IER Film and Inkjet Printing Method for Full-Color Transflective Cholesteric LCD

Szu-Fen Chen, Chao-Heng Huang, Jhih-Ping Lu, Meng-Xi Chan, and Han-Ping D. Shieh

***Abstract*—A transflective cholesteric liquid crystal display (Ch-LCD) is demonstrated by using the image-enhanced reflector (IER) film on the top of the transmissive region to provide the similar paths for both transmissive and reflective light, thus, to display same image color in any ambience, improving the image quality. For full color display, the inkjet printing was applied and the patterned Ch-LC droplet was successfully deposited on the substrate. Thus, full-color Ch-LCD can be fabricated by IJP.**

***Index Terms*—Cholesteric liquid crystal display (Ch-LCD) ink-jet printing (IJP).**

I. Introduction

REFLECTIVE cholesteric liquid crystal display (Ch-LCD) [1] is a bistable device which consumes less power than reflective STN or thin-film transistor (TFT) displays. Thus, Ch-LCD is a strong contender for e-books and other applications. Yet, the reflective Ch-LCD under dark ambience is very low contrast, thus, transflective display is a good option. However, Ch-LCDs are still not applicable for such transflective structure due to lack of dark state in transmissive region. Further, several methods have been proposed to demonstrate a full color Ch-LCD, such as stacking cells with primary RGB colors [2], exposing different UV intensity to generate different pitch lengths [3], doping different twist agents to create RGB color pixels [4], and patterning conventional color filters on a black and white Ch-LCD [5], [6]. Although these methods improve the display characteristics, the complex process and high cost remain issues. To obtain transflective capability, we demonstrated a feasible transflective Ch-LCD by using image-enhanced reflector (IER) film. In addition, the full-color Ch-LCD can be achieved by using inkjet printing (IJP) method.

II. Monochromatic Transflective Ch-LCD

To achieve transflective capability, each pixel is divided into reflective and transmissive regions. In transmissive region, an IER is in position to reflect the backlight into reflective pixels [7]. There is a backlight source at the back of the display, followed by the Ch-LCD sandwiched by two circular polarizers used to yield the bright state and dark state of reflective and transmissive modes for Ch-LCD. Assume the Ch-layer left handed, so that it reflects the left (L) circularly polarized light and transmits the right (R) circularly polarized part. Thus, the upper and rear circular polarizers are left-circular (LCP) and right-circular polarizers (RCP), respectively.

In the reflective mode, the backlight is off. In the planar state, the ambient light is incident to reflective pixels and transformed into L light by the LCP. Since the Ch-layer is left handed, the L light is reflected within the reflection band of the cholesteric. As a result, the bright state is yielded, as shown in Fig. 1(a). In the focal conic state, the L light is transmitted by the Ch-layer and is absorbed by the RCP. As a result, the dark state is yielded, also shown in Fig. 1(a).

In the transmissive mode, the backlight is on. In the planar state, the backlight is incident to the transmissive regions and transformed into R light by the RCP. On the transmission channel, the R light is transmitted to impinge onto the IER. Upon the reflection, the R light becomes L light and is reflected by Ch-LC layer to the viewer. Again, the bright state is achieved, as shown in Fig. 1(b). In the focal conic state, the backlight initially converted to R light is transmitted by the Ch-layer and absorbed by the LCP. Hence, the dark state is achieved, as shown in Fig. 1(b). The same bright and dark states for both reflective and transmissive channels are essential since the backlight is needed to turn on for the legibility in the not-too-dark ambience. Thus, with IER structure, the transflective Ch-LCD displays the same image color under any ambience, improving the image quality of the device.

A. Simulation Results

By using TracePro, the IER structure was analyzed and optimized by varying the IER width and the overcoat thickness (OC) between the IER and the cholesteric layer. The IER width was optimized by varying its length up to 18 μm while OC thickness was fixed at 30 μm. With increasing IER width, the transmittance in the bight state increases gradually, eventually the optimized IER width of 16 μm has been obtained for achieving high brightness and high CR of transmissive mode in the transflective Ch-LCD, as shown in Fig. 2. Further, the OC layer was optimized by varying its thickness up to 1mm by fixing the IER width to 16 μm. As show in Fig. 2, the transmittance at OC of 600 μm was 3.4%, superior to 2% at OC of 3 μm. Thus, the glass substrate, of 600 μm thick, can be applied as an OC layer to increase the spacing from the IER to Ch-layer. As a result, the

Manuscript received July 5, 2005; revised July 28, 2005.

