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A Single Gap Transflective Display with Single Gamma Curve in the Fringe Field Switching Mode

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The single-gap transflective liquid crystal display utilizing the fringe-field switching mode has a problem such that the voltage–dependent transmittance and reflectance curves do not match each other and thus a dual driving circuit is required. This study shows that the optimization of an angle of the electrode used in the transmissive and reflective area solves this problem so that the transflective display with a single gamma curve for reflective and transmissive region is possible.
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KEYWORDS: transflective liquid crystal display, fringe-field switching, single gamma curve

Due to rapid developments in mobile communication, distinguishing features such as wide viewing angle, high color purity, good outdoor legibility, and fast response time are claimed in portable liquid crystal displays (LCDs). Nevertheless, transmissive LCDs do not have good outdoor legibility so that the improvement in image quality is required. Conversely, reflective LCDs have good outdoor legibility but they become difficult to read when the light intensity is weak. As a result, transflective LCDs are highly required in the area of mobile phones because they can be used in outdoor and indoor capacities with relatively lower power consumption than that in transmissive display.[1–3] Recently, to make the single-gap transflective LCDs, several LC modes, such as vertical alignment (VA),[4] and fringe-field switching (FFS)[5–7] and in-plane switching[8,9] with homogenous alignment, have been proposed. However, driving schemes of VA and FFS devices are rather complicated due to the difference in the voltage–dependent reflectance (*V*–*R*) and transmittance (*V*–*T*) curves. Consequently, two driving circuits for the reflective and transmissive region are required to realize a high image quality.

In our previous report,[7] the cell structure of the single-gap transflective LCD using the FFS mode was suggested, in which the LC with negative dielectric anisotropy and the in-cell retarder were used. In the device, the LC director rotates by 22.5° and 45° in the reflective and transmissive regions, respectively, and thus the *V*–*T* and *V*–*R* curves do not match each other. However, the pixel design is rather flexible in the FFS mode such that the slit angle of the pixel electrode can be adjusted separately in the reflective and transmissive region, as shown in Fig. 1. In other words, the angle (α) between the LC director and field direction are different from one another in both regions.

In the FFS device, electro-optic characteristics, especially voltage–dependent threshold voltage V_{th} mainly depends on dielectric anisotropy of the LC, electrode width (w) and distance (l), cell gap[10] and α.[11] However, changing physical parameters of the cell such as dielectric anisotropy of the LC, w and l, and cell gap results in a change in V_{th} at the same rate in the transmissive and reflective region, whereas difference in results in different V_{th}s. Therefore, to realize a single-gap and single gamma transflective LCD, all other parameters should be constant except α. Therefore, in this paper, we optimized in which the voltage dependent–*R* and –*T* matches.

For the calculations, a LCD master (Shintech, Japan) was used. An electrode structure with an electrode width of 3 μm and a distance of 4.5 μm between electrodes with passivation thickness 4000 Å was considered. Here, the LC with physical parameters, such as dielectric anisotropy $\Delta\varepsilon = -4.0$, and elastic constants $K_1 = 13.5$, $K_2 = 6.5$, $K_3 = 15.1$ pN was used, and the surface tilt angle of the LC was 2°. Here, to calculate the reflectance and transmittance, a 2×2 extended Jones matrix was used. The transmittances for the single and parallel polarizers were assumed to be 41%, and 35%, respectively.

The optical cell configuration of the single-cell gap transflective using the FFS mode is described in Fig. 2. The switching principle of the device was described in the previous report.[7] One noticeable aspect of the device is that the rotation angle of the LC director should be 22.5° and 45° in the reflective and transmissive regions, respectively, to maximize light efficiency in the white state. Therefore, in the previous cell, the operating voltage at which the maximum light efficiency occurred was two times higher in the transmissive region than that in the reflective region.

Figure 3 shows voltage–dependent transmittance and reflectance as a function of electrode slit angle, which is the same as α. In the transmissive region, as the slit angle increases from 10° to 50°, the driving voltage increases greatly while the transmittance decrease slightly because the LC director cannot rotate 45° in a cell with the slit angle of 40° due to strong surface anchoring which is assumed. In the reflective region, the reflectance remains about the same when the slit angle increases from 10° to 55° since in this region, the rotation angle of the LC director 22.5° is required to maximize light efficiency. However, the operating voltage increases with increasing α. In the FFS device, the light efficiency is dependent on the electrode position, unlike that in the conventional twist nematic (TN) cell, such that it is oscillating periodically since the dielectric torque is periodically changing along electrode. Figure 4 shows how the transmittance and reflectance manage to appear along electrode positions. As already described, to maximize the

