Combined holographic optical elements for multicolor holographic screens and indicators

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Abstract. A combination of holographic and diffractive optical elements (HOE-DOEs) for multicolor signs-symbolic information display system, screens and indicators is described. These elements combine the functions of high-efficiency four-level diffractive optical elements with spectral plasmon filters having a variable bandwidth dependent on the angle of incidence. The main parameters of such HOE-DOEs were determined using the Fourier modes method. The theoretical results show that a four-level diffraction grating and a plasmon filter can be combined based on their spectral-angular characteristics, opening up the possibility for their use in display systems.

1. Introduction

Currently, one of the most promising practical applications of flat optics is the development of holographic and diffractive optical elements (HOE-DOEs) with binary and multi-level surface relief, as well as their integration into optical devices. HOE-DOEs with light guide substrates are used in miniature display systems [1-6]. With these combined elements, the weight and size of display and visualization systems can be significantly reduced [3,4], which allows for their use in new applications, especially in automotive and aviation systems [2,4,5], where the display is superimposed on real world imagery.

The use of holographic indicators in different climatic conditions requires the selection of special photosensitive materials for HOE-DOEs. These elements may need to be physically protected or recorded directly into the glass [4]. There is a significant problem with the low diffraction efficiency of these devices [1-3]. Improved efficiency would allow for the use of less powerful illumination source including the possibility of using OLED-displays. In order to project multi-colored images, HOE-DOEs need to be designed with the specified spectral and angular selectivity. The development of a new type of combined HOE-DOEs with increased diffraction efficiency and spectral-angular selectivity for different photosensitive materials and glass will facilitate the development of a new generation of signs-symbolic information displays, based on holographic optical elements and light guide substrates.

2. Combined holographic optical element scheme

The main component of a holographic indicator is a signs-symbolic information output device, which can be mounted directly on the head of pilots, soldiers, vehicle riders, etc. These devices include a glass substrate [1-2], in which radiation can propagate with total internal reflection, and diffraction gratings (DG) at the input and output [1-2]. A major disadvantage of these relief-phase gratings is their low diffraction efficiency and their location on a layer of photosensitive material, which may not be suitable for operational conditions. Therefore, either this material needs to be protected or the grating must be fabricated directly in the glass with maximum diffraction efficiency, i.e. multi-level structures rather than binary structures are required, as shown in Figure 1.

HOE-DOEs can perform with increased efficiency for signs-symbolic information display DGs by using a few quantization levels of the surface microrelief. To generate multicolor images by holographic indicators, spectral filters must be used for selecting the incident wavelengths.

The most promising method for spectral selection when the source is white or polychromatic light is the use of plasmonic effects in metal-dielectric thin films [7-8]. This enables the creation of broadband and narrow band spectral filters with adjustable bandwidth by changing the angle of incidence of the input light. The use of these spectral filters in the new generation of miniature devices and data indication systems provides a high spectral-angular selectivity of transmitted or reflected optical radiation, which allows for the display of multicolor images.

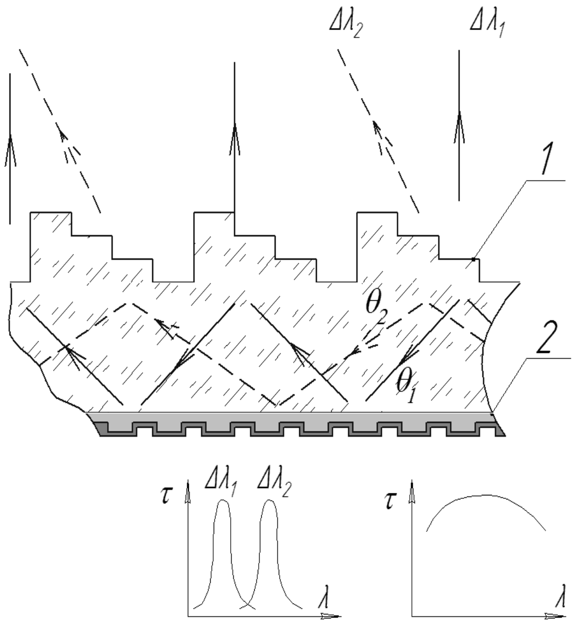

Figure 1. Schematic representation of the combined two-component HOE-DOE consisting of four-level DG1 and plasmon filter 2.

A combined two-component HOE-DOE configuration is shown in Figure 1, where a phase four-level element outputs the light, and a metallized diffraction grating performs the spectral selection. The rectangular metal diffraction grating has a transmission spectrum of the zero diffraction order, which depends on the angle of incidence. Depending on the angle of incidence of the polychromatic radiation, the plasmon filter selects which wavelengths are directed to a four-level HOE-DOE. A two- to four-level DG is used as the HOE-DOE.

3. Theoretical studies

The diffraction efficiency of any diffractive structure can be determined by Maxwell's equations. Numerous studies are devoted to finding a rigorous solution for electromagnetic diffraction by periodic structures. In this paper, the Fourier modes method is used to determine the parameters of the DGs. This is one of the most common methods used [9-10]. It is implemented using MATLAB software. Using his software, the diffraction of a plane wave on a DG is solved for various structures and the spectral characteristics and energy parameters of different diffraction orders are calculated.

