

Reflective three-dimensional displays using the cholesteric liquid crystal with an inner patterned retarder

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Abstract: We propose a reflective three-dimensional (3D) display using a cholesteric liquid crystal (ChLC) with an inner patterned retarder producing half-wave retardation. The inner patterned retarder, fabricated by selective ultra-violet exposure to the aligned reactive mesogen, divides the circularly polarized light reflected from the ChLC layer into two orthogonal circular polarizations. These reflected orthogonal polarizations construct stereoscopic 3D images without any optical components such as a polarizer and backlight unit.

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1. Introduction

Flat panel displays have been developed to achieve excellent performances such as low power consumption, high contrast ratio, high definition, and light weight. Although the performances of these displays reach a high level, where the display hardware nowadays is far better than most content, most display technologies are still limited to the realization of two dimensional (2D) images. Recently, three dimensional (3D) displays have attracted great interest as the next generation displays since they can construct realistic images with image depth [1, 2]. Especially, the stereoscopic 3D displays with viewing glasses have been widely developed and commercialized due to their good display performances and unlimited viewing points [3–8]. In the glasses-based 3D displays, to produce the binocular disparity, a liquid crystal display (LCD) panel generates two different images arriving at the left and right eyes. Mainly, two types of the glasses-based 3D displays are proposed. One is a shutter-glasses 3D display and the other is a patterned retarder 3D display. In the former 3D display, the shutter glasses divide two images corresponding to the left and right eyes through switching the polarization states synchronized with the 3D displayed images [3, 4]. Here, the LCD panel is almost similar to the conventional LCD for the 2D images except for the time-division operation to generate the binocular images. In the patterned retarder 3D displays, two images with different polarization states corresponding to the left and right eyes are generated by the patterned retarder, which is generally attached on the outside of the LCD panel to change the polarization state. Although various stereoscopic 3D displays with good display performances have been developed and fabricated, a reflective 3D display with low power consumption has not been proposed so far.

In this work, we proposed a reflective 3D display based on the cholesteric liquid crystal (ChLC) display with an embedded patterned retarder. Since the ChLC display using the polarization-selective reflection is operated in a reflective mode without a polarizer, the patterned retarder can be embedded within the LCD panel. The inner patterned retarder was fabricated by the selective ultra-violet (UV) exposure to liquid crystalline polymer (LCP) through an amplitude photo-mask. Here, the patterned LCP layer changes orthogonally the polarization state of the reflected light from the ChLC cell [2, 9]. We could obtain stereoscopic 3D images through dividing the reflected light into two orthogonal polarizations. In addition, this reflective 3D display does not require a color filter and backlight unit since the reflective ChLC mode is used [10–12]. The reflective 3D display proposed here is expected to create novel 3D displays with low power consumption due to their memory characteristics in the conventional ChLC modes and the reflective configuration without backlight unit.

2. Operating principle and experiments

Figure 1 shows a schematic diagram of our reflective 3D display based on the ChLC panel with an inner patterned retarder. The incident light was selectively reflected from the ChLC layer with the same circular polarization as the handedness of the cholesteric helix and the same Bragg wavelength determined by the helical pitch of the ChLC [13]. In the patterned region, the polarization state of the reflected light is orthogonally changed by the half-wave retarder. On the other hand, the polarization state still remains unchanged in the non-patterned region. These orthogonal polarization states reflected from the ChLC panel with the inner patterned retarder generate the stereoscopic 3D images in the reflective configuration.

To fabricate the reflective 3D display proposed here, the alignment layer of RN1199 (Nissan Chemical) was coated on top of the indium-tin-oxide (ITO) evaporated substrates and rubbed unidirectionally to promote planar alignment. For the inner patterned retarder, the reactive mesogen (RM) of RMS03-013C (E. Merck) was coated on the rubbed ITO substrate. The RM is uniformly aligned along the rubbing direction like the LC. The ordinary and

extraordinary refractive indices of RMS03-013C are 1.680 and 1.543, respectively. The thickness of the RM film was 2.3 μm corresponding to the half-wave retardation. Finally, the patterned LCP retarder was fabricated by the selective polymerization of the RM with UV exposure through an amplitude mask with striped shapes and the removal of the RM residue from the non-exposed regions with RM solvent of propylene glycol monomethyl ether acetate [14]. Here, both width and interval of the stripes were 200 μm .