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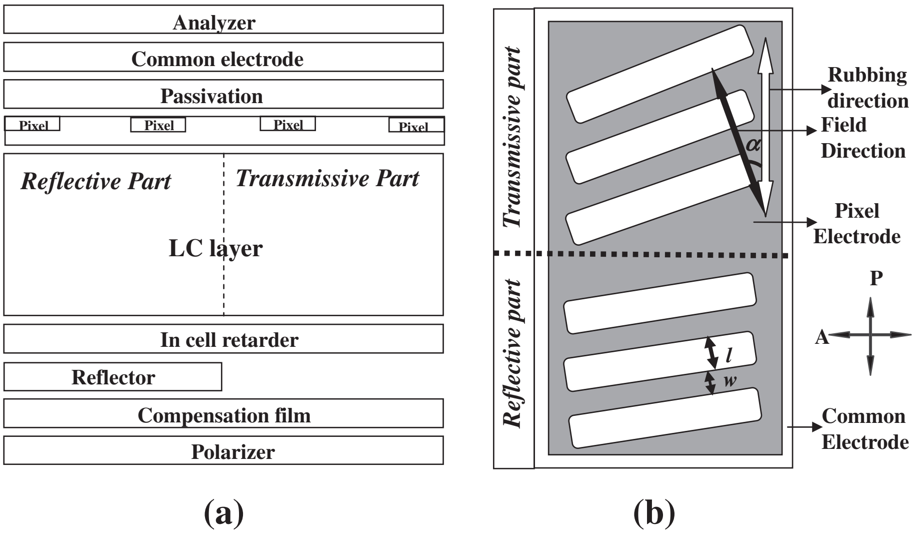

Fig. 1. Electrode structure of the transflective display using the FFS mode: (a) cross-sectional and (b) top view.

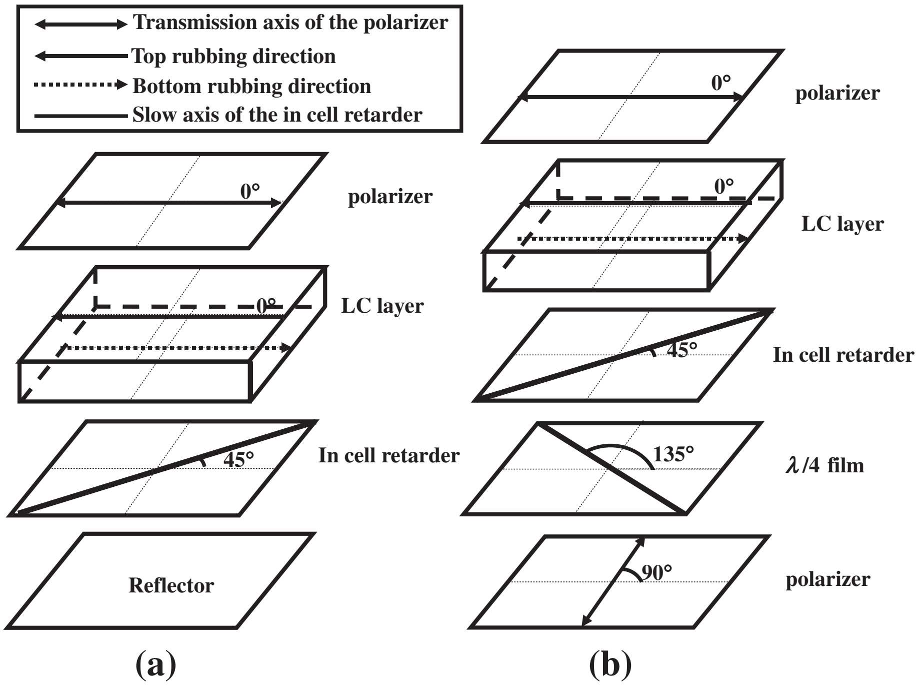

Fig. 2. Cell configurations of optical layers in device: (a) reflective and (b) transmissive part.

light efficiency in the transmissive region, the LC director should rotate by 45°, however, when α is 45°, this does not occur due to the strong anchoring of the LC on the surface. In the reflective region, even when α is 45°, the LC director can rotate by 22.5° at an increased voltage so that the light efficiency remains about the same along electrode position although α increases from 10° to 45°. These results indicate that the angle α can be adjustable to match *V–T* and *V–R* curves to each other without sacrificing the light efficiency. Figure 5 shows *V–T* and *V–R* curves in the optimized cell condition when α is 20° and 55° in the transmissive and reflective region, respectively. Although the two curves do not match each other perfectly, they can be controlled with a single gamma curve.

