

Novel Holographic Color Filters with Double Transmission Holograms

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ABSTRACT

A novel transmission structure of holographic color filters is introduced. The device is based on the natural characteristics of angular color dispersion in transmission holograms, and the optical reciprocity interacting with two same transmission structure. The type of holographic color filters, differed from before, is composed of two same structure of transmission holograms which are laminated on the both side of transparent substrate. The first transmission hologram diffract normally incident white light, generally emitted from metal halide lamp, into transparent substrate with angular color separation. The diffracted beams transmitted through substrate and are separated for different R, G, B wavelengths. At last, the different R, G, B beams normally couple out with the second hologram as same structure as first one due to optical reciprocity. A light beam matrix mask (LBM) is presented to produce R, G, B pixel, and provided an approach in LCD application.

Key Words:Holographic Optical Elements, Diffraction Optics, Color Filters, Holographic Technology.

1.INTRODUCTION

Holographic optical elements based on phase volume holograms present a new optical function and a fantastic application in LCD projectors. Arrays of colored filters for LCD are made by reflection holography in dichromated gelatin¹. The micro lens array (MLA), focuses the incident light into color cell aperture with a applied three hologram layers². A diffractive transmission grating is used for a compact spatio-chromatic single-LCD projection architecture³. Holographic microlens matrices for selective focusing of a primary color is applied in single- and 3-LCD system⁴.

The advantage of volume holographic elements is the 100% theoretical diffraction efficiency in one diffraction order they can reach. Compared to method of multilayer thin film technique, the manufacturing process of phase volume hologram is simple by the beam interference exposure geometry. The mass production of phase volume hologram can also lead to low cost by using the optical duplication process from a holographic master. Multiple and complex optical function can be completed by a specific superposition in same thickness scale of the thin film

A novel transmission structure for holographic color filters is introduced for LCD application. This structure is based on the natural characteristics of angular color dispersion in transmission holograms and the optical reciprocity interacting with two same transmission structures. The holographic color filters is composed of two same structure of transmission holograms which are laminated on the both side of transparent substrate. The first transmission hologram diffracts normally incident white light, generally emitted from metal halide lamp, into transparent substrate with angular color separation. The diffracted beam transmitted through substrate and are separated for different R, G, B wavelengths. At last, the different R, G, B beams normally couple out with the second hologram as same structure as first one due to optical reciprocity.

2. BACKGROUND

2.1 Basic Idea

Diffraction characteristics of phase volume transmission hologram is analyzed and based on the Kogelnik's coupled wave theory⁵. For the transmission holograms, the two beams construction is generally shown as in Fig.1. The reference beam and object beam are formed a interference on the same side of holographic recording material. The fringe period of volume transmission hologram is illustrated as following form,

$$\Lambda = \frac{\lambda_o}{\sin \theta_r + \sin \theta_d} \quad (1)$$

where θ_r and θ_d are the incident angle of reference and object beam to surface normal respectively, λ_o is the wavelength of construction, and Λ is the fringe period of hologram.

When reconstruction, the diffraction property of transmission holograms can be also maintained as the constructive format with a different reconstructed angle θ_1^r , a different diffraction angle θ_2^r , and a reconstructed wavelength λ_r .

$$\Lambda = \frac{\lambda_r}{\sin \theta_1^r + \sin \theta_2^r} \quad (2)$$

If the beam of construction and reconstruction are normal incidence to surface plane, *i.e.* θ_1^r and θ_r are equal to zero. Then, Eq.(2) can be simplified as following expression, Eq.(3). That mean, different reconstructed wavelength will have a different diffraction angle due to the natural characteristics of angular selection.

$$\frac{\sin \theta_2^r}{\lambda_r} = \frac{\sin \theta_d}{\lambda_o} \quad (3)$$

