[6] Combined holographic optical elements for indicators of sign and symbolic information

Odinokov S.B., Zherdev A.Y., Kolyuchkin V.V., Solomashenko A.B.
Bauman Moscow State Technical Universitv

Abstract

Combined holographic optical elements for optical systems of multicolor signs and symbolic information indicators are described. This element combines the functions of four-level diffractive optical elements with high diffraction efficiency and spectral plasmon filters with variable bandwidth depending on the incidence angle. The theoretical studies suggest the possibility of combining the two types of items in one combined structure.

Keywords: *holographic display, diffractive optical element, multilevel diffraction grating, plasmon grating, diffraction efficiency.*
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Introduction

One of the most promising "flat" optics practical applications is the development of holographic and diffractive optical elements (HOE-DOE) with binary and multilevel surface reliefs, as well as the creation of instruments and devices on the basis thereof [1]. Holographic and diffractive optical elements has come to be used, along with light-guiding plates, in miniature information display systems that has propelled them to the next qualitatively new level allowing significantly reduce weight-and-size parameters of visual display systems, especially in the systems provided for vehicles and helicopters where an observed image is overlapped with a real scene [2-4, 8, 9]. Performance of holographic displays in various climatic conditions stipulates the necessity to select a special photosensitive material to obtain the holographic optical element or protect it or obtain holographic and diffractive optical elements directly in glass. Moreover, while developing such systems, we currently face an acute problem of increasing the diffraction efficiency of holographic optical elements required to possibly use less powered and, respectively, properly sized imaging source light systems and possibly transfer to OLED-displays [5]. At this time the crucial task is to obtain multicolor images using holographic displays, i.e. creating holographic and diffractive optical elements with a proper angular spectral selectivity. Thus, development of a new type of combined holographic optical elements with higher diffraction efficiency and angular spectral selectivity on different photosensitive materials and in glass would enable to solve individual problems of creating a new generation of displays of sign and symbolic information based on holographic optical elements and light-guiding plates.

Diagram of the combined holographic optical element

A diagram of an indicator of sign and symbolic information is given in Figure 1. The main component of the indicator is an optical indicator of sign and symbolic information to be readout by an operator which shall be fixated directly on a head of a pilot, a fighter or a cycler, etc. The indicator includes the following: an image source which forms the sign and symbolic information required by the operator; an optical system collimating light beams to be entered to the light-guiding plate with the diffractive optical elements, and then to be transferred to the operator.

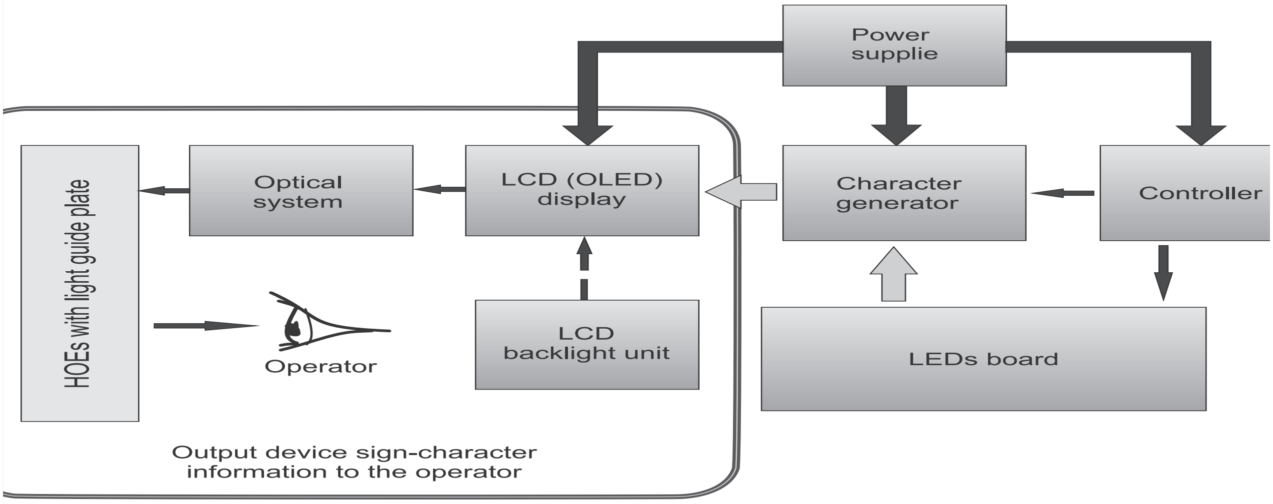


Fig. 1. Diagram of the optical indicator of sign and symbolic information with the combined holographic optical element

Thus, the main discriminating element of the holographic display is a glass plate in which the light can be scattered under the influence of the total internal reflection (TIR) with on-surface-applied diffractive gratings (DG) for emission input and output from the plate [6-9]. A major drawback of such relief-phase gratings is their low diffraction efficiency [6,7], and also the fact that they are obtained in a photosensitive material coating which does not always have satisfying operating characteristics. Therefore it is necessary to consider the possibility to obtain diffractive gratings directly in glass [11,12]. Papers [13,14] describe high-efficient binary diffractive optical elements obtained in layers of photo– or electro resists. In order to provide the increased diffraction efficiency of the diffractive optical elements directly obtained in glass, it is necessary to perform surface microrelief discritization of the diffractive optical elements, i.e. to obtain not binary but and multilevel structures [12], as shown in Figure 2.

