Design of a symmetric blazed grating sheet embedded in an autostereoscopic display

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This study proposes a diffractive autostereoscopic display technology that utilizes blazed grating embedded in the liquid crystal panel to deliver a stereo image pair to both eyes. Having the diffractive red green blue beams as the color source of the panel, color filters are no longer required in this system. From the simulation analyses, not only could the brightness achieve 77.90%, but no serious chromatic aberration or cross talk appeared.   © 2011 Optical Society of America

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Autostereoscopic visual images are generated from the left-viewing image and the right-viewing image being directly delivered to the left and right retinas without wearing any devices so that the brain generates the stereopsis and determines the depth of the object through the binocular disparity of the two images [1]. Nonetheless, present technologies are not problem-free and common problems include insufficient brightness, moiré, and cross talk, so that users cannot watch for a long period of time [2,3]. Chen *et al.* first proposed diffractive optical elements (DOEs) to replace the present splitters of shaded and lenticular stereo image pairs, where DOEs were directly attached to the color filter of the panel so that the symmetric design separately generated +1 order diffraction, which was the binocular position to view stereoscopic images [4]. Su *et al.* further proposed producing the splitters of stereoscopic displays with holographic optical elements and proved the feasibility of diffractive stereoscopic splitting [5]. Direct attachment on panels was considered convenient; however, abrasion resistance was required for the substrate of the material. Besides, the design of DOEs was based on specific wavelengths of red green blue (RGB) generated by laser light, further complicating the process.

For this reason, this study proposed to embed blazed grating in the panel so that it could be protected from external damage, such as press, scratches, and spikes, to prolong the time of use. A single-size grating cycle could benefit from the simplification of the implementation and the high efficiency of the yield. Moreover, the diffractive RGB beams being directly treated as the color sources of the panel allowed for the deletion of the color filter on the panel so that the panel could be made more lightweight, reducing production costs and resulting in easier mass production [6]. The entire structure is shown as Fig. 1. An 8.9 in. panel was utilized as the reference basis. In order to achieve the disparity angle of binocular stereoscopic images, this study designed the highest diffractive intensity with +1 order diffraction as the entrance pupil direction to generate the positions of left and right fields of view (FOVs) with a symmetric arrangement, such as the left and right zones shown in Fig. 2.

The backlight applied the mixed light of three dominant wavelengths, namely R 625 nm, G 525 nm, and B 465 nm. With the calculation of Eq. (1), the relations between the diffraction angle and the cycle of blazed grating could be defined.

$$n \sin \theta_m = \frac{m\lambda}{p}, \tag{1}$$

where θ_m represents the diffraction angle, $m = 1$ the diffraction order, T the horizontal size of the panel, E the binocular distance, $n = 1.5$ the material of blazed grating, λ the wavelength, and P the blazed grating cycle.

Nevertheless, a planoconvex lens array sheet needed to be attached on the back of the blazed grating in order to accurately deliver the diffractive RGB beams to the RGB subpixel in the liquid crystal panel. Based on the acceptable light range of pupils, a prism sheet attached under the glass panel allowing the emergent light to enter
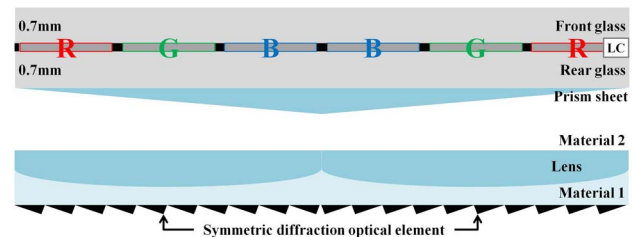

Fig. 1. (Color online) Structure diagram of diffractive stereoscopic system and blazed grating.
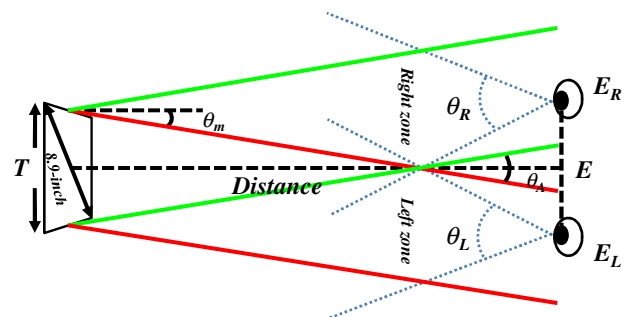

