4.4: Transflective Liquid Crystal Display Using In-plane Switching Effect

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Abstract: A transflective in-plane switching (TR IPS) LCD with separate electrodes and reflectors is proposed and its electro-optic properties are simulated. As the rubbing angle increases, the TR IPS LCD exhibits a lower threshold voltage, faster response time, and the T-mode can keep the same maximum transmittance but the reflectance in the R-mode is lowered. A reflector extension/shift method is proposed to improve the reflectance of the R-mode so that the R-mode has a better matched performance as the T-mode for realizing a single gamma and single driver TR IPS LCD.

Keywords: transflective liquid crystal display, response time, in-plane switching.

1. Introduction

Transflective (TR) LCDs have been widely used in portable displays such as cell phones, e-books, and personal computers because its readability is not limited by the ambient lighting conditions. Quite few LC modes have been proposed for TR LCDs, e.g., the mixed-mode twisted nematic (MTN) mode [1], homogeneous mode [2], optically-compensated-bent (OCB) mode [3], vertical aligned (VA) mode [4], hybrid-aligned nematic (HAN) mode [5], IPS mode [6, 7] and fringe-field switching (FFS) mode [8]. The cell configurations can be divided into dual-cell gap or single cell gap, and multi-circuit (TFT) driving or single-circuit driving. Among them, the single cell gap and single TFT driving is preferred because of its simpler manufacturing process.

In this paper, we proposed a single cell gap and single TFT TR-IPS LCD with separated electrodes and reflectors. Rubbing angle effect on the voltage-dependent transmittance and reflectance (VT&VR) cures and response times are investigated. A reflector extension/shift method is proposed to improve the gamma curve of the R-mode based on the flexible design of the reflectors.

2. Device Structure and Working Principle

Figure 1 shows a typical device structure of the TR-IPS LCD, where the pixel and common electrodes are on the inner side of the top substrate, and the pixilated reflectors are on the inner side of the bottom substrate which align with the top electrodes. Since the top ITO electrodes are transparent, the regions between and above the neighboring reflectors are used as T-part while the regions above the reflectors are used as R-part. For simulations, we chose the electrode width to be ~7 μm, electrode gap ~10 μm, reflector width ~ 7 μm, cell gap ~ 4 μm and a positive LC Merck mixture MLC-6692.

Figure 1 shows the device structure of the TR-IPS LCD and its working principle in the (a) voltage-off and (b) voltage–on states. At V=0, the LC molecules are homogenously aligned in the LC cell with 1° pretilt angle and rubbing angle φ with respect to the stripe electrodes. The LC rubbing direction is arranged to be along the transmission axis of the linear polarizer LP1. Two broadband λ/4 films consisting of a half-wave film and a quarter-wave film are used. As shown in Fig. 1, film 1 is imbedded between the LC layer and the reflectors as the in-cell phase retarder and film 2 is laminated to the inner side of the bottom polarizer (LP2). In the reflective mode, the linearly polarized ambient light from LP1 passes through the LC layer without changing its polarization, but becomes circularly polarized after propagating through the wide band λ/4 film 1. Upon returning from the reflectors, the light enters the wide band λ/4 film 1 and the LC layer again and becomes a linearly polarized light with its polarization axis rotated by 90°. Therefore, it is absorbed by LP1, and the cell appears dark.

In the transmissive area for the T-mode, the incident backlight light firstly passes through the linear polarizer LP2 and the broadband λ/4 film 2, then through the broadband λ/4 film 1 (whose optical axis is orthogonal to that of the broadband λ/4 film 2) and the LC layer, and is blocked by the second linear polarizer LP1. Both R and T modes are normally black.

When the transverse electric field exceeds the Freedericksz threshold, the LC directors are twisted by the electric field. Therefore, the light transmits through the TR-IPS device, and a bright state can be obtained in both T and R-modes. To get the maximum transmittance and reflectance, the effective LC cell retardation value (d·Δn) should be λ/2 for both T-mode and R-mode.