In accordance to [10], at least 4 discritization levels of the surface microrelief are sufficient to double the diffraction efficiency if compared with the usage of binary structures. Therefore the diffractive gratings directly obtained in glass will be used as the holographic optical elements for indicators of sign and symbolic information, and their improved efficiency will be achieved by producing several disritization levels of a saw-tooth surface microrelief of the grating.

It is possible to solve the problem of producing multicolor images in indicators through the usage of spectral filters selecting the light scattered on the holographic and diffractive optical elements in accordance with wavelengths. Papers [15-17,20,21] present transmission spectral filters with high efficiency. However only the filters representing the metallic diffractive grating [20] can operate with sufficiently large apertures of incidence angles that is important for performance of the holographic display. The use of plasmon effects in thin metal-dielectric films [20-25] allows us to create broadband and narrowband spectral filters with the adjustable bandwidth when changing the input light incidence angle. Application of such spectral filters in new-generation miniature devices and indication and information display systems allows additionally provide necessary spectral-angular selectivity of transmitted or returned emission that in turn allows create color (multicolor) images.

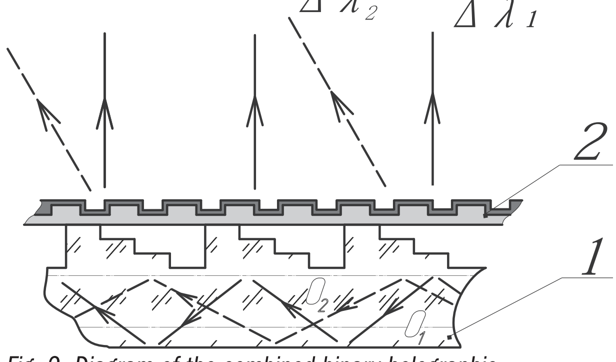
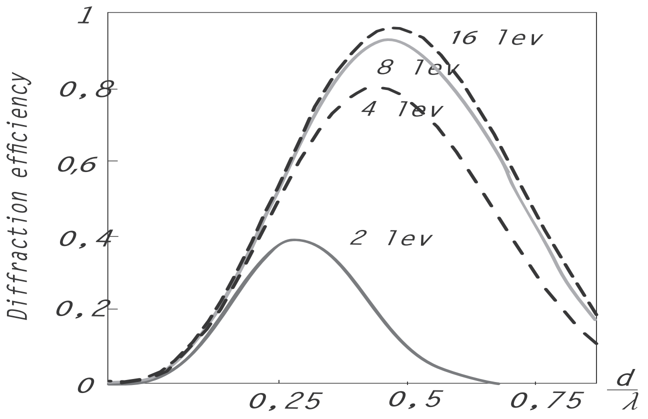


Fig. 2. Diagram of the combined binary holographic and diffractive optical element consisting of the plasmon filter of 2- and 4-level diffractive grating 1.

The diagram of the combined binary holographic optical element consisting of the four-level diffractive grating, which performs function of the light beam extraction from the light-guiding plate, and of the metallic diffractive grating, which performs the light spectral selection, is shown in Figure 2. The following model was considered herewith. Emission is scattered under the influence of the total internal reflection inside of



component of emission extracted by the grating from a light fiber.

Theoretical studies

Diffractive efficiency of any diffraction structure may be determined using Maxwell's equations. There is a great deal of papers devoted to rigorous solution of the direct problem of electromagnetic diffraction on periodic structures [27,28]. In order to determine parameters of the diffractive grating we will use in this paper the Fourier-modes method which is one of the most common and universal methods [26,29-34]. Implementation of the Fourier method was carried out in MATLAB software environment wherefore a proper software program has been written. This program solves the direct problem of plane wave diffraction on rectangular diffractive gratings that allows analyze the structures to be studied and obtain spectral characteristics and power parameters in different diffraction orders.

In order to extract emission from the plate it is necessary to ensure the maximum diffractive efficiency, therefore we will construct the diagram of dependences of the grating diffraction efficiency on the relief depth for different number of discritization levels of the surface relief of the diffractive grating.

As seen from Figure 3, the maximum diffraction efficiency of the grating can be achieved when the number of discritization levels of the grating surface relief is more than eight. It is technologically quite difficult to manufacture in glass the grating with 8 and more discritization levels therefore we will only focus on four levels. Thereby it is theoretically possible to obtain the twice higher diffraction efficiency than in the case with the binary relief.