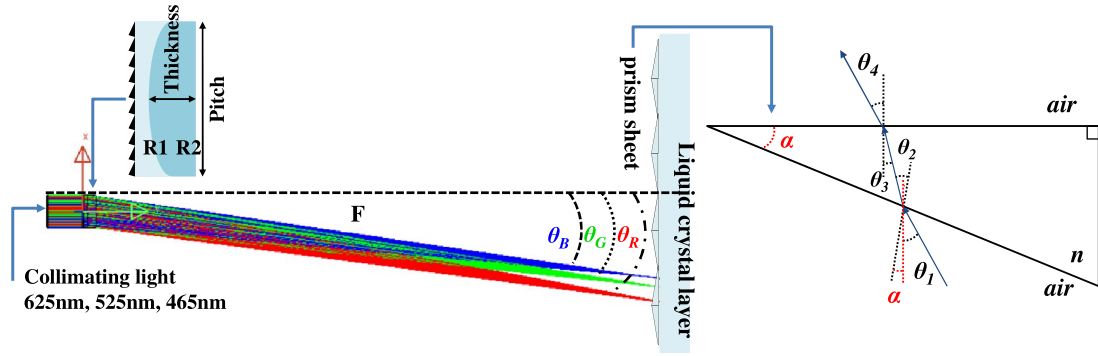Fig. 2. (Color online) Optical path diagram of diffractive stereoscopic system.

Fig. 3. (Color online) System structure and light path diagram.

the allowable area of pupils could prevent it from chromatic aberration. Referring to the panel specifications and the element structure in Fig. 3, the focal length of the planoconvex lens was 3.3 mm, the pitch being the panel pixel size 189 μm, the thickness 50 μm, and R1 and R2 being 863 μm and infinity, respectively. Figure 3 also shows the relations between the emergence angle of prism sheet θ_4 and the vertex angle α and the incidence angle θ_1. The emergence angle θ_4 was further defined as the relevant parameter of the prism sheet obtained from Eq. (2).

$$\theta_4 = \sin^{-1}\left\{ n \sin\left\{ \sin^{-1}\left[\frac{\sin(\theta_1 + \alpha)}{n} \right] - \alpha \right\} \right\}. \quad (2)$$

Having completed the design of the blazed grating, the lens array sheet, and the prism sheet, the optical simulation software LightTool was utilized to be embedded in the diffractive autostereoscopic display system, as shown in Fig. 4. In the figure, when the backlight is passing the blazed grating, +1 order diffraction could indeed be generated and divided into three light sources. After passing the lens array sheet, RGB could accurately enter the subpixel areas of the panel, as shown in the arrangement on the right.

With rigorous coupled-wave analysis, when a blazed grating cycle was less than 1/10 wavelength, the change of the wavelength could affect the change of diffraction efficiency [7,8]. In this case, when 625 nm (λ_R), 525 nm (λ_G), and 465 nm (λ_B) were passing the 4 μm blazed grating, the diffraction efficiency presented 72.52%, 84.08%, and 85.41%, respectively. With simulations and the calculation of Eq. (3), the overall system efficiency showed 77.90%, as shown in Fig. 5. In comparison with traditional shaded stereoscopic displays, which have dark and bright alternate vertical lines attached on the panel, the brightness performance dropped down to 22.42%. The chrome-plated reflection grating proposed by Chen *et al.* in 2008, which could absorb the shaded grating or recycle the diffused light, could merely increase up to 43.2% [2], which was less than half of the original brightness. Consequently, the proposed splitting
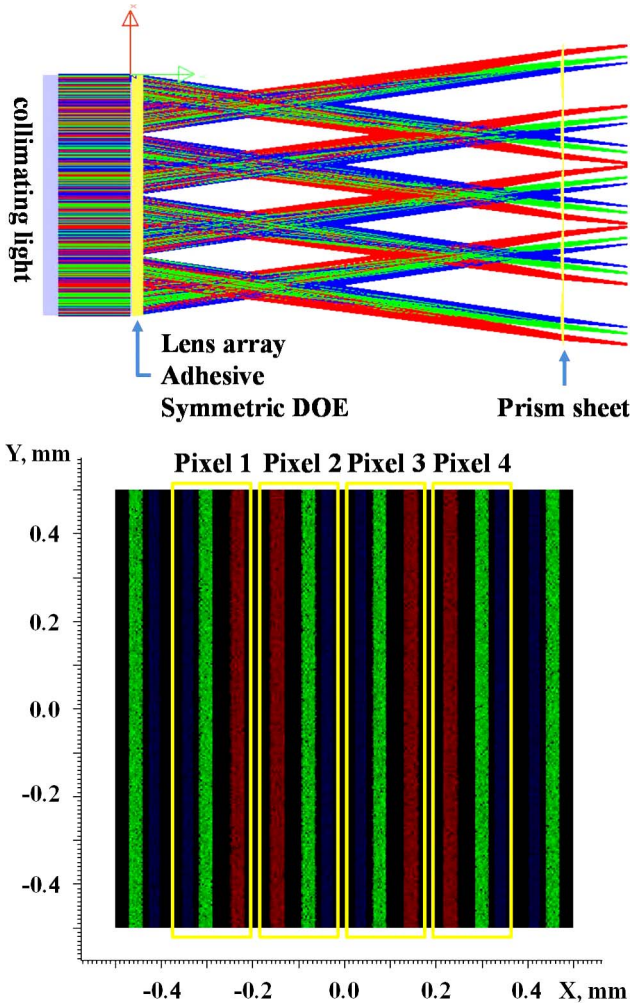