Take a differentiation with respect to wavelength λ_r . Eq.(3) can be rewritten by the following expression,

$$\frac{d\theta_2^r}{d\lambda_r} = \frac{\sin\theta_d}{\lambda_0 \cdot \cos\theta_2^r} = \frac{\sin\theta_d}{\lambda_0 \cdot \sqrt{1 - (\mu_r \cdot \sin\theta_d)^2}}, \quad (4)$$

Then,

$$\Delta\theta_2^r = \frac{\sin\theta_d}{\lambda_0 \cdot \cos\theta_2^r} \cdot \Delta\lambda_r = \frac{\sin\theta_d}{\lambda_0 \cdot \sqrt{1 - (\mu_r \cdot \sin\theta_d)^2}} \cdot \Delta\lambda_r \quad (5)$$

$\therefore \Delta\lambda \uparrow \rightarrow \Delta\theta \uparrow$, i.e. a linear angular deviation

where $\Delta\lambda$ is the wavelength deviation from the reconstruction and $\mu_r = \lambda_r / \lambda_0$, it would cause a different color separation in diffraction. If the white light is incident, the three primary colors are separated to R, G, B.

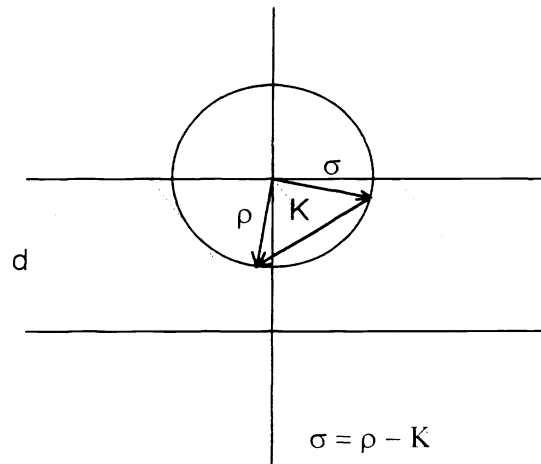


Fig. 1 Construction geometry of phase volume transmission hologram.

2.2 Optical Reciprocity

The holographic color filters, differed from before, is composed of two same structure of transmission holograms which are laminated on the both side of transparent substrate, as shown in Fig. 2. The first transmission hologram diffract normally incident white light, generally emitted from metal halide or other light source, into transparent substrate with angular color separation. The diffracted beams transmitted through substrate and are separated for different R, G, B

wavelengths. At last, the different R, G, B beams normally couple out with the second hologram as same structure as first one, *i.e.* called optical reciprocity as clearly seen the k-vector diagram in Fig. 2b.

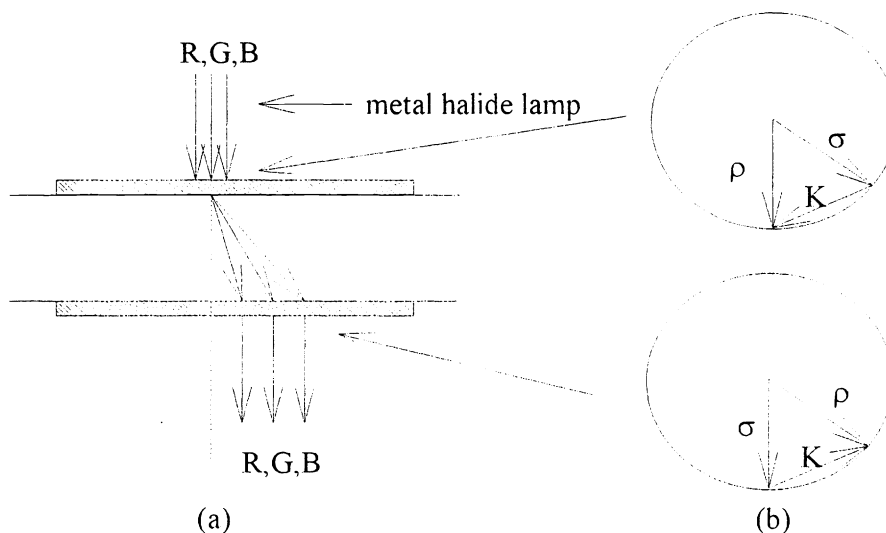


Fig. 2 (a). Geometry of double transmission hologram, (b). K-vector diagram of optical reciprocity.

