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Transflective Liquid Crystal Display with Single Cell Gap in Patterned Vertically Aligned Mode

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We propose a novel transflective liquid crystal display (LCD) configuration with a single cell gap in a patterned vertically aligned (PVA) mode. In this work, the optical path difference in a single cell gap is simply compensated by introducing pixel electrode structures between transmissive and reflective parts in a PVA mode. In addition, our transflective LCD was constructed with the same optical configuration such as that of polarizers and retardation films over the whole panel area. The simulated and measured electro-optic characteristics in the transmissive and reflective parts of our novel transflective LCD have shown good agreement with each other over the whole gray scale range. [DOI: 10.1143/JJAP.45.7827]

KEYWORDS: transflective LCD, single cell gap, patterned vertically aligned mode

1. Introduction

Recently, transflective liquid crystal displays (LCDs) have been attracting considerable attention for mobile device applications such as tablet personal computers, e-books, personal data assistants and mobile phones owing to their good display performance under indoor and outdoor environments, as well as low power consumption.[1,2] Most transflective LCDs consist of two subpixels of the transmissive and reflective regions. The early transflective LCDs are constructed with multi-cell gap structures in subpixels of transmissive and reflective parts for compensating the optical path difference between two subpixels.[3,4] Although the transflective LCD with a multi-cell gap structure shows good optical characteristics, the manufacturing processes are cumbersome in the case of normal transmissive LCD and the display performances are degraded owing to the non uniform alignments of liquid crystal (LC) molecules at the interface of the two parts. To overcome this problem, the methods of adopting two kinds of LC modes have been presented in a single cell gap structure.[5,6] However, the different LC modes result in different LC responses to the applied voltage, such as in threshold voltage and voltage–transmittance/reflectance (V–T/R) characteristics. Thus, different driving schemes are required for the transmissive and reflective parts to realize a high image quality and the complexity of driving circuits are increased.

In this paper, we propose a new transflective LCD configuration with a single cell gap. By designing the pixel electrode structure in a patterned vertically aligned (PVA) mode, the optical path difference between the transmissive and reflective parts could be simply compensated. Since the birefringence axis of the LC layer is generated in a different azimuthal direction by our designed electrode structure, our transflective LCD could be constructed with the same polarizers and retardation films over the whole panel area. Both the simulation and measurement results obtained on the electro-optic (EO) characteristics of the transmissive and reflective parts match well matched each other over the whole gray scale range.

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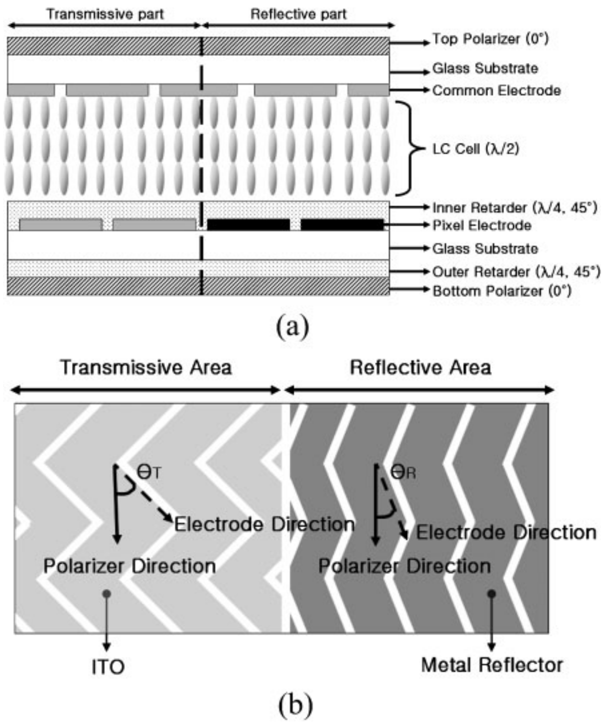

Fig. 1. Schematic diagram of proposed transflective LCD: (a) cross-sectional structure and (b) pixel electrode configuration of bottom substrate in transmissive and reflective parts.