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Digital Object Identifier 10.1109/JDT.2005.858917

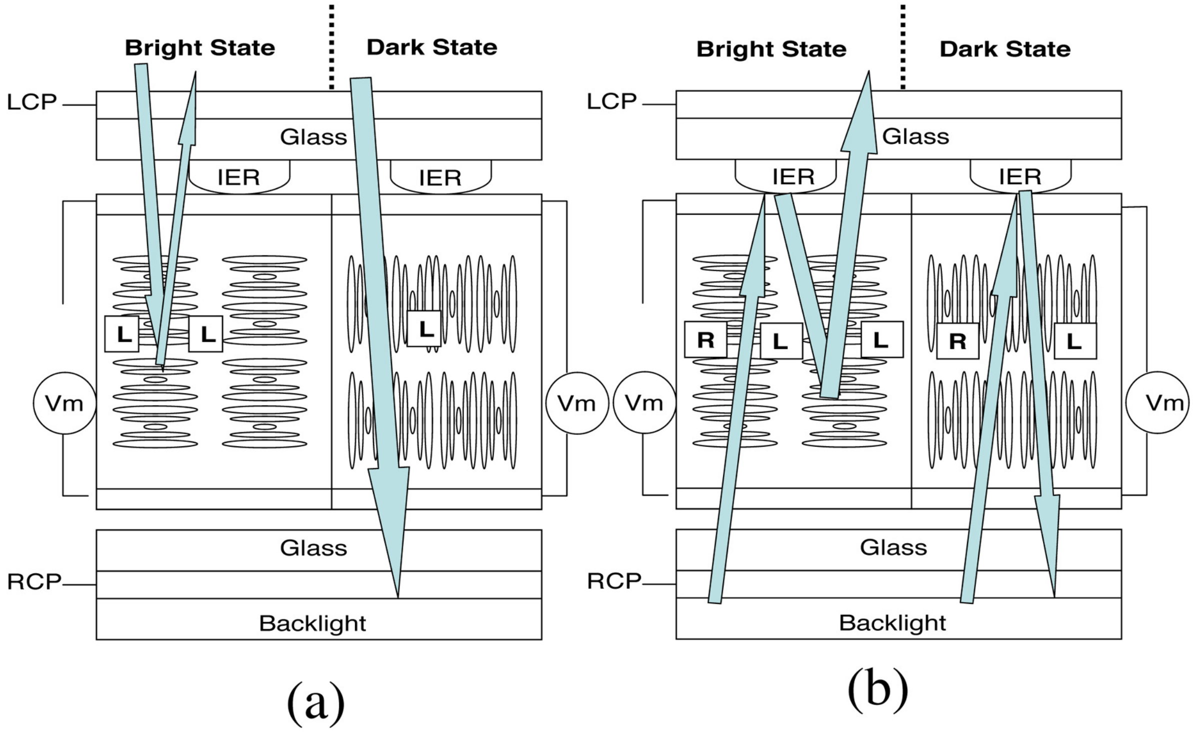

Fig. 1. Schematics of the proposed transflective Ch-LCD for (a) reflective mode and (b) transmissive mode. (Color version available online at http://ieeexplore.ieee.org.)

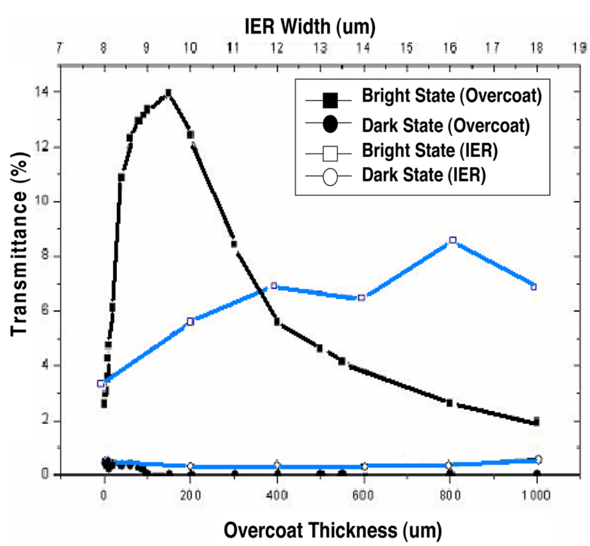

Fig. 2. Transmissive light efficiency in bright and dark states with various OC thicknesses and IER width. (Color version available online at http://ieeexplore.ieee.org.)