3. Simulation Results and Discussion

3.1 LC Director Distribution

Figure 2 plots the side view of the LC director distribution of the IPS LCD at V=4.75 V_{rms}. The transverse electric fields between the neighboring electrodes twist the LC directors in the xy-plane, which have more phase retardation in the T-mode. Meanwhile, the R-part is only partially switched which contributes less to the phase retardation. This difference helps to balance the phase retardation for the T- and R-modes because the light
traverses the LC layer twice in the R-mode, but only once in the T-mode.

Figure 1. The device structure of the TR-IPS LCD and its working principle in the (a) voltage-off and (b) voltage-on states.

Figure 2. Director profiles of the IPS cell at V=4.75 V_{rms}.

3.2 VT & VR Curves at Different Cell Gaps

Figure 3 plots the voltage-dependent transmittance (VT) and reflectance (VR) curves under different cell gaps at λ=550 nm. In the T-mode, the peak transmittance increases as the cell gap increases from d=3 μm and reaches a maximum (~33% out of 37%) at d=4 μm and V~4.75 V_{rms}. Keep on increasing cell gap leads to a decreased transmittance, but its corresponding driving voltage at the maximum transmittance is lowered (5 V_{rms} at d=3 μm and 4.5 V_{rms} at d=5 μm). Different from T-mode, the reflectance of the R-mode decreases with the increasing cell gap, while the corresponding driving voltage at the first peak in the curves is lowered from more than 8 V_{rms} at d=3 μm to 4.5 V_{rms} at d=5 μm.

Figure 3. The VT (a) and VR (b) curves under different cell gaps at λ=550 nm.

3.3 VT & VR Curves at Different Rubbing Angles

Figure 4 shows the rubbing angle effect on the VT and VR curves for the 4 μm IPS cell at λ=550 nm. For the T-mode, the threshold voltage decreases but the on-state voltage...
increases as the rubbing angle increases. For a larger rubbing angle, the LC directors can be reoriented more easily. As a result, the threshold voltage decreases. However, the total phase retardation is reduced so that the on-state voltage is increased. Similar situation occurs for the R-mode [9].

3.4 Response Time at Different Rubbing Angles

Figure 5 plots the time-dependent (Tt) curves of the T-mode and R-mode under different rubbing angles for the 4-μm IPS cell at λ=550 nm. The applied voltage is chosen at its respective maximum transmittance/reflectance voltage point. It can be seen that the response time is shortened as the rubbing angle increases for both T- and R-modes. The sacrifice is a little higher driving voltage as the rubbing angle becomes larger.

3.5 Varied Reflector Width on the Influence of VT&VR Curves

Here, we used a reflector extension/shift method to investigate its influence on the VT and VR curves. Specially, we want to improve the reflectance by changing the reflector widths to tune the effective phase retardation over the R-mode. As shown in Fig. 6, the T-mode is only slightly influenced by the variation of the reflector widths from 5μm to 9μm at φ=10°, d=4μm and λ=550 nm. On the contrary, the R-mode is evidently influenced by the variation of the reflector width. At 5μm reflector width, the R-mode has a reflectance of about 30% at V=5 Vrms which is comparable to the transmittance of the T-mode. Therefore, we can vary the reflector width to match the reflectance curve of the R-mode to the transmittance curve of the T-mode for realizing a single gamma and single driver TR IPS-LCD.
rubbing angle is found to greatly influence the performance of the TR IPS-LCD. As the rubbing angle increases, the threshold voltage is reduced and the response time shortened. In the meantime, the T-mode can still keep the same maximum transmittance even though the reflectance in the R-mode is lowered. The reflector extension/shift method is proposed to improve the reflectance curve in the R-mode. Our results indicate that it is possible to realize a high quality single gamma and single driver TR IPS-LCD by optimizing the reflectance curve of the R-mode to fit better with the transmittance curve of the T-mode.

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6. References