2. Cell Structure and Operation Principle

The schematic diagram of our proposed configuration is shown in Fig. 1. It is composed of two parallel polarizers, inner and outer $\lambda/4$ retardation films rotated by 45° with respect to the optic axis of polarizer, and a vertically aligned LC layer. All these configurations were applied in the same manner to the transmissive and reflective parts. The LC mode used was a patterned vertically alignment mode and the maximum value of field-induced LC retardation was $\lambda/2$. The pixel electrode structure was patterned with a chevron shape, as shown in Fig. 1(b), which is conventional for wide-viewing applications. The pixel electrode of the transmissive part was made of indium–tin-oxide (ITO),

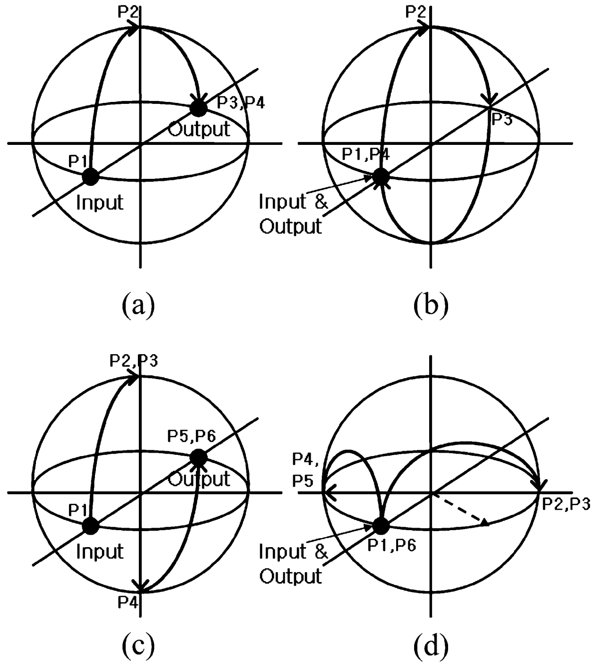

Fig. 2. Poincare sphere representation of polarization path of (a) dark and (b) bright states in transmissive part, and (c) dark and (d) bright states in reflective part.

which was patterned by 45° with respect to the input polarizer. To control optical retardation in the LC layer, the electrodes in the reflective part were made of aluminum (Al) with a patterning angle of 22.5°.

Figure 2 shows the polarization paths on the Poincare sphere[7] of the transmissive and reflective parts in our transflective LCD. In the transmissive part for the field-off state, the linearly polarized light becomes linear light by rotating 90° through the inner and outer $\lambda/4$ retardation films by 45°, we can obtain the dark state after passing through the parallel output polarizer [see Fig. 2(a)]. For the field-on state, LC molecules rotate 45° with an effective retardation value of $\lambda/2$; thus, the linear light passing through the retardation films becomes linearly polarized light parallel to the input polarizer angle, as shown in Fig. 2(b). In the reflective part at the field-off state, the linearly polarized light only passes through the LC layer without any change in polarization, and becomes circularly polarized after passing through the inner retardation film. After reflection, it propagates along the retarder and LC layer again only by changing the handedness of light, as shown in Fig. 2(c). For the field-on state, the linearly polarized input light rotates 45° by passing through a 22.5°-rotated LC layer; thus, the inner retarder cannot change the polarization of light. Since the rotation angle of the reflected light is changed to −45° and the light passing through the inner retarder and LC layer becomes parallel with respect to the input polarizer, we can obtain a bright state as in the transmissive part as shown in Fig. 2(d). Thus, the transmissive and reflective parts in our transflective LCD have the same optical state in both the field-on and -off states.

3. Experiments

The transflective LC cell was made using two glass substrates deposited with ITO for the transmissive part and Al for the reflective part as pixel electrodes. For the inner retardation film, we used the reactive mesogen RMS03-001 from Merck. The retardation value of RMS03-001 after polymerization was about 155 nm; thus we had to fabricate a thin $\lambda/4$ retardation layer of 1.0 μm thickness. To control the direction of the inner retardation layer, we used the conventional polyimide alignment material RN1199 (Nissan Chemical, Japan). First, we coated the RN1199 on the electrode surface and imidized it at 220 °C for 1 h. The polyimide film was rubbed unidirectionally by 45° with respect to the input polarizer to produce a planar alignment of reactive mesogen molecules. After that, we coated RMS03-001 on the polyimide layer and dried it at 60 °C for 5 min. The molecules of the reactive mesogen have been aligned along with the rubbing direction of polyimide. For the polymerization of RMS03-001, we irradiated unpolarized UV light of 365 nm wavelength under a nitrogen atmosphere and then baked it at 120 °C for 1 h to obtain hard and stable retardation films inside the cell. AL1H659 polyimide (JSR, Japan) was coated on the retardation layer and the electrode of the upper substrates for the vertical alignment of LC molecules and cured at 210 °C for 1 h. The cell thickness was maintained using glass spacers of 3.1 μm thickness. The LC used was MLC6610 (Merck), which was injected into the cell by capillary action at room temperature. Two polarizers and outer retardation films were attached to the outer sides of the cell.