In this case, the following model is considered. Light propagates by total internal reflection within the glass substrate that has a refractive index of 1.51, as shown in Figure 1. The grating has a period d= 490 nm [3], and its surface microrelief consists of 2–4 levels. The radiation has wavelengths of 440, 532 and 635 nm and is TE- polarized. Light from the first diffraction order is diffracted out of the substrate by DG 1.

Basic parameters of the HOE-DOEs are calculated by the software. The relief depth of the four-level grating is 350 nm. The diffraction efficiency and spectral characteristics corresponding to different wavelengths and incidence angles are shown in figure 2.

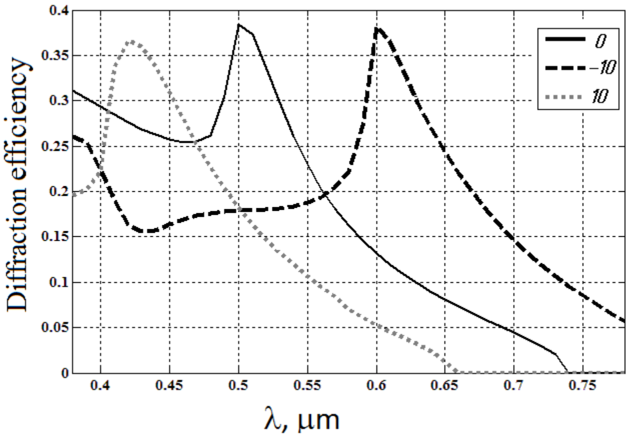

Figure 2. Diffraction efficiency of four-level profile diffraction grating corresponding to wavelength of incident radiation. The angles of incidence are -10°, 0°, and 10°.

A plasmon filter [7-8] may be used for spectral selection. It consists of a glass substrate and a photoresist layer with a meander grating coated by a layer of silver and SiO_2. The meander structure can be produced in the photoresist or glass layer by lithography and ion-plasma etching technology. The features of the resulting structure are investigated.

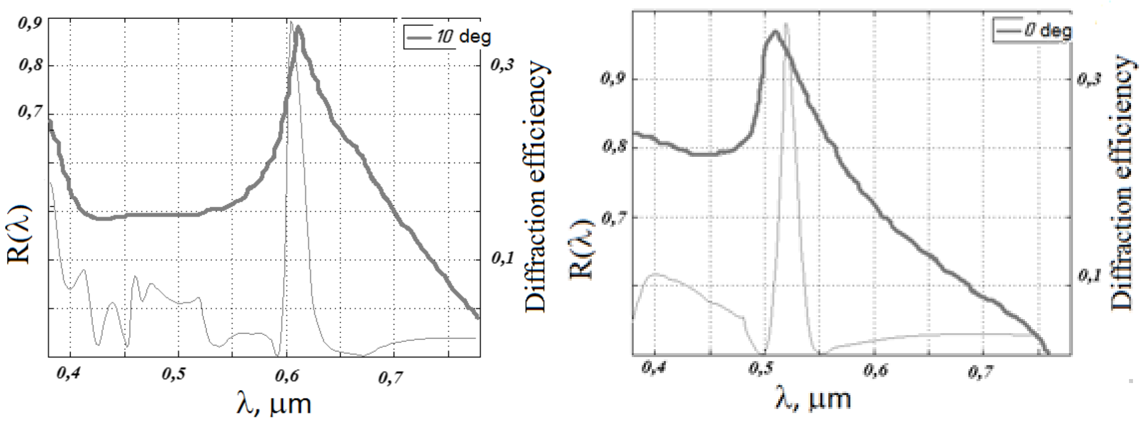

Figure 3. Diffraction efficiency of the four-level diffraction grating at incidence angles of 10° and 0° (dark lines) and radiation spectrum R(λ) reflected from the plasmon filter (light lines), corresponding to wavelength of incident radiation.

The optimal parameters of a spectral filter, which is a part of the combined HOE-DOE, are a meander structure with a period of 500 nm on a glass substrate with a refractive index n = 1.51, a resist layer with a thickness of 40 nm, a metallic silver layer of thickness 30 nm, and a SiO_2 layer of thickness 20 nm. Under these parameters, the spectral peak width is less than 20 nm and a strong correlation of the reflected radiation wavelength with its angle of incidence is observed, which suggests the possibility of obtaining a multicolor image.

The graphs in Figure 3, calculated by Fourier modes method, show that the two elements (four-level DG and plasmon filter) are combined by their spectral-angular characteristics, and can thus work together, which indicates the possibility of obtaining a combined HOE-DOE.

4. Conclusion

The combination of four-level diffractive optical elements having high diffraction efficiency with spectral filters that have a bandwidth that varies with the angle of incidence inside a single HOE-DOE has been explored. This is a new direction for the development of miniaturized data indication systems. To analyze these elements, Fourier modes method is used for solving Maxwell's equations. It involves the implementation of special software to solve the direct diffraction of a plane electromagnetic wave by a meander structure. The theoretical results suggest the possibility of using this combined HOE-DOE for displays, screens, and indicators showing signs-symbolic information.

Acknowledgments

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