P-162: Transflective LCD in a Patterned Vertically Aligned Mode with a Single Cell Gap

You-Jin Lee, Hak-Rin Kim, Tae-Hee Lee, Jong-Wook Jung and Jae-Hoon Kim[1]
Department of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea

Jong Sun Choi
Department of Electrical, Information & Control Engineering, Hongik University, Seoul 121-791, Korea

Abstract

We proposed a transflective liquid crystal display (LCD) with a single cell gap in a patterned vertically aligned mode by adopting different geometry of electrode in the transmissive and reflective parts. Since the difference of the electrode structure induces the difference of the optical retardation in each part, we can easily fabricate transflective LCDs with good electro-optic characteristics even in the same cell gap.

1. Introduction

Recently, transflective liquid crystal displays (LCDs) have been much attention for mobile applications since their high display performance under indoor and outdoor environments as well as low power consumption [1,2]. In the early works, transflective LCDs are constructed by multi-cell gap structures in subpixels of transmissive and reflective parts for compensating optical path difference between two subpixels [3,4]. But in this case, the manufacturing processes are very complicate and the display performances are degraded because the alignments of liquid crystal molecules are non-uniform near the interface of subpixels. To overcome this problem, the methods of adopting two kinds of LC modes are presented in a single cell gap structure [5,6]. However, the different LC modes result in different LC response to the applied voltage such as threshold voltage and voltage-transmittance/reflectance (V-T/R) characteristics. Thus, different driving schemes are needed 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, optical path difference could be simply compensated between a transmissive part and a reflective part. 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. The simulated and measured electro-optic (EO) characteristics in a transmissive part and a reflective part results for our transflective LCDs are well matched each other over the whole gray scale range.

2. Cell Structure and Operation Principle

The schematic diagram of the proposed configuration is shown in Fig. 1. It is composed of two parallel polarizers, inner- and outer- λ /4 retardation films rotated by 45° with respect to optic axis of polarizer, and a vertically aligned LC layer. All these configurations were the same in a transmissive part and a reflective part. The used LC mode was PVA mode and the maximum value of filed-induced LC retardation was λ /2. The pixel electrode structure was patterned with chevron shape as shown in Fig. 1(b) which is conventional for wide-viewing applications. The pixel electrode of transmissive part was made of ITO which was patterned by 45° with respect to input polarizer. In order to control optical retardation, the electrodes in reflective part were made of Al with patterning by 22.5°.

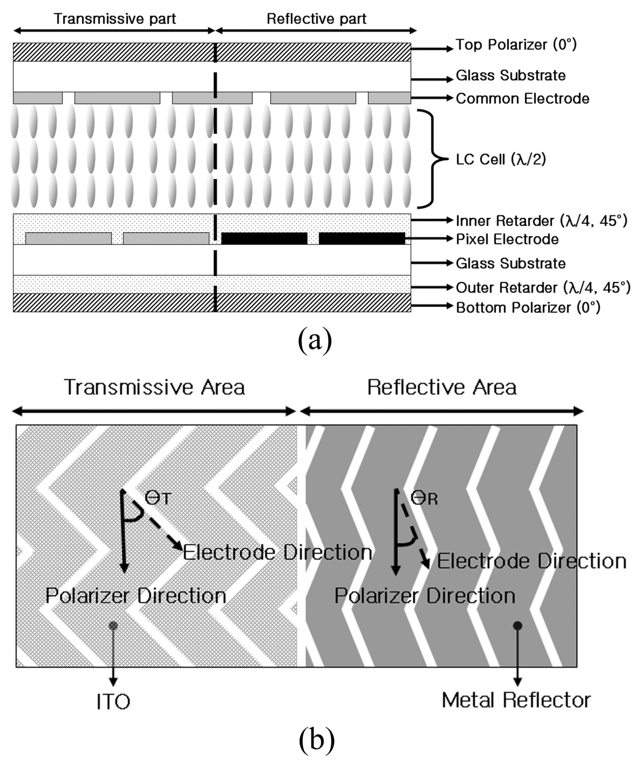

Figure 1. The schematic diagram of transflective LCD : (a) is a cross sectional structure and (b) is pixel electrode configuration of the bottom substrate.

Figure 2 shows the polarization paths on the poincare sphere [7] of the transmissive and reflective parts in our proposed transflective LCD. In the transmissive part for field-off state, the linearly polarized light becomes the linear light by rotating 90°

[1] E-mail : jhoon@hanyang.ac.kr

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through inner- and outer- $\lambda/4$ retardation films by 45°, we can get dark state after passing through the parallel output polarizer (see Fig. 2 (a)). For field-on state, the LC molecules rotates 45° with effective retardation value of $\lambda/2$, so the linear light passed through retardation films becomes the linearly polarized light parallel to input polarizer angle as shown in Fig. 2 (b). In the reflective part for field-off state, the linearly polarized light just pass through the LC layer without any change of polarization, and becomes circularly polarized after inner retardation film. After reflection, it propagates along the retarder and LC layer again only with 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 22.5° rotated LC layer, so the inner retarder cannot change the polarization of light. Since the rotation angle of reflected light changed to - 45° and the light though inner retarder and LC layer becomes parallel with respect to input polarizer, we can obtain the bright state as shown in Fig. 2 (d).

