The optical design method for dual-mode transflective LCD

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Abstract

Depending on the optical design method, a novel dual-mode transflective LCD with proper LC material and optical films was developed. The design increased the optical transmittance and the reflectivity of dual-mode transflective LCDs with the proper parameters of cell gap, alignment layer and optical films. These parameters were evaluated by computer simulation. The simulation results also revealed that the transmissive and reflective states presented similar performance in the transflective LCDs.

1. Introduction

Based on the growing market of the notebook computers, personal digital assistants, digital cameras, and cell phones, to develop handheld liquid crystal display (LCD) devices becomes the hot topic in the recent years. Depending on the readability requirement in any environment, a transflective LCD device which combines the capabilities of transmissive and reflective structures provides a good image quality in the dark, increases the readability outdoors, and reduces power consumption. There are several methods to satisfy the optical design of transflective LCD which include multi cell gap, dual-TFT (dual-γ), and dual-mode. In this work we provide optical design method and model of dual mode transflective LCD to improve the image quality of both transmissive and reflective states.

Figure 1 represents the structure of the uniquely designed dual-mode transflective LCDs which includes both transmissive and reflective regions in one sub-pixel. The transmissive regions adopt homogenous alignment mode/ electronic controlled birefringence (ECB) mode, and the reflective regions use the hybrid alignment nematic (HAN) mode. According to the foregoing statements, the LC molecules of the transmissive regions align horizontally on both top and bottom alignment layers. In the reflective regions, the LC molecules align horizontally on the bottom alignment layer, and align vertically on the top alignment layer. Depending on the alignment properties, the phase retardation of LC layer in reflective regions is half of the phase retardation of LC layer in transmissive regions. The phase difference between two regions would be avoided. The fact that ambient light passing through the reflective regions and the back light passing through the transmissive regions would be the same.

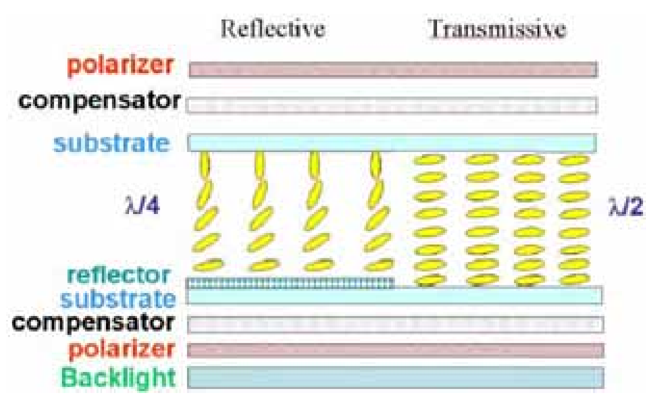

Figure 1: The structure of dual-mode single cell gap transflective LCDs.

Thus, within realizing the dual-mode single cell gap transflective LCDs, to improve the electro optical properties of both states is the major topic. However, the transmittance and reflectivity will change with the wavelengths of light (R, G, and B) and should also depend on the characteristics such as LC molecules, alignment conditions and optical films. Based on the above, we develop a novel optical design method which includes parameters of the cell gap, alignment layers and optical films to enhance the display performance of both transmissive and reflective states.

2. Results

In this study, the phase retardation of LC layer in transmissive regions could be indicated R_t . The magnitude of R_t was

$$2\pi\frac{d\Delta n}{\lambda}.$$

The phase retardation of LC layer in reflective regions could be indicated R_r . The magnitude of R_r was

$$\frac{1}{2}\cdot 2\pi\frac{d\Delta n}{\lambda}.$$

The difference between extra-ordinary and ordinary reflective indexes of LC molecules, Δn was

$$\Delta n = n_e - n_o .$$

"d" represented the cell gap of LC layer, and "λ" indicated the wavelength. The positive LC (MERCK) (Δn ~0.0922) could be adopted. The phase retardation of the transmissive and reflective regions could then be π and $\pi/2$, respectively. Based on the above, the cell gap would be 2.96um and the alignment angle would be -45° if the maximum Δn of the LC molecular was utilized.