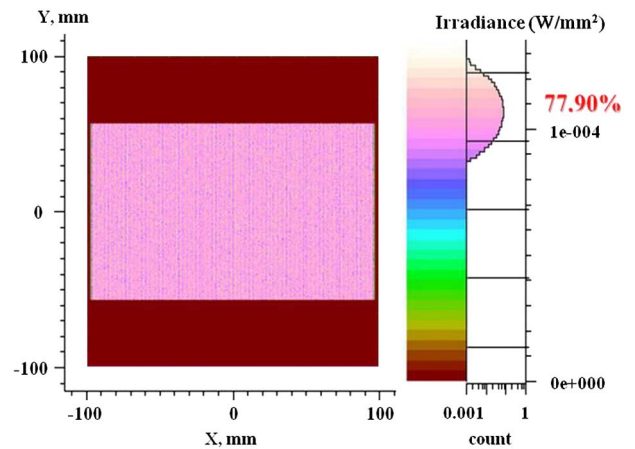Fig. 4. (Color online) Simulated light path of the diffractive stereoscopic system panel.

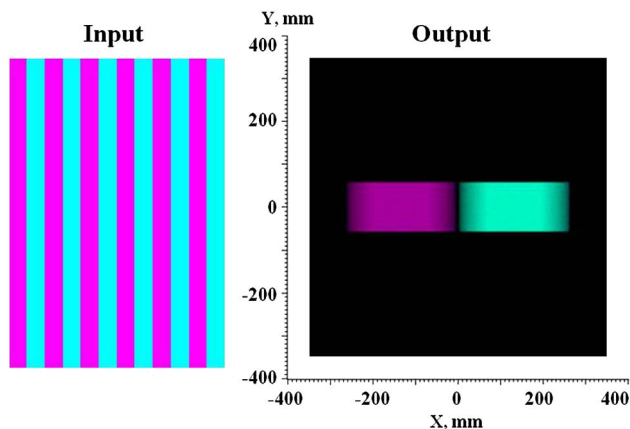Fig. 5. (Color online) Brightness performance of diffractive autostereoscopic display system.

Fig. 6. (Color online) Left- and right-viewing images of magenta and cyan.

with DOEs could solve the problem of insufficient brightness.

$$\text{Total efficiency} = \frac{PW_{\text{output}}}{PW_{\text{input}}} \times 100\%. \qquad (3)$$

Aiming at the verification of chromatic aberration, color-matching was utilized. Having a set of magenta and cyan alternate images being simulated, the pair of images could be actually delivered to both the left and right FOV, as shown in Fig. 6. Generally speaking, traditional stereoscopic displays were the stereoscopic images based on pixels, but shaded or cylindrical lenticular stereoscopic images were likely to suffer a chromatic aberration [2]. Having RGB diffraction as the color source of the panel, it was easier to control the movement of light; besides, with symmetric blazed grating to accurately separate left and right color lights, overlaps would not appear. Moreover, cross talk in the traditional autostereoscopic technology was about 2–10% [9]. From the simulation results, as shown in Fig. 7, the left FOV completely received the light, while the right FOV did not.

According to the above simulations, the proposed DOEs not only could successfully separate the required left and right images from the stereoscopic image, but the diffractive RGB beams could also replace color filters. Furthermore, the simulated results verified that the efficiency could reach 77.90%, which did not merely improve the problem of brightness reduction with traditional shaded technology, but also solved the problem of
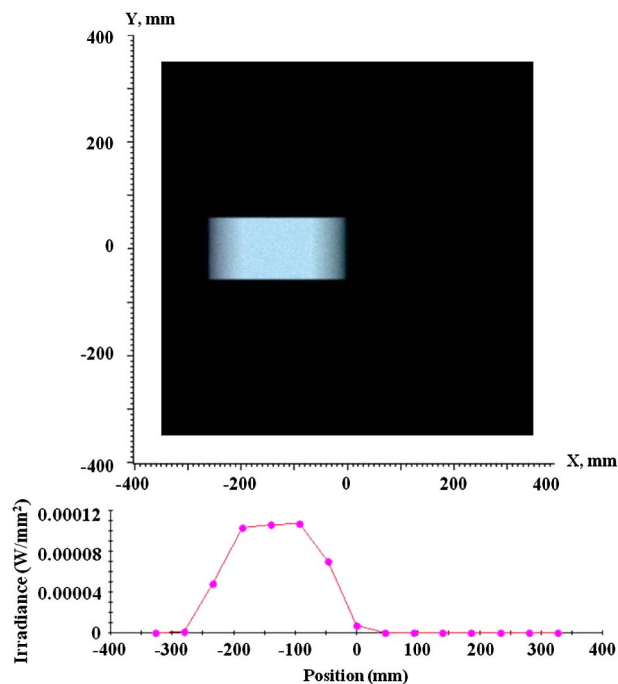

Fig. 7. (Color online) Simulation results of cross talk.

chromatic aberration. Moreover, the symmetric splitting allowed the left and right images to be delivered to accurate positions that it did not cause cross talk in comparison with traditional atuotereoscopic displays.

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