4. Results and Discussion

The EO characteristics from the numerical calculation of our proposed structure are shown in Fig. 3. The simulation was performed by Expert LCD (Davan Tech., Korea) and the optical calculation was performed on the basis of the 2×2 extended Jones matrix method.[8] Two polarizers are set to be parallel with each other and the cell gap (d) is 3.1 μm. The ordinary and extraordinary refractive indices of LC are 1.5824 and 1.4828, respectively. We used the dielectric anisotropy $\Delta\varepsilon = -3.1$, the elastic constants $K_1 = 14.6 \times 10^{-12}$ N and $K_3 = 16.5 \times 10^{-12}$ N, and the rotational viscosity $\gamma = 148$ mPa·s. The direction of the LC molecules in the presence of the applied voltage is perpendicular to the angle of the electrode along with electric field direction. When the patterning angles of electrodes are 45 and 22.5° for the transmissive and reflective parts, respectively, the EO

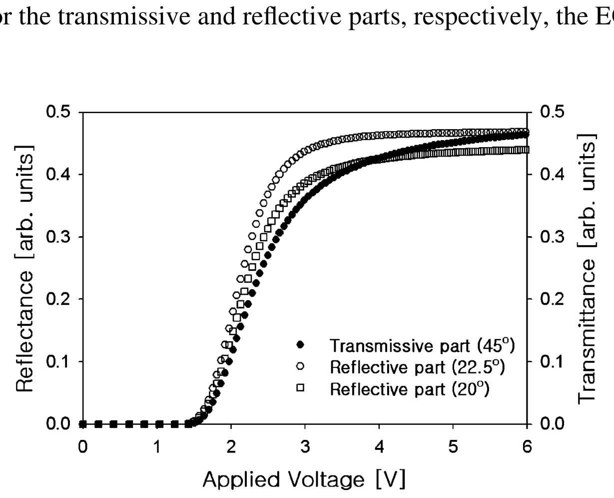

Fig. 3. Simulated EO characteristics of developed transflective cell for various patterning angles.

characteristics and threshold voltage well agree with each other in the field-on and -off states, as shown in Fig. 3. However, in the gray scale range, there still exists a mismatch in the EO characteristics between the transmissive and reflective modes. This type of mismatch requires different LC cell driving schemes for each part to achieve a good display performance. We could solve this problem by fine tuning the patterning angle of the electrode in the reflective part. When we change the angle of the electrode pattern in the reflective part, the LC molecules in that area lie at different azimuthal directions considering the patterned angle in the presence of applied voltage. As a result, we obtained different EO characteristics in the reflective region, which agreed well with those of the transmissive part in the gray scale driving scheme. In our optical configuration, the crossing points of transmissive and reflective graphs are shifted to the left with the patterning angle of the reflective electrode. We found that the patterning angle of 19° generates the best-fit EO characteristics with the 45° transmissive part at the gray level as shown in Fig. 3. The maximum optical signal is different between the transmissive and reflective parts owing to optical loss. However, a slight difference in the white state is negligible because the intensity of the light source for each part is different and the human eye is not highly sensitive in the bright state compared with that in the dark state. Note that for other optical configurations, the curves can be different so that the optimized reflective angle can be different.

To confirm the simulated results, we made a real test cell under the same conditions as those in the calculation. Figure 4 shows the polarizing microscopic texture of our transflective LCD. Figures 4(a), 4(c), and 4(e) show the textures obtained at applied voltages of 0, 4, and 11 V, respectively, of the transmissive part. Figures 4(b), 4(d), and 4(f) show the textures of the reflective part at the same applied voltages. As expected, the two parts show almost the same optical behavior, including threshold voltage and transmittance. This can be verified by measuring the V–T/R characteristics. Figure 5 shows the result of the measured EO characteristics. Transmittance and reflectance are normalized to examine the essential characteristics of both parts. The EO characteristics of the transmissive and reflective parts agree well over the whole gray scale range. Thus, the same driving scheme is applicable for our transflective LC cell.