Table 1: Reflective index of LC (MERCK)

Dispersion	436nm	546nm	633nm
n_e	1.5976	1.5770	1.5691
n_o	1.4960	1.4848	1.4800
dn	0.1016	0.0922	0.0891

However, it was difficult to manufacture a LCD with 2.96um cell gap. And, the appropriate cell gap (3.9um or larger) would be easier for the producing process. The index difference $\Delta n(\theta)$ of the LC layer would be influenced by various alignment angles of LC molecules.

$$\frac{1}{n^2(\theta)} = \frac{\cos^2\theta}{n_o^2} + \frac{\sin^2\theta}{n_e^2}$$

Next, in figure 2, which indicated the phase retardation of LC layer in reflective mode could be approached $\frac{\pi}{2}$ when the azimuthal angles of horizontal alignment were $\pm 24°$ or $\pm 66°$. The appropriate azimuthal angle was shown in figure 3 which demonstrated that the R-T and V-T curves of reflective mode and transmissive mode are much similar if azimuthal alignment angle was -24°. Therefore, the similar voltage-transmittance (V-T) and voltage-reflectance (V-R) curves could be obtained with specific azimuthal alignment angle.

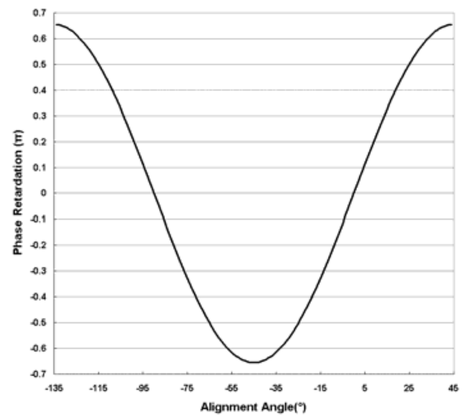

Figure 2: The phase retardation of different alignment angles of the reflective state

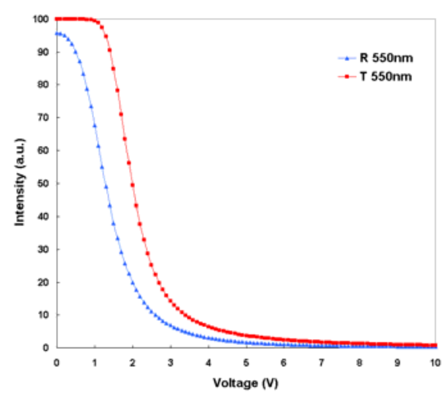

Figure 3: R-T curve vs. V-T curve

However, the phase retardation of the LC layer would be varied with different wavelengths of light (R, G, and B). Figure 4(a) and 4(b) represented how light wavelengths affected the transmittance and reflectance which were changed with different phase retardations.

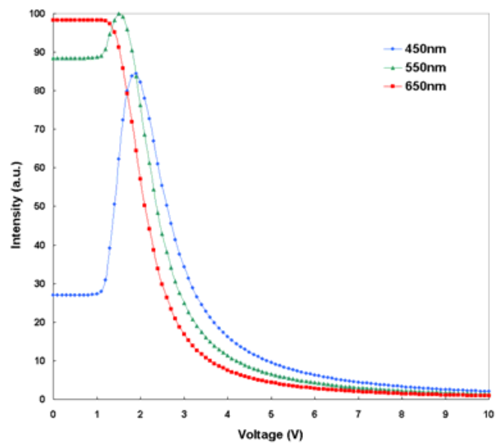

Figure 4(a): the V-T curve of the transmissive state without WB QWP.

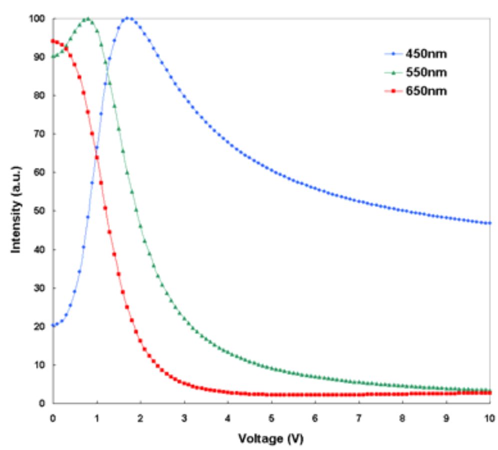

Figure 4(b): the R-T curve of the reflective state without WB QWP.

In addition, the optical films including the polarizers and wide-band quarter waveplates (WB QWP) should be arranged on the out surfaces of the top and the bottom substrates. Moreover, the wide-band quarter waveplate could be fabricated by laminating a quarter waveplate and a half waveplate. The phase retardation of the LC layer and the optical films dispersion would be reduced by modifying the foregoing factors.

