A Single Cell Gap Transflective LCD in a Patterned Vertically Aligned Mode

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Abstract

We have demonstrated a transflective liquid crystal display (LCD) with a single cell gap in a patterned vertically aligned mode. In our configuration, the different electrode structure in a transmissive and a reflective part was suggested to compensate an optical path difference of each region. As the result, the similar electro-optic characteristic of each region was obtained which results in an enhanced performance of the device. Moreover, suggested technique can be highly effective to realize the practical transflective LCD due to the simple fabrication process.

1. Introduction

Various transflective liquid crystal displays (LCDs) modes have been proposed for the mobile displays since their high display performance under both indoor and outdoor environments as well as low power consumption [1, 2]. The transflective LCD is divided into two subpixels, one of which is a transmissive part that transmitted the light from the backlight, and the other is a reflective part that reflected the ambient light. For this reason, between two pixels induced optical path difference exist, so , in early works, transflective LCDs adopted multi-cell gap structures in subpixels of transmissive and reflective parts [3, 4].

In this configuration, the retardation effect of liquid crystal (LC) on the light is the same for subpixels. But, this structure requires very complicate manufacturing process and induces disclination of LC at the interface of two subpixel. Therefore, for last years, several single cell gap structures which adopted dual modes have been proposed to overcome these problems [5, 6]. Although these techniques successfully solved the problem of multi-cell gap structure, each mode requires different driving circuit since it results in different LC response such as threshold voltage and voltage-transmittance/reflectance(V-T/R) characteristics. In this paper, we have developed a transflective liquid crystal display (LCD) with a single cell gap in a patterned vertically aligned mode. The difference of the optical retardation in each part is compensated by adopting different geometry of electrode between the transmissive and reflective parts. The simulated and measured electro-optic (EO) characteristics in a transmissive part and a reflective part are well matched each other over the whole gray scale range.

2. Device Structure and Operation Principle

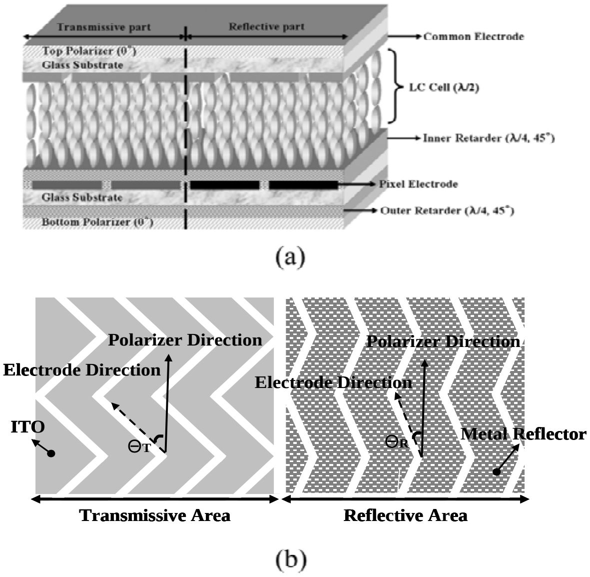
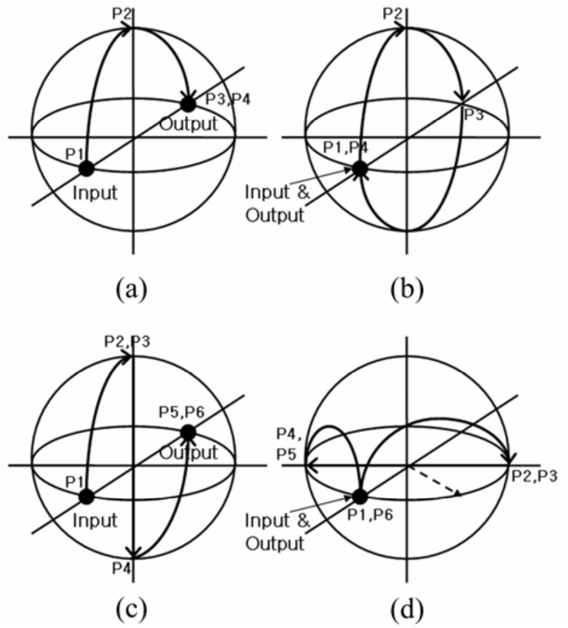


Figure 1. The schematic diagram of transflective LCD : (a) is a cross sectional structure and (b) is pixel electrode configuration of the bottom substrate.

Figure 1 shows a schematic diagram of our proposed transflective LCD with a single cell gap in a patterned vertically aligned (PVA) mode. In this transflective LCD, the two polarizers are parallel to each other, inner and outer $\lambda/4$ retardation films are placed at 45° with respect to the polarizer, and a vertically aligned LC layer is inserted in it. The maximum value of filed-induced LC retardation was $\lambda/2$. 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 consisted of indium-tin-oxide (ITO) and the angle of patterned ITO (Θ_T) was 45° with respect to the polarizers. The pixel electrode of reflective part was consisted of aluminum (Al) for mirror effect and the angle of patterned Al(Θ_R) was 22.5° .