Fig. 3. The dependence of diffraction efficiency of the diffractive grating with 2-, 4-, 8- and 16-level microrelief profile on the microrelief depth

One of the ways of implementation of the spectral filter based on the papers below [20,21] is the four-layer plasmon filter consisting of the glass substrate, a photo-resist coating with a meander grating coated with silver and SiO_2.

It is more convenient to obtain a meander structure in the resist coating or on the glass using the electron-beam lithography and ion-plasma etching technology and, respectively, for this particular structure the basic parameters will be investigated below. It would be possible to further obtain this structure using the method of galvanic copying and replicating on thin films.

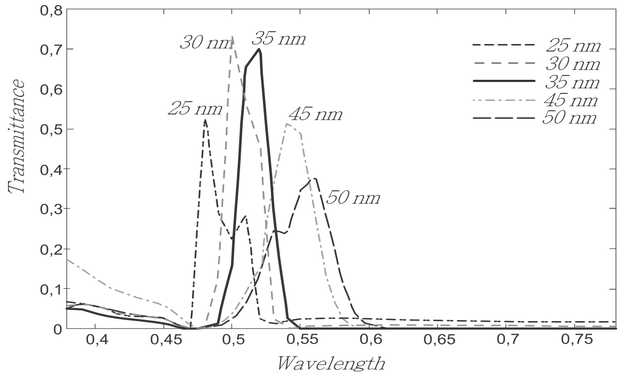


Fig. 4. The dependence of relative intensity of transmitted emission on the meander grating height

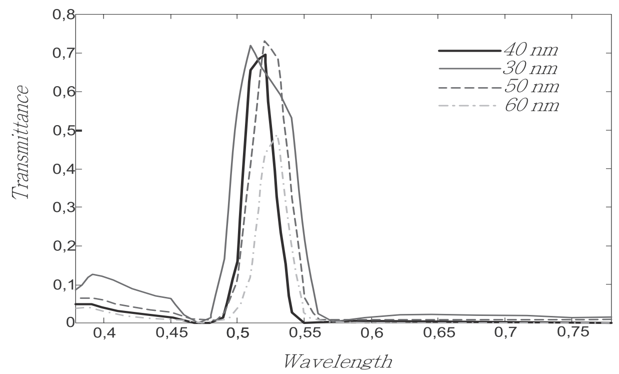


Fig. 5. The dependence of relative intensity of transmitted emission on the silver coating width

Based on the dependencies shown in Figures 4 and 5, we can conclude that optimum parameters of the spectral filter included into the combined holographic optical elements are the meander structure with a period of 0.45 μm on the glass substrate with n=1.51 with the grating height of 35 nm metalized with the silver coating of 40 nm. In this case the width of a spectral peak does not exceed 40–50 nm. Change of the grating height and silver coating thickness shall result to reducing a transmission ratio of the filter and broadening the transmitted emission spectrum.

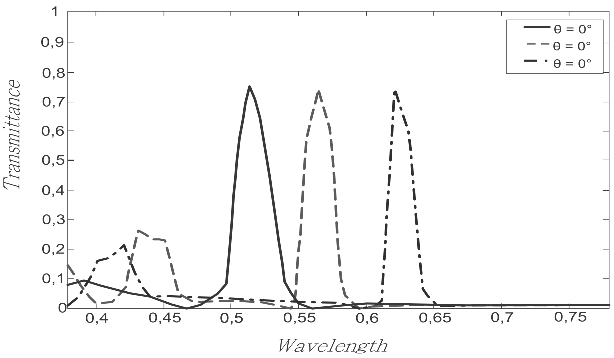


Fig. 6. The dependence of relative intensity of reflected emission on its incidence angle on the transmission plasmon filter

Figure 6 shows the dependence of relative intensity of transmitted emission on the emission incidence angle on the spectral plasmon filter. Proceeding from the chart, we can observe explicit matching of the wavelength of the transmitted emission to its incidence angle on the filter that makes it possible to obtain the multicolor image by applying combined holographic optical elements in holographic displays.

Conclusion

Connecting in combined holographic optical elements the functions of multilevel diffractive optical elements with higher diffraction efficiency and the spectral filters with the variable bandwidth depending on the incidence angle is a new direction for the development of miniature indication systems and information display systems. In order to analyze these elements we have used the Fourier-modes method to solve Maxwell's equations which involves the implementation of software solutions for the direct diffraction problem of a plane electromagnetic wave on the meandering structure. Due to this program we have identified the basic parameters of the combined element and the relationship therebetween for the four-level diffractive grating and also the spectral filter based on the metallic grating, which comprise the combined holographic optical element. The obtained theoretical results suggest the possibility to use this type of combined holographic optical elements in indicators of sign and symbolic information.

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