Figure 5 denoted that after measuring the V-T curve of test cell which was a sandwiched structure combining a pair of ITO glass with horizontal alignment layer and 3.9um cell gap by using Otsuka LCD5100, the V-T curves results of the simulation and measurement were similar to each other.

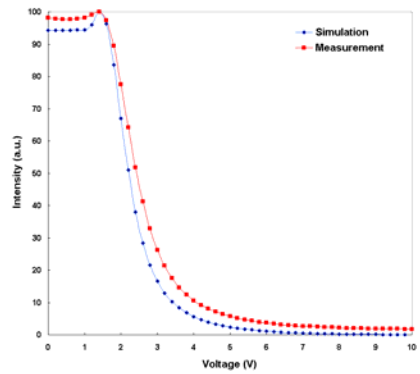

Figure 5: Comparison with simulation and measurement results

3. Conclusion

A similar phase difference of visible light passing through transmissive and reflective regions could be approached. Figure 6(a) and 6(b) demonstrated that the V-T curves of the transmissive state were similar to the V-R curves of the reflective state. The transmitting maximum values of various wavelengths of R, G, and B were close to each other in the transmissive state. The reflective state also had similar characteristics with the former. This outcome could not only reduce the dispersion due to LC molecules and the optical films simultaneously but also enhance the color performance of the transflective LCDs.

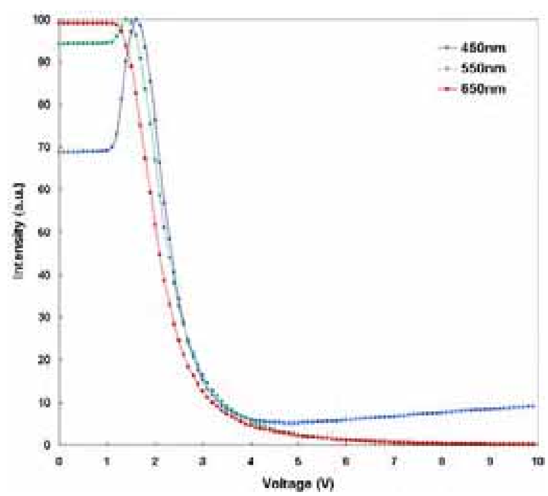

Figure 6(a): the V-T curve of the transmissive state with WB QWP.

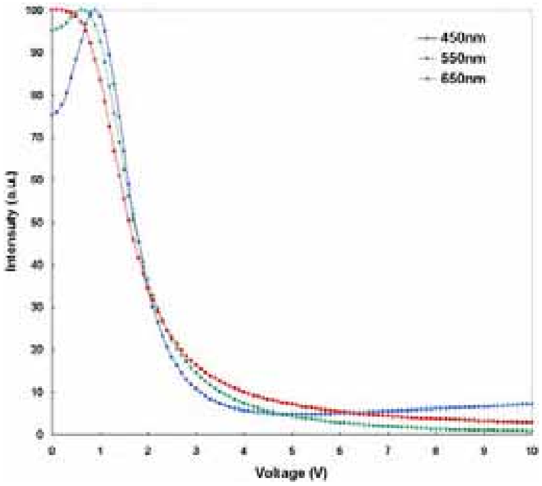

Figure 6(b): the R-T curve of the reflective state with WB QWP

In this work, we investigated an optical design method for dual-mode transflective LCDs. This design method provided a way to not only reduce dispersion due to the LC layer with optical films, but also enhance the optical performance in both reflective mode and transmissive mode of transflective LCDs.

4. Acknowledgements

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5. References

[1] M. Jisaki and H. Yamahuchi, "Development of transflevtive LCD for high contrast and wide viewing angle by using hometropic alignment", Asia Display/IDW'01, 133(2001).

[2] M. Kubo, Y. Narutaki, A. Ban, and et.al., US6195140, 2001

[3] C. Y. Chen and Y. R. Shen, US6806929, 2004

[4] Heume-II Baek et al., "New design of transflective LCD with single retardation film", IDW'00, 41(2000).

[5] Y. Y. Fan, H. C. Chiang, T. Y. Ho, Y. M. Chen, and et. al., SID'04, 647(2004)

[6] Masumi Kubo et al., "Development of advanced TFT with good legibility under any intensity of ambient light", IDW'99, p.183.