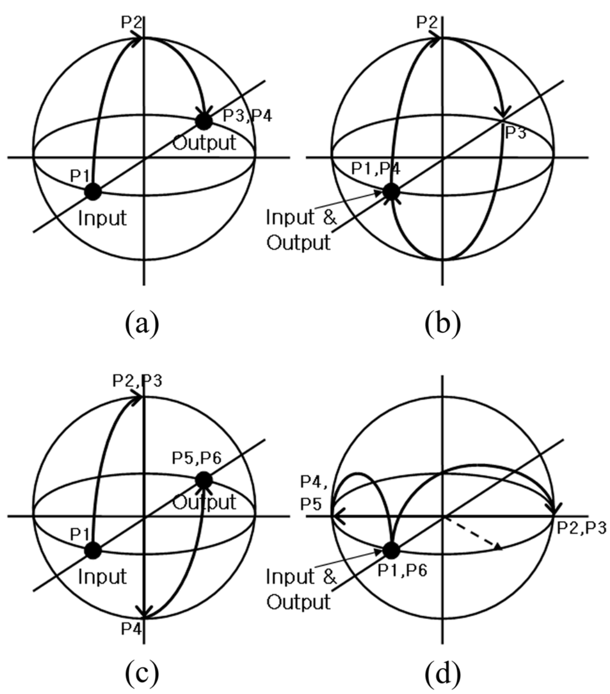

Figure 2. Poincare sphere representation of the polarization path of (a) dark and (b) bright state in the transmissive part and (c) dark and (d) bright state in the reflection part.

3. Experiments

The transflective LC cell was made using two glass substrates deposited with indium-tin-oxide for the transmissive part and aluminum for the reflective part as electrodes, respectively. For the inner retardation film, if conventional retardation films whose thickness is more than 50μ m are used inside of a LC cell, the parallax problems will be occurred. To overcome this problem, we used the reactive mesogen, RMS03-001 (Merck). The retardation value of RMS03-001 after polymerization is about 0.1, so we could fabricate thin $\lambda/4$ retardation layer which thickness was 1.6μ m. To control the direction of inner retardation layer, we used the conventional polyimide alignment material, RN1199 (Nissan Chemical Ind., Japan). First, we coated the RN1199 on the electrode surface and imidized at 220℃ for 1 hour. The polyimide film was rubbed unidirectionally by 45° with respective to input polarizer to produce planar alignment of reactive mesogen molecules. And then, we coated the RMS03-001 on the polyimide layer and dried at 60℃ for 5 minute. For polymerization of RMS03-001, we irradiated the unpolarized UV light of 365 nm under a nitrogen atmosphere and then baked at 120℃ for 1 hour. So, we got the hard and stable retardation films. The polyimide of AL1H689 (JSR Co., Japan) was coated on the retardation layer and electrode of the upper substrates for vertical alignment of LC molecules and cured at 210℃. The cell thickness was maintained using glass spacers of 3.1μ m thick. The MLC6610 (Merck) was injected into the cell by capillary action at room temperature. Two polarizers were attached to outer sides of the cell.

4. Results and Discussion

The EO characteristics from numerical calculation of the proposed structure are shown in Fig. 3 (a). A simulation was performed by Expert LCD (Davan Tech Co., Korea) and an optical calculation was based on the 2 X 2 extended Jones matrix methods [8]. For the simulations, the retardation value of the inner- and outer- retardation films which optical axes are 45° with respect to input light's polarization direction are $\lambda/4$, 158 nm, for He-Ne laser light. Two polarizers are set to parallel each other and the cell gap (d) is 3.1μ m. The material parameters of LC were the ordinary refractive index n_o = 1.5824, the extraordinary refractive index n_e = 1.4828, the dielectric anisotropy $\Delta\varepsilon$ = -3.1, the elastic constants, $K_1 = 14.6 \times 10^{-12}$ N, $K_3 = 16.5 \times 10^{-12}$ N, and the rotational viscosity γ = 148 mPa·sec. The direction of LC molecules in the presence of the applied voltage is perpendicular to the angle of electrode along with electric filed direction. When the patterning angles of electrodes are 45° and 22.5° for the transmissive and reflective part, respectively, the EO characteristics and threshold voltage are well matched each other at the field-on and -off state such as results of optical path analysis using poincare sphere representation. But, in the gray scale range, there still exists mismatch of the EO characteristics between the transmissive and reflective mode. This kind of mismatch needs the different driving schemes of LC cell for each part to achieve good display performance. We can solve this problem by fine tuning of the patterning angle of electrode in reflective part. When decreasing the electrode angle, the slop of the voltage-dependent reflectance curve is decreased so that the EO characteristics are well matched between the transmissive and reflective part. We found that the patterning angle of 19° gives the best EO characteristics. A little bit difference for white state is not so significant problem because the intensity of source light for each part is different and the human eye is not so sensitive in bright state.