2.3 Characteristics of phase transmission hologram

The following equations are applied to calculate the spectral profile of theoretical diffraction efficiency, as shown in Fig. 3. The spectral distribution of phase transmission hologram is wider due to the surface rainbow effect.

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

$$v = \frac{\pi \cdot n_1 \cdot d}{\lambda \cdot (C_R \cdot C_S)^{1/2}}$$

$$\xi = \frac{d}{2} \cdot \frac{K \cdot \cos(\phi - \theta) - K^2 \lambda / (4\pi n)}{C_S} \quad (6)$$

where $C_R = \cos\theta_r$, and $C_S = \cos\theta_r - 2 \cos(\phi - \theta_0) \cos\phi$. The parameters C_R, C_S is a measure of the exposure angle from the surface normal, η is the diffraction efficiency of hologram, λ_0 is the

wavelength at Bragg condition, θ_0 is the incident angle at Bragg condition, and d is the grating thickness. The performance of transmission holograms, as exhibited by their diffraction efficiency and bandwidth, depends on their index modulation recorded in the film. However, the high index modulation of hologram will achieve a better performance of volume hologram.

3. EFFICIENCY AND CHROMATICITY ANALYSIS

3.1 Diffraction efficiency

The theoretical diffraction efficiency spectral profile can be modelled by Eq. (6). The optical efficiency in each color distribution is shown as Fig. 3. The thickness of Fig. 3a is 40 μm , and Fig. 3b is 50 μm . In general, the optimum index modulation of volume transmission photopolymer can obtain a higher value up to 0.060, that mean, a high transmission efficiency.

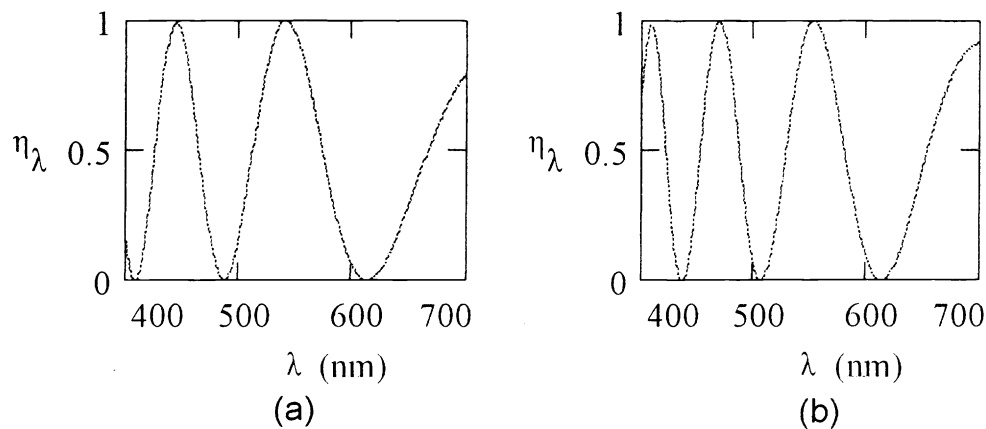


Fig. 3 The theoretical DE in each color distribution with different thickness.

3.2 Chromaticity

The chromaticity diagram is following CIE1931 standard with a comparison of conventional color filter, as shown in Fig. 4. The theoretical analysis of chromaticity is larger than conventional color dyed filters.