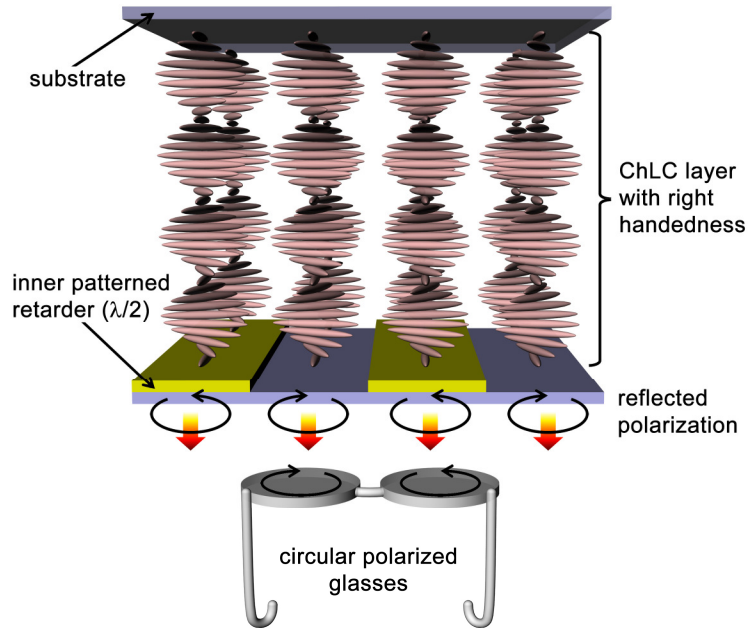


Fig. 1. Schematic diagram of the ChLC device with the inner patterned retarder for the reflective 3D display.

The nematic LC of MLC6875 (75.8 wt.%, E. Merck) and the chiral dopant of R811 (24.2 wt.%, E. Merck) were used for the ChLC mixture with the right-handed helical structure. The ChLC mixture was stirred in an isotropic phase for 24 h to mix the chiral dopant into the nematic LC completely. After assembling the LCP-patterned substrate and the RN1199-coated substrate without any patterns, the ChLC mixture was injected into the assembled substrates by capillary action in the isotropic phase. The cell thickness was maintained using glass spacers of 10 μm .

The polarizing optical microscope (Nikon, E600W POL) and the surface profiler (Tencor Instruments, Alpha-Step 500) were used to take microscopic textures and characterize the patterns, respectively. All measurements were carried out at room temperature.

3. Results and discussion

The ChLC layer forms the helical structure with right-handedness under no external electric field due to the planar alignment of both substrates as shown in Fig. 1. The patterned retarder generating two orthogonal circular polarizations was formed on the inner surface of the front substrate to convert the polarization states of the light reflected from the ChLC layer.

Figure 2 shows microscopic textures and the surface profile of the patterned retarder fabricated with the RM. Here, the optic axis of the patterned retarder was rotated by 45° with respect to the direction of the striped patterns and one of crossed polarizers. The optic axis is easily controlled by the rubbing direction of the alignment layer. It should be noted that the direction of the optic axis is insignificant in the half-wave retarder for the ChLC 3D display because the orthogonal switching of the circular polarization is independent of the optic axis of the half-wave retarder. Under crossed polarizers, the patterned regions exhibit bright states

due to the orthogonal change of the linear polarization of the incident light and the non-patterned regions show dark states since maintenance of the incident polarization as shown in Fig. 2(a). On the other hand, transmittance is switched between two regions under parallel polarizers. Figure 2(b) shows the surface morphology and the corresponding phase retardation of the patterned retarder where both width and interval of the stripes are $200\ \mu\text{m}$. As shown in Fig. 2(b), the height of the stripes is measured to be about $2.3\ \mu\text{m}$, which matches half-wave (π) retardation since the birefringence of the RMS03-013C is 0.137.

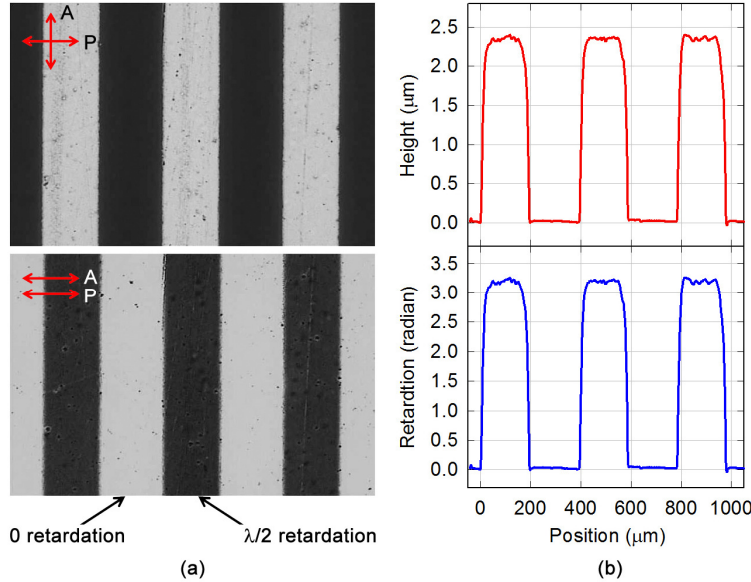


Fig. 2. (a) Polarization microscopic textures of the patterned retarder under crossed polarizers and parallel polarizers. Letters “A” and “P” denote the directions of the analyzer and polarizer, respectively. (b) The surface morphology and the phase retardation of the corresponding patterned retarder.

