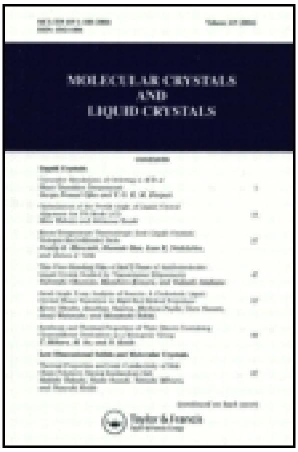

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Single Pixel Transflective Liquid Crystal Display with Cholesteric Half Mirror

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We propose a transflective liquid crystal display (LCD) operated in a whole pixel configuration consisting of the single-polarized LC cell and the broadband cholesteric LC (ChLC) half mirror. The broadband spectrum ChLC film is used for a polarization-sensitive mirror which reflects a given circular polarization but transmits its orthogonal polarization. Our transflective LCD can be demonstrated by just replacing the polarizer, placed toward a backlight unit in the conventional cross-polarized LC modes, with the ChLC half mirror.

Keywords Cholesteric liquid crystal; circular polarizer; polarization-sensitive mirror; transflective LCD

1. Introduction

Transflective liquid crystal displays (LCDs) have attracted much attention for mobile applications since their superior device performances can be achieved under both indoor and outdoor environments [1,2]. Since the incident light passes twice through the LC layer in the reflective mode, the conventional transflective LCDs consist of two sub-pixels of the transmissive and reflective regions. The various transflective LC modes such as the LC structures with the different cell gaps in a single LC mode [2–5] or the different modes in a single cell gap [6–8] were reported. However, the former LC modes with different cell gaps require complex fabrication processes. Moreover, the fringe-field effect and the LC deformations at topographical boundaries produced from the different cell gaps are inevitably involved. Although these transflective LCDs with two subpixels have good optical characteristics, they have unavoidable drawbacks including the complicated process or the degradation of the display performances such as aperture ratio. Recently, the single pixel transflective LC mode without dividing into two subpixels were reported [9,10].

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In these transflective LC modes, however, the complicated optical designs as well as low optical efficiency were involved.

In this work, we propose a simple configuration of a single pixel transflective LC mode consisting of a single-polarized LC cell as an optical modulator and a cholesteric liquid crystal (ChLC) film with broadband reflection spectra as a half mirror. Here, the ChLC half mirror selectively reflects a certain circular polarization but transmits the orthogonal circular polarization in entire visible light [11]. All LC modes based on the electrically controlled retardation modulated from $\lambda/4$ to $3\lambda/4$ can be used for our LC layer. As a result, our single pixel transflective LC mode without dividing into two subpixels is obtained by just replacing the polarizer, placed toward a backlight unit in the conventional cross-polarized LC modes, with the ChLC half mirror.

2. Cell Structure and Operating Principle

A schematic diagram of our transflective LCD with a ChLC half mirror in a single pixel configuration is shown in Figure 1. The single pixel transflective LCD consists of the ChLC half mirror and the single-polarized LC cell. The ChLC half mirror with broadband reflection spectra was prepared by the helical structure with the pitch gradient covering entire visible range. The pitch gradient was stabilized through ultraviolet (UV) exposure to the reactive mesogen (RM) with chirality mixed into the nematic LC [11]. The chirality of the RM governs the helical sense of the broadband spectrum ChLC film and the reflected circular polarization. For the LC cell, we simply used a planar aligned LC mode where the LC molecules were unidirectionally aligned parallel to two substrates. The planar aligned LC cell was placed by 45° with respect to a polarizer as shown in Figure 1. The retardation of the LC cell was modulated from $\lambda/4$ to $3\lambda/4$ for the full sweep of grey levels.

In the transmissive mode, the ChLC half mirror acts as a circular polarizer with left handedness along the propagating direction of an incident light, whereas a reflector reflecting the right-handed circular polarization in the reflective mode. Figure 2 shows an operating principle of our single pixel transflective LC mode. In the

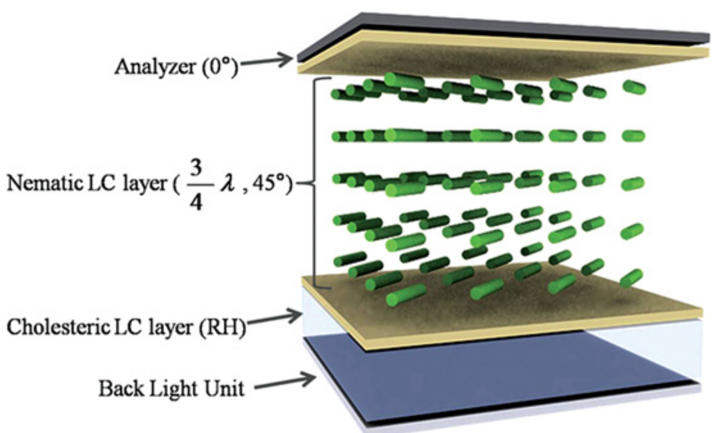

Figure 1. A schematic diagram of our single pixel transflective LCD with a ChLC half mirror in a single pixel configuration. (Figure appears in color online.)