4. PROCESS

To investigate the color separation of phase transmission holograms, the constructed angle of transmission hologram were 0 degree and 20 degree, according to basic theory of transmission holograms. The transmission holographic recording films can be utilized DCG or photopolymer for this experimental. The Du Pont holographic photopolymer materials is best way for our structure, such as HRF 150, 600-001 or 609. HRF 150 has a film thickness of 38 μm . HRF 600 have a optimal thickness 20 μm with higer index modulation up to 0.061. HRF 609 has a wider

spectral characteristics. This photopolymer hologram is constructed by the dry processing which is followed the steps of exposure, UV curing and baking. To record hologram, a 532 nm Nd:YAG laser or 514 Argon laser is used for exposure, which the laser intensity was 2 mW/cm^2 . The optimal film speed of DuPont HFR 600-001 is from 80 to 120 mJ/cm^2 . The process of UV curing was 100 mJ/cm^2 . Finally, the film was heated in an air-flowed oven at 120°C to 150°C for two hours for increasing the index modulation and efficiency. The photopolymer of HRF 600-001 with a thickness of $20 \text{ }\mu\text{m}$ is utilized for this structure. The R, G, and B color can easily be separated in this double transmission holograms. But the FWHM bandwidth of real spectral profile is $25 \text{ }\mu\text{m}$ due to the thickness of HRF 600. The multilayered photopolymer structure may solve this problem.

To understand the color properties of phase volume holograms, we used the behavior of diffraction efficiency measurement to analyze the color separation of photopolymer hologram. The measurement of diffraction property is realized by the setup of PDA optical spectrograph card. The type of the light source is metal halide lamp with a UV filter, and extend of illuminating light angle $\pm 5^\circ$.

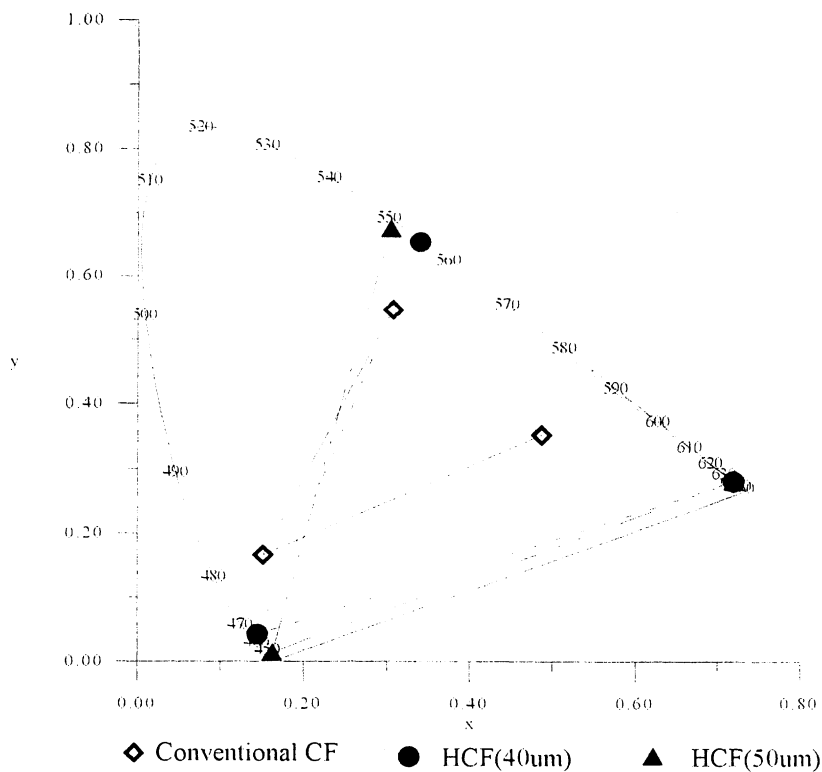


Fig. 4 The color chromaticity of theoretical approach in Fig.3.