In summary, we have investigated electro-optic characteristics dependent on angle between LC director and field direction and suggested a single-gap transflective display with a single gamma using the FFS mode. With different angles of slit electrode in the transmissive and reflective region, the operation voltage reaches the same value although the LC director rotates by 22.5° and 45° in the reflective and transmissive region, respectively.

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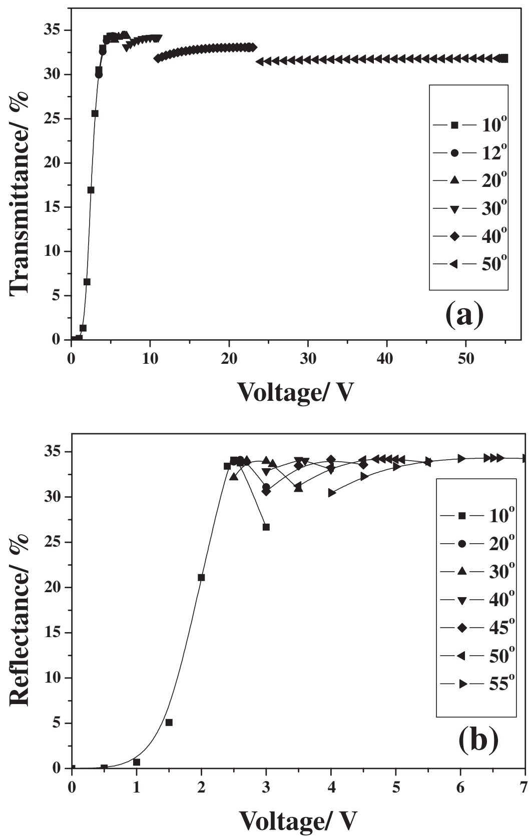

Fig. 3. Voltage–dependent (a) transmittance and (b) reflectance curves as a function of different α's.

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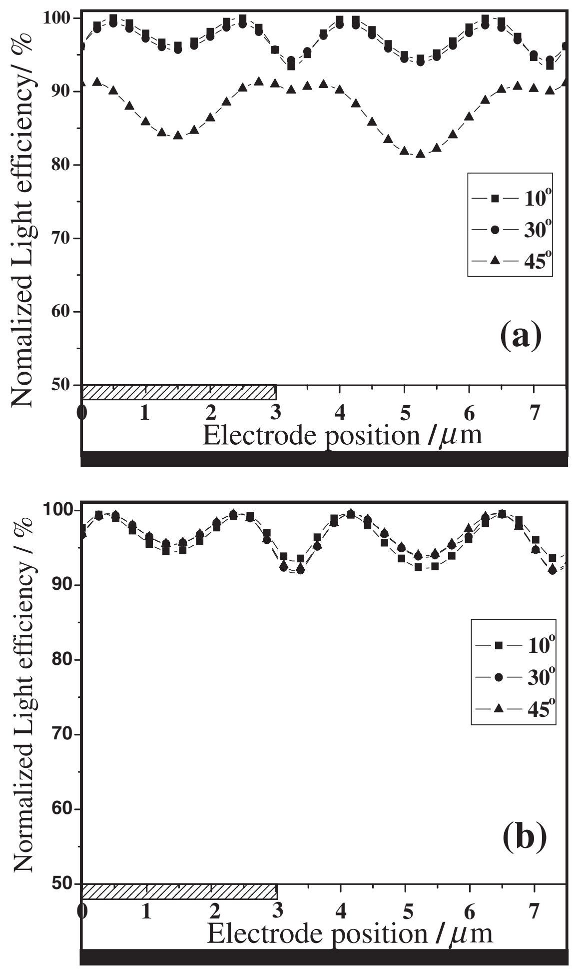

Fig. 4. Transmittance distribution along electrode position at operating voltages as a function of αs in the (a) transmissive and (b) reflective part.

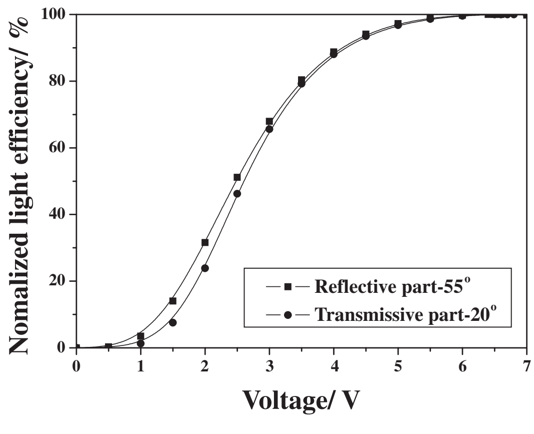

Fig. 5. Voltage–dependent normalized transmittance and reflectance curves in the device.