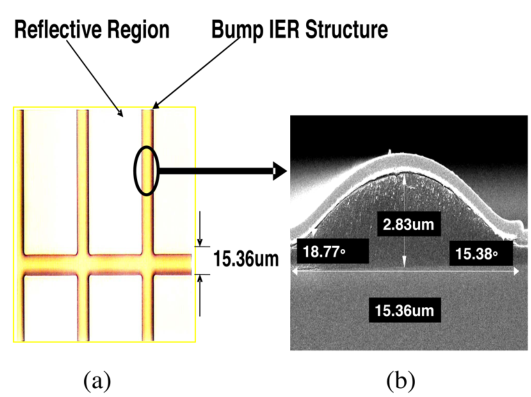

Fig. 3. (a) Fabricated IER film measured by Optical Microscope and (b) cross section of the bump-IER structure by SEM at reflowing temperature of 14°C. (Color version available online at http://ieeexplore.ieee.org.)

IER structure is not necessary to be constructed inside the device, rather, the IER film is realized by laminating on the upper glass of the Ch-LCD for transflective ability.

B. Fabrication and Experimental Results

According to the simulation results, the IER film was fabricated by first coating photoresist PC403 on the glass substrate. Then, the IER structure was fabricated by using patterning and reflow process to obtain bump profile. After that, an aluminum film was sputtered. Finally, the Al layer outside the IER was etched off by using wet etching process. The fabricated IER film was shown in Fig. 3(a) and its cross section was shown in Fig. 3(b).

To examine the performance of IER on Ch-LCD, the transmission and reflection spectrum of the transflective Ch-LCD with IER film in both bright and dark states were measured. The Ch-LC material with the reflection wavelength of 550 nm was utilized. As shown in Fig. 4, in the planar texture of both modes, both peak transmittance and reflectance of the device occurred at the wavelength of $\lambda = 570$ nm. Thus, with difference of light efficiency, the reflective mode was in light green color, whereas the transmissive mode was in dark green color. Further, in the dark state, the reflectance of the device was close to 0.5% in the visible spectrum, whereas the transmittance has

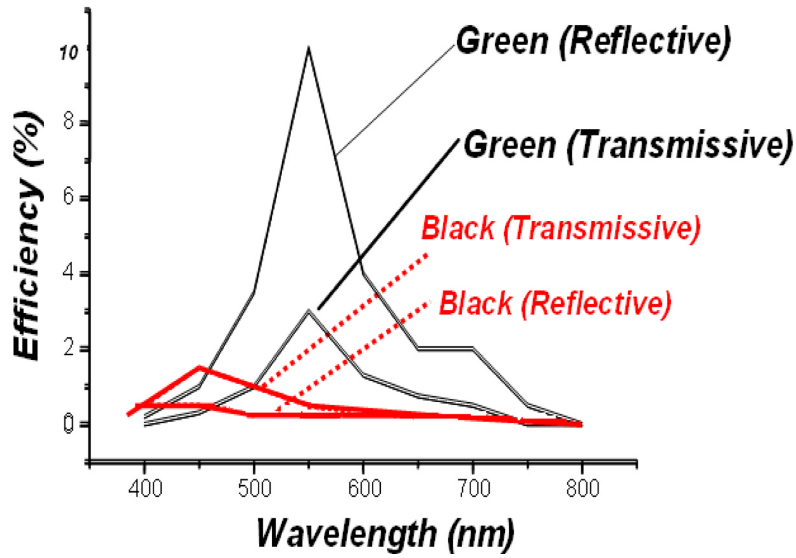

Fig. 4. Measured spectrum of the transflective Ch-LCD with IER film by ConoScope. (Color version available online at http://ieeexplore.ieee.org.)