5. APPLICATION

Holographic color filters applied in LCD displays provide an important approach by producing these filters with a holographic process. Especially, they are different from the conventional type of colored dyes which are impregnated into a polymer matrix and thin film interference layers evaporated in a vacuum chamber. The advantage of holographic color filters is easier to produce than dyed filters and also have the properties of sharp edges with respect to thin film filters. Many technologies for manufacturing holographic filters are well known now, such as holographic mirror, holographic notch filter, holographic sun-protective glasses etc..

The novel transmission structure is based on the natural characteristics of wider angular color dispersion in transmission holograms and the optical reciprocity interacting with two same transmission structures. A light beam matrix mask (LBM) is adopted in front of color filters structure in order to produce R, G, B pixels, as shown in Fig. 5 and 6. The white light beam is incident into a cell of matrix mask and passes through double-hologram structure for the purpose of producing a set of R, G, B pixels. Due to the converting efficiency of this novel device, it can be used fully, the individual R, G, B beam can reach a higher efficiency. Another advantage of this structure is simple to make and compact to use.

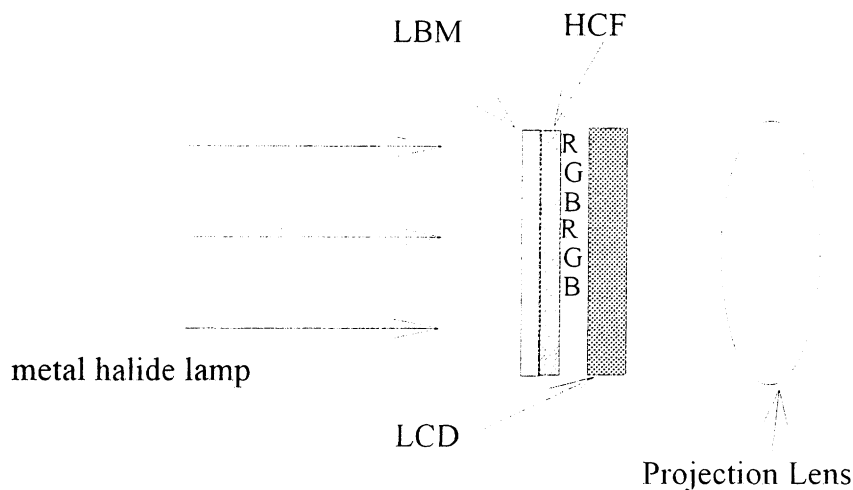


Fig. 5 Application of holographic color filters in LCD display.

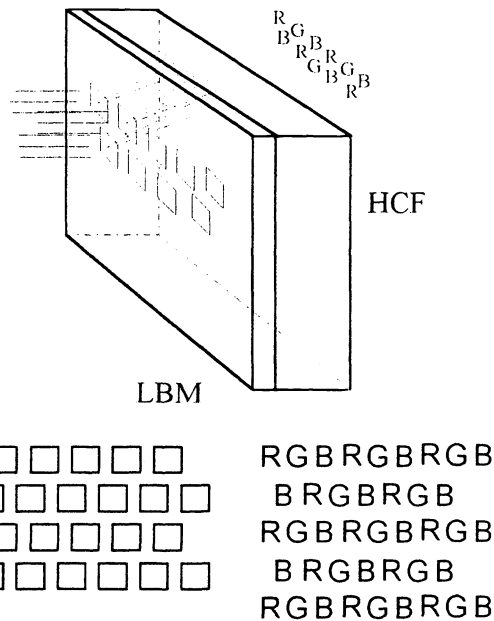


Fig.6 Arrangement of light beam matrix mask.

6. CONCLUSIONS

A novel holographic color filters is demonstrated for LCD application. The filters are produced through a process of phase volume transmission holograms. Holographic filters are easier to make than dyed or interference filters. The chromaticity of holographic color filters is larger than conventional color filters. The pass transmission can be reached high and their blocking transmission is low. Holographic technology has proved a significant application in color generation for LCDs.

7. REFERENCES

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