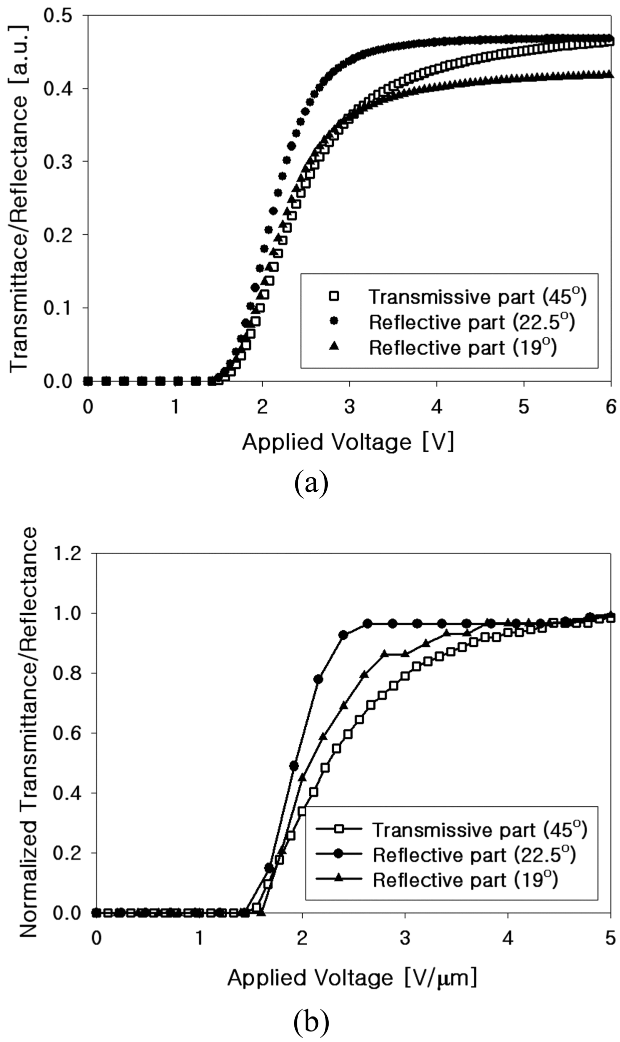

Figure 3. The (a) simulated and (b) measured EO characteristics of our transflective cell.

To confirm the simulated results, we made a real test cell with the same conditions as those in calculation. Figure 3 (b) shows the result of measured EO characteristics. The transmittance and reflectance are normalized to examine the essential features of both parts. The EO characteristics have good agreement for simulation results and are well matched between the transmissive and reflective part over the whole gray scale range. Thus, the same driving scheme is applicable for our transflective LC cell.

Also, we measured the EO response time as shown in Fig. 4. The rising and falling times were found to be 10.1 msec and 6.2 msec, respectively. The slight slow rising time was due to low dielectric anisotropy ($\Delta\varepsilon$ = -3.1) and the wide width of electrode pattern (~ 180μ m). This problem can be overcome easily. Nevertheless, the switching time of our cell is fast enough for moving picture applications.

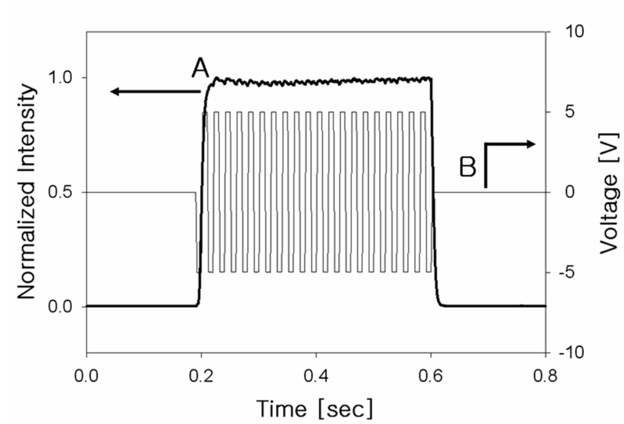

Figure 4. The EO response time of our transflective LCD. The lines A and B are the normalized EO response and the input pulse, respectively.

5. Concluding Remarks

We proposed a new transflective LCD in PVA mode with a single cell gap. By designing the pixel electrode structure, we could compensate the optical path difference between a transmissive and reflective part and use the same optical configuration of polarizers and retardation films in both parts, which is highly important in massive fabrication. The simulated and measured EO characteristics in a transmissive and reflective part results for our transflective LCDs are well matched each other over the whole gray scale range.

6. Acknowledgements

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7. References

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