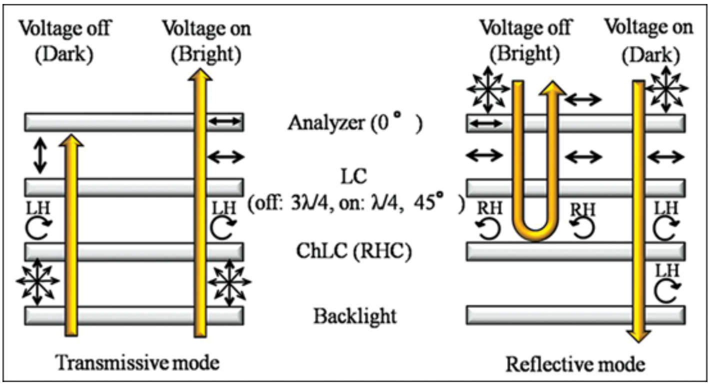

Figure 2. Operating principles of our transflective LCD in the (a) transmissive and (b) reflective modes. (Figure appears in color online.)

transmissive mode, the exiting light from the ChLC film with right-handed twisting sense is circularly polarized in left handedness. In the absence of an applied voltage, the LC layer produces the phase retardation of $3\lambda/4$ and its optic axis is placed at 45° with respect to the polarizer (0°). Therefore, the light passing through the LC layer is linearly polarized perpendicular to the polarizer, and thus the dark state is obtained. Applying the external voltage, on the other hand, the phase retardation of the LC layer becomes to be $\lambda/4$. In such situation, the left-handed circular polarization is changed by the LC layer to the linear polarization parallel to the polarizer, and the thus bright state is achieved.

In the reflective mode, the incident light is linearly polarized at 0° by the polarizer. In the absence of an applied voltage, the phase retardation of the LC layer is $3\lambda/4$ and thus the exiting light from the LC layer is circularly polarized in right handedness as shown in Figure 2. The right-handed circular polarization is reflected at the ChLC film and changes into the linear polarization parallel to the polarizer. Therefore, the bright state is obtained. In contrast, when the phase retardation of the LC layer is $\lambda/4$, the linearly polarized incident light (0°) changes into the left-handed circular polarization, no reflection occurs at the ChLC film. In should be noted that our LC cell modulated from $\lambda/4$ the $3\lambda/4$ is equivalent to two stacked layers of the LC cell modulated from 0 the $\lambda/2$ and a static $\lambda/4$ plate, whose optic axes coincide with each other.

3. Experiments

The broadband spectrum ChLC film was fabricated by UV exposure to the ChLC mixture of host nematic LC (E48, E. Merck), RM with chirality (RMM703, E. Merck), and photoinitiator (Igacure651, Ciba Speciality Chemicals). The mixing ratio of the E48, RMM703, and Igacure651 is 87:12:1. The ChLC mixture was injected between sandwiched glass substrates with 6 μm cell gap, coated with RN1199 (Nissan Chemical) and rubbed antiparallelly for planar alignment, by capillary action in the isotropic phase. Finally, UV light (0.12 mW/cm^2) was exposed to the sandwiched cell for 4 min to produce broadband spectrum covering entire visible range [11].

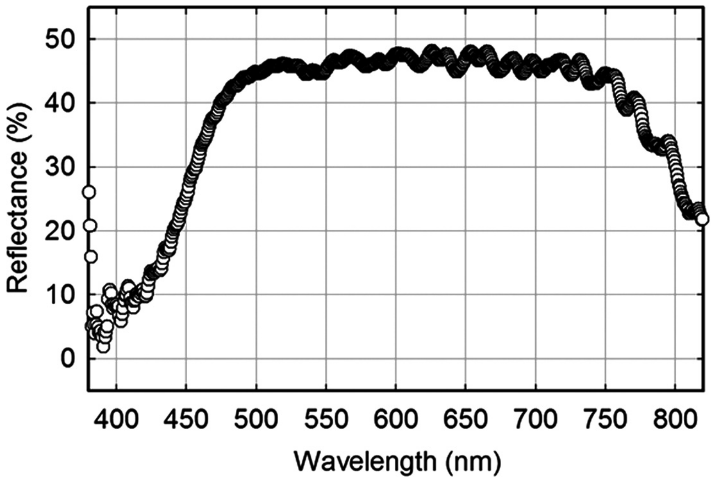

Figure 3. Reflection spectrum of the broadband ChLC film.

The single-polarized LCD was prepared with a nematic LC of MLC6233 (E. Merck). The SE7492 (Nissan Chemical) was spin-coated on top of the indium-tin-oxide (ITO) evaporated substrates, followed by unidirectional rubbing to promote planar alignment. The rubbing axis of the homogeneously aligned LC layer made an angle of 45° with respect to a polarizer so that the LC layer acted as the $3\lambda/4$ plate in the absence of an applied field. The cell gap was maintained using columnar spacers of 5.27 μm tall patterned with SU-8 (MicroChem. Co.).

