1. Variation of diffraction efficiency with wavelength for different values of depth of refractive index modulation (n_1) at fixed value of $\Lambda = 0.51\ \mu\text{m}$, $n = 1.61$ and $d = 8\ \mu\text{m}$.

where parameters ξ and υ are defined by the following relations

$$\xi = \delta \frac{2\pi n}{\lambda} d \ \sin\theta \quad \& \quad \upsilon = \frac{\pi n_1 d}{\lambda \ \cos\theta} \tag{2}$$

where n_1 is the depth of refractive index modulation, d is the film thickness, n is the average refractive index of the medium, λ is the free space wave-length of the reconstruction light beam and δ is the angular deviation in radians with respect to Bragg's angle θ.

Bragg's angle θ is related to the fringe spacing Λ recorded in the hologram through the relation given by

$$\sin\theta = \frac{\lambda}{2n\Lambda} \quad \& \quad \cos\theta = \left\{1 - \left(\frac{\lambda}{2n\Lambda}\right)^2\right\}^{1/2} \tag{3}$$

When the illumination is made at Bragg's angle (i.e. $\delta = 0$) we have from Eq. (1)

$$\eta = \sin^2 \upsilon \tag{4}$$

$$\eta = \sin^2 \left(\frac{\pi n_1 d}{\lambda \ \cos\theta}\right) \tag{5}$$

$$\eta = \sin^2 \left(\frac{\pi n_1 d}{\lambda \{1 - (\lambda/2n\Lambda)^2\}^{1/2}}\right) \tag{6}$$

3. Analysis of spectral characteristics

Using Eq. (6) variation in diffraction efficiency (η) with wavelength at Bragg's angle for different values of depth of refractive index modulation (n_1) and fixed (but different) values of fringe spacing (Λ) and film thickness (d) are plotted in Figs. 1, 2 and 3.

Fig. 1 shows that to record a light filter exhibiting maximum efficiency for ultraviolet and lower wavelength range relatively lower film thickness or/and lower depth of refractive index modulation is required. Whereas, for higher wavelength region (near infrared) higher film thickness or/and higher depth of refractive index modulation is required as shown in Fig. 3. For visible region there should be a proper optimization between film thickness and depth of refractive index modulation. While drawing the curves for spectral characteristics (Figs. 1–3) care has been taken to ensure that criteria for thick phase transmission hologram is fulfilled for which Eq. (6) is valid [22]. A hologram is said to be thick if its Q parameter ($Q = 2\pi\lambda d/n\Lambda^2$) is greater or equal to 10 ($Q \geq 10$).

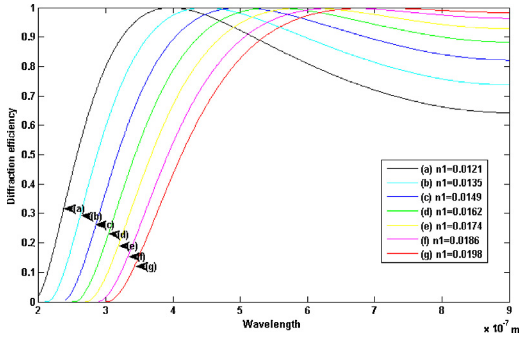

Fig. 2. Variation of diffraction efficiency with wavelength for different values of depth of refractive index modulation (n_1) at fixed value of $\Lambda = 0.51\ \mu\text{m}$, $n = 1.61$ and $d = 16\ \mu\text{m}$.

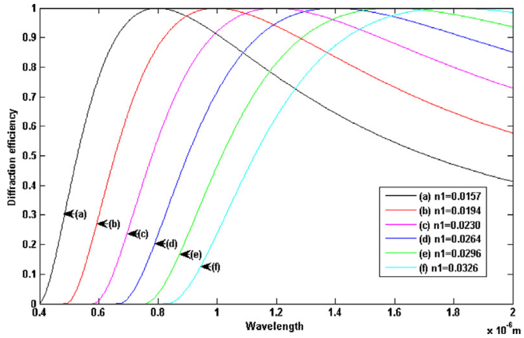

Fig. 3. Variation of diffraction efficiency with wavelength for different values of depth of refractive index modulation (n_1) at fixed value of $\Lambda = 1.32\ \mu\text{m}$, $n = 1.61$ and $d = 25\ \mu\text{m}$.

4. Experimental

4.1. Recording and play back geometry of hololenses for wavelength selective light filter

Hololens as a class of light filter is recorded using two coherent waves derived from the same laser source. Out of two coherent waves one is spherical wave and the other is a plane wave. Fig. 4 shows a typical recording geometry for hololens. To prevent formation of spurious grating, the waves should be recorded under index matched condition [23]. For present work a holographic light filter has been recorded on commercially available high resolution silver halide plate PFG-01 (film thickness $d = 8\ \mu\text{m}$ and average refractive index $n = 1.61$) using a He–Ne Laser ($\lambda = 0.6328\ \mu\text{m}$) of power 2 mW. The exposed film was processed using standard procedure [24,25]. Angle between plane wave and reference wave at the time of recording was $\theta = 45°$. Fringe spacing in the recorded hologram was $\Lambda = \lambda/(2n \sin\theta/2) = 0.51\ \mu\text{m}$ and depth of refractive index modulation ($n_1 =$) 0.0155. Recorded holographic light filter is played back as shown in Fig. 5 using white light coming out of a Tungsten Halogen Lamp.

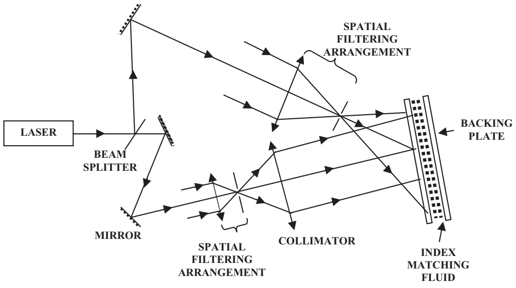

Fig. 4. Schematic of the recording geometry for hololens.