Also, we measured the EO response times of the transmissive and reflective parts as shown in Fig. 6. Since the graphs of the EO response times for the transmissive and reflective parts overlap over the whole region, the two graphs are difficult to distinguish. The rising and falling times were found to be 10.1 and 6.2 ms, respectively, at the transmissive part. For the reflective part, we obtain 9.5 and 6.1 ms, respectively, which are almost the same as for the transmissive part. These results indicate that the response of LC molecules to applied voltage at the transmissive and reflective parts are almost the same. The slightly slow rising time was due to the low dielectric anisotropy ($\Delta\varepsilon = -3.1$) and the large width of the electrode pattern (180 μm). This problem can be overcome easily. Nevertheless, the switching time of our cell is sufficiently fast for presenting a moving picture without any motion blurring.

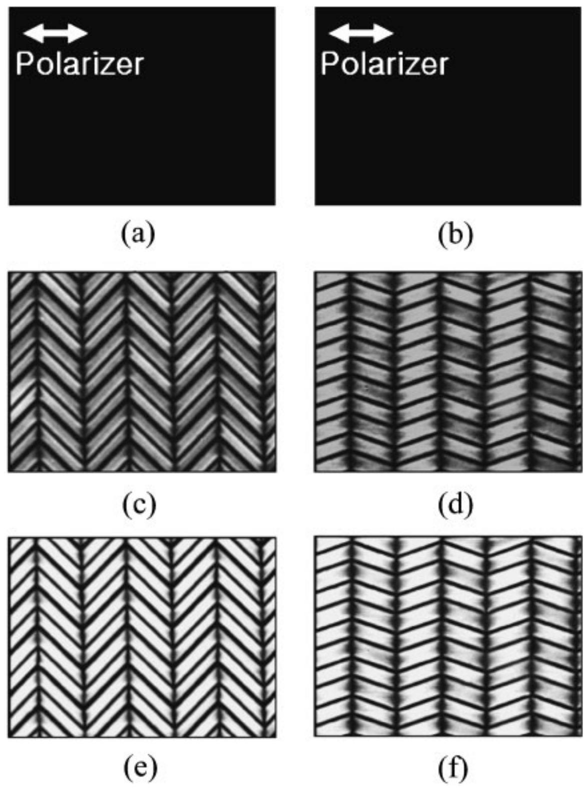

Fig. 4. Polarizing microscopic images of developed transflective LCD. (a), (c), and (e) are textures at applied voltages of 0, 4, and 11 V in transmissive part, respectively. (b), (d), and (f) are textures at reflective part at the same applied voltages.

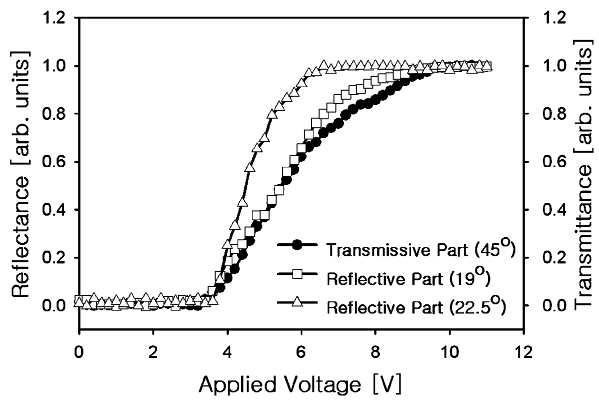

Fig. 5. Measured EO characteristics of developed transflective cell.

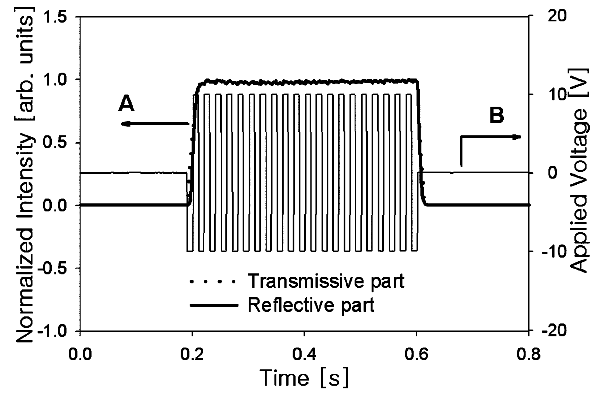

Fig. 6. EO response time of developed transflective LCD. Lines A and B are the normalized EO response and the input pulse, respectively.

5. Conclusions

We proposed a new transflective LCD in a PVA mode with a single cell gap. By optimizing the electrode patterning in the transmissive and reflective parts, we compensated the optical path difference between these two parts. As a result, our transflective LCD was constructed with the same polarizers and retardation films over the whole panel area, which is highly important in mass production. The structure of our transflective LCD showed that the simulated and measured EO characteristics in the transmissive and reflective parts agree well with matched each other over the whole gray scale range.

Acknowledgements

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