The microscopic textures of our transflective LC mode were characterized using a polarizing microscope (E600 W POL, Nikon) with a frame-grabbing system (SDC-450, Samsung). The electro-optic (EO) properties were measured using a He-Ne laser (633 nm), a digitized oscilloscope (TDS745D, Tektronix), and a photo-detector. All the measurements were carried out at room temperature.

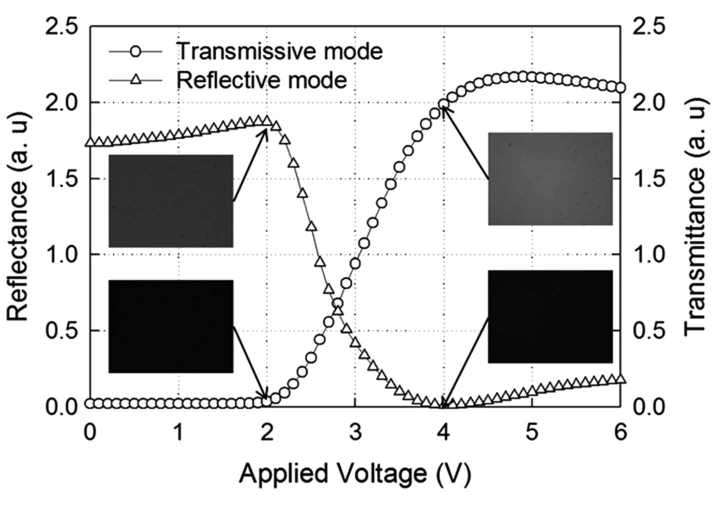

Figure 4. The EO transmittance and the corresponding microscopic images of our transflective LCD in both transmissive and reflective modes.

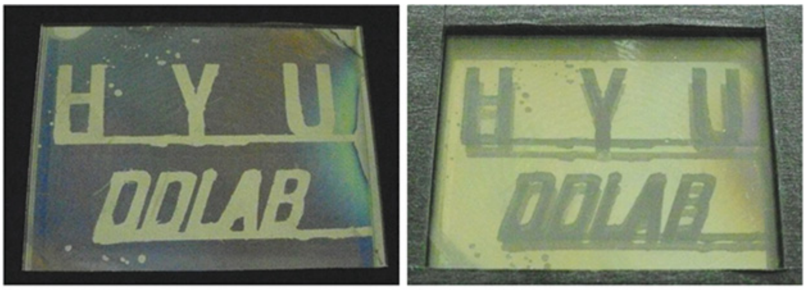

Figure 5. Prototypes of our single pixel transflective LCD in the (a) transmissive and (b) reflective modes. (Figure appears in color online.)

3. Results and Discussion

Figure 3 shows the measured reflection spectrum of the broadband ChLC film fabricated by UV exposure to the ChLC mixture with the RM. The polarization state of the reflected light is determined by the twisting sense of the RM chirality. The UV intensity gradient along the cell depth produces the pitch gradient of the ChLC phase [11], and thus the reflection spectrum broadens covering entire visible range as shown in Figure 3. As a result, the ChLC film with the broadband reflection spectrum is adoptable to the half mirror for our single pixel transflective LCD.

The EO performances and the corresponding microscopic textures of our single pixel transflective LCD in both transmissive and reflective modes are shown in Figure 4. In our cell configuration, since the phase retardation of the LC layer reduces from $3\lambda/4$ to 0 with increasing an applied voltage, the transmittance and the reflectance bounce at a certain voltage of about 4 V matching the phase retardation of $\lambda/4$ in the LC cell. To operating our transflective LCD in full grey levels, we used the voltage range producing the phase retardation between $3\lambda/4$ and $\lambda/4$.

Figure 5 shows a prototype of a 2-inch single pixel transflective LCD with the broadband ChLC film. We directly patterned the ITO electrode showing characters of "HYU DDLAB" to demonstrate our transflective LCD in both reflective and transmissive modes. In transmissive mode as shown in Figure 5(a), the patterned electrode regions ("HYU DDLAB") were turned on and the bright state was obtained, whereas the dark state was shown in them in the reflective mode as shown in Figure 5(b).

4. Conclusion

We demonstrated the single pixel transflective LCD without dividing into two subpixels using the boradband spectrum ChLC half mirror. The half mirror with the helical pitch gradient of the ChLC selectively reflects a circular polarization corresponding to the twisting sense of the ChLC but transmits the orthogonal circular polarization in entire visible range. Using the whole pixel for each operating mode, the good optical efficiency was obtained. In addition, the display configuration of the transflective LCD presented here was very simple because our transflective LCD could be demonstrated by just replacing the polarizer, placed toward a backlight unit in the conventional cross-polarized LC modes, with the ChLC half mirror. It should be expected that our proposed LC mode could be applicable to transflective LCD with the good optical performances.

Acknowledgment

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