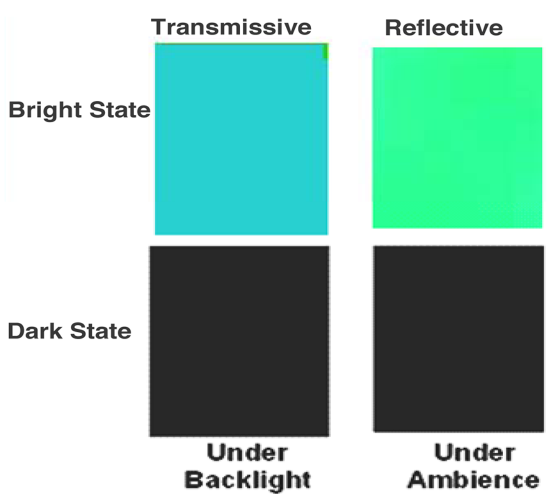

Fig. 5. Photographs of monochromatic transflective Ch-LCD with IER film in transmissive mode under backlighting in a dark room and in reflective mode under office lighting. (Color version available online at http://ieeexplore.ieee.org.)

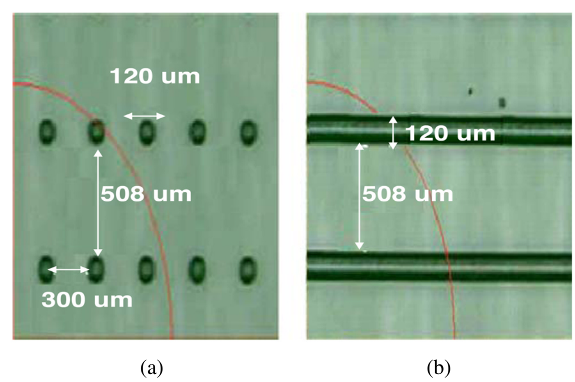

Fig. 6. Cholesteric LCs. (a) dot and (b) stripe pattern deposited on the glass substrate by inkjet printing. (Color version available online at http://ieeexplore.ieee.org.)

its peak value of 1.8% at the wavelength of 450 nm. Thus, the reflective mode was in black color whereas the transmissive mode displayed the bluish black. Thus, with the IER film, the transflective Ch-LCD was able to display the same image color in any ambience, greatly improving the image quality. The visual appearance was shown in Fig. 5. Further, the contrast in transmissive mode is low due to the fact that the focal-conic texture will depolarize the light that is right circularly polarized. Thus, to enhance the CR and light efficiency, the absorption layer should be patterned on the bottom substrate and well aligned to the upper substrate.

III. A Novel Full Color Transflective Ch-LCD by Inkjet Printing Method

Inkjet printing is an efficient and cost-effective method for full color Ch-LCD with benefits of color patterning without masks, large device area capability, and high efficiency of using material, compared to the conventional fabrication process for full color Ch-LCD [2]–[5], [6]. Further, since the Ch-LC reflects light centered at the wavelength given by $\lambda o = nPo$, where n is the average refractive index and Po is the pitch of helical structure, thus, the primary color (RGB) Ch-LC materials is obtained by tuning the pitch to the specific length [8]. Therefore, we proposed to use piezoelectric IJP [9] to pattern RGB Ch-LC droplets on the corresponding reflective region of the pixel on the bottom substrate, thus to efficiently achieve the full color Ch-LCD display.

To apply IJP into full color Ch-LCD, we first demonstrated that the green Ch-LC with extremely high viscosity is compatible with IJP and the green Ch-LC droplet is able to pattern on the glass substrate. By increasing the temperature the viscosity of Ch-LC was successfully decreased to a certain value required for the injection of Ch-LC by IJP. The photographs of dot and stripe patterned Ch-LC deposited by piezoelectric print head on the glass substrate are shown in Fig. 6. The dot diameter, as shown in Fig. 6(a) was 120 μm and lateral and vertical pitches were 300 μm and 508 μm, respectively. Further, by continuous depositing the dot Ch-LC, the stripe-patterned Ch-LC was successfully deposited on the glass substrate, as shown in