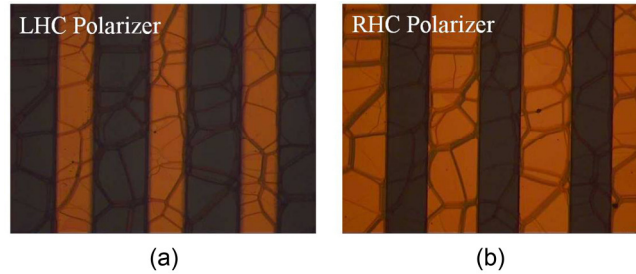


Fig. 3. Microscopic textures of our ChLC device under (a) left-handed circular polarizer and (b) right-handed circular polarizer.

Figure 3 shows microscopic textures of the ChLC device with inner patterned retarder shown in Fig. 2 under two orthogonal circular polarizers. In the non-patterned regions, the right-handed circular (RHC) polarization of the reflected light still remains unchanged and thus the reflected light is blocked by the left-handed circular (LHC) polarizer. Note that the incomplete dark states shown here result from the subtle difference between the wavelength, satisfying a condition of the half-wave retarder and the wavelength of the reflection corresponding to a helical pitch of the ChLC. In the patterned regions, the RHC polarization is converted to the LHC polarization passing through the half-wave retarder. Finally, the bright state was obtained in the patterned regions under LHC polarizer as shown in Fig. 3(a). As a result, the dark stripes and the reddish stripes in Fig. 3(a) represent the non-patterned regions

and the patterned regions, respectively. Similarly, under the RHC polarizer as shown in Fig. 3(b), the dark stripes and the reddish stripes depict the patterned regions and the non-patterned regions, respectively. Wearing eyeglasses with the orthogonal circular polarizations, the left and right images were divided by the patterned retarder and the 3D images were constructed.

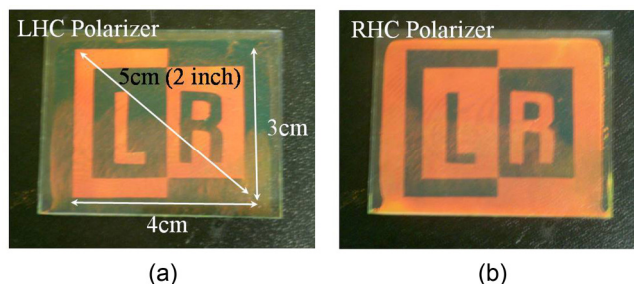


Fig. 4. Prototype images of our reflective 3D ChLC cell in a stereoscopic type using the circularly polarized eyeglasses: images under (a) left-handed circular polarizer and (b) left-handed circular polarizer.

Figure 4 shows a 2-inch prototype of the reflective 3D display with the inner patterned retarder. To demonstrate two different images for left and right eyes, we directly patterned the LCP retarder by using the UV exposure to the RM layer through the photo-mask. Therefore, the inverted images were observed under the LHC polarizer and the RHC polarizer. The maximum reflectance and the contrast ratio were measured to be about 32% and 15:1, respectively. In the real display mode, the LCP retarders are formed at one of two subpixels in each pixel. The images for left and right eyes are constructed from each subpixel in a whole panel. Operating the ChLC, their memory characteristics could be useful for low power consumption.

4. Conclusion

In this work, we proposed the reflective stereoscopic 3D display based on the ChLC panel with inner patterned retarder acting as the half-wave retarder. The inner patterned retarder was fabricated by the selective UV exposure to the RM through an amplitude photo-mask. Since the ChLC mode with the polarization-selective reflectance, no polarizer is required and thus the inner patterned retarder is applicable in the stereoscopic 3D display. In addition, the ChLC mode with the wavelength-selective reflectance gives rise to elimination of the color filter and the backlight unit. Also, a multi-pitch stabilized ChLC mode [15] would be adoptable to produce a full color ChLC display under a single panel configuration in this stereoscopic 3D display. This reflective 3D display proposed here is expected to create the novel 3D displays with low power consumption.

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