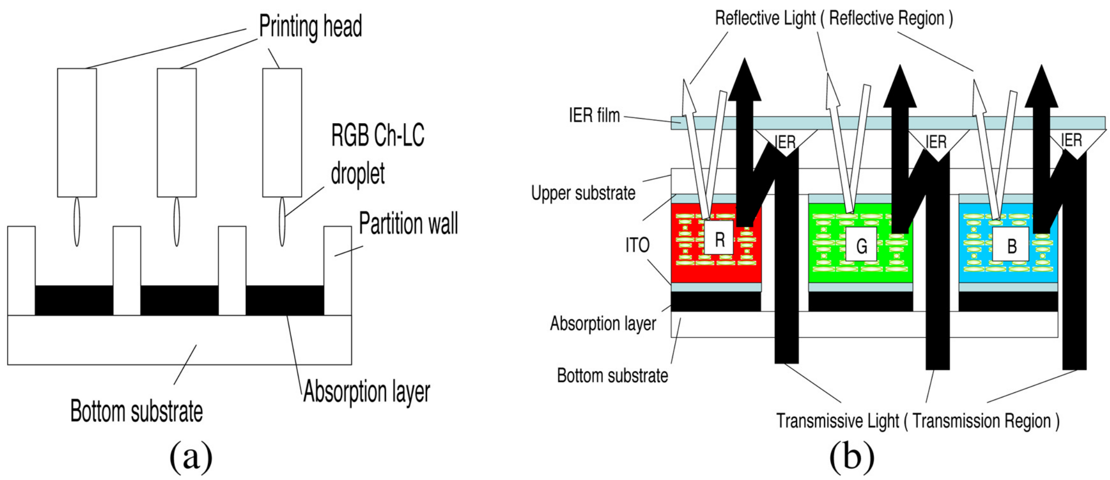

Fig. 7. Full-color transflective Ch-LCD can be obtained by (a) first patterning RGB Ch-LC with IJP on bottom substrate with an absorption layer and partition wall and then (b) laminating IER film on the upper substrate and well aligning to the bottom substrate. (Color version available online at http://ieeexplore.ieee.org.)

Fig. 6(b). The diameter was still 120 μm and the vertical pitch was 508 μm. From Fig. 6(a) and (b), only a small number of satellite dots were appeared near the patterned Ch-LC. Thus, the stability to deposit the Ch-LC with the IJP was high. As the green dot- and stripe-patterned Ch-LC with high printing quality were obtained, IJP can be utilized to deposit the RGB Ch-LC droplets into the corresponding sub-pixel region divided with the bank or wall, realizing the color patterning of RGB sub-pixels. Thus, the full color Ch-LCD can be efficiently fabricated by IJP.

IV. Discussion

The application of IJP with RGB Ch-LC materials yields color patterning of the pixels for full color Ch-LCD. Moreover, for transflective capability, the IER film, instead of internal IER structure, will be positioned in the transmissive region patterned with high transmittance partition wall on the bottom substrate, whereas the RGB Ch-LC will be deposited with IJP in the reflective region patterned with the absorption layer on the bottom substrate. Further, to yield high light efficiency and C.R., the absorption layer, instead of RCP and LCP, will be patterned next to the partition wall to obtain the "dark state". As a result, the full color transflective Ch-LCD can be obtained by using IER film and patterning RGB Ch-LC with IJP, as schematically shown in Fig. 7.

Further, the highest transmittance is yielded at OC of 150 μm, equivalent to the thickness of plastic substrate, thus, additional flexible capabilities can be realized.

V. Conclusion

We have successfully demonstrated the transflective Ch-LCD can be obtained by using IER film and the full-color capability can be achieved by applying the IJP method with RGB Ch-LC materials. The IER film is realized since the Ch-LCD with outer IER yields higher efficiency than that with inner IER. Thus, the IER film was used to enable the reflective and transmissive modes displaying the same image color under any ambience. Moreover, since IJP successfully deposited dot and stripe patterned green Ch-LC droplet on the substrate, thus, full color transflective Ch-LCD can be achieved by patterning RGB pixel for full-color Ch-LC with IJP on the reflective region patterned with absorption layer and applying IER film on the transmissive region patterned with high transmittance wall on the bottom substrate.

Acknowledgment

The author would like express their appreciation to H.-M. Tsai of Industrial Technology Research Institute, Hsinchu, Taiwan, R.O.C., and Y.-P. Huang of AUO for valuable discussion and technical support.

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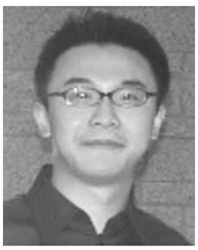

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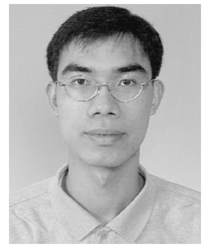

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