Figure 2 shows operational principle of the transmissive and reflective parts using the poincare sphere [7]. In the dark state of transmissive part, 0° linearly polarized light is changed to 90° linearly light after passing the inner and outer $\lambda/4$ retardation films by 45°. So we can get the dark state because polarizers are parallel to each other, as shown in Fig 2(a). In the bright state, the LC molecules rotates 45°with effective retardation films becomes the linearly polarized light parallel to input polarizer angle as shown in Fig 2(b). In the dark state of reflective part, 0° linearly polarized light passing though vertically aligned LC layer and inner- $\lambda/4$ retardation film by 45° is changed to circularly polarized light. After reflection, it propagates along the retarder and LC layer again only with changing the handedness of light, as shown in Fig. 2 (c). In the bright state, 0° linearly polarized light passing through rotated LC layer by 22.5° is changed to 45° linearly polarized light. So, the inner retarder cannot change the polarization of light. After the rotation angle of reflected light is changed to - 45° and the light passing through inner retarder and LC layer come to 0° linearly polarized light, as shown in Fig. 2(d).



(a) (b)

(c) (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. Experimental

For the inner retardation film, we used the reactive mesogen, RMS03-001 (Merck). The retardation value of RMS03-001 after polymerization is about 155nm, and we obtain a thin $\lambda/4$ retardation mesogen layer with thickness of 1.0μm for 633nm. To control the direction of inner retardation layer, we used the conventional polyimide alignment material, RN1199 (Nissan Chemical Ind.). For aligning the molecular ordering of mesogen uniformly, we first spin-coated RN1199 on the pixel electrode surface and dried at 100℃ for 30min in a first step and at 220℃ for 40min in full curing process. The polyimide film was rubbed unidirectionally by 45° with respective to input polarizer to produce planar alignment of reactive mesogen molecules. Then, RMS03-001 was spin-coated on the polyimide layer and baked at 60℃ during 5 minutes. For the polymerization of RMS03-001, this layer is exposed to the unpolarized UV light of 365 nm under a nitrogen atmosphere and then baked at 120℃ for 1 hour. In final, we got the stable $\lambda/4$ retardation films of liquid crystalline polymer as an inner retarder. For a vertical alignment of LCs, we spin-coated commercial homeotropic aligning agent AL1H659 (JSR Co) on both substrates. The cell thickness was maintained by using glass spacers of 3.1μm thick. The nematic LC of MLC6610 (Merck) was injected into the cell by a capillary action at room temperature. Outer retardation film and additional polarizers were attached to outer sides of the cell.

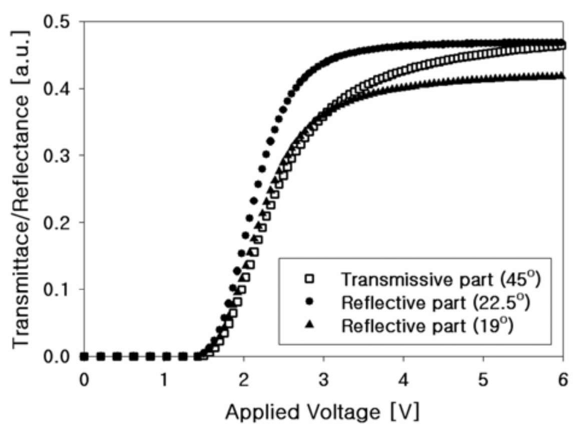


Figure 3. The simulated EO characteristics of our transflective cell

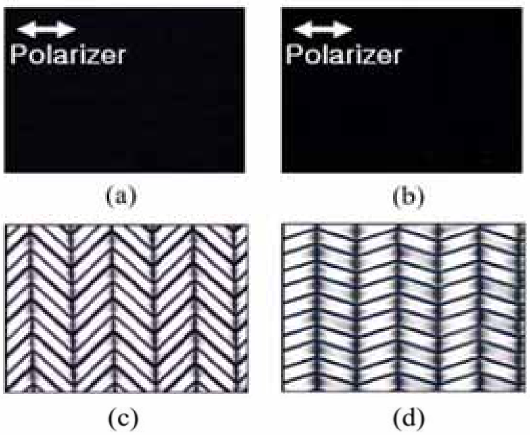
4. Results and Discussion

In order to confirm the EO characteristics of device, we performed numerical calculation of the proposed structure, as shown in Fig. 3. A simulation was performed by commercial simulation program of Expert LCD (Davan Tech Co.) and an optical calculation was based on the 2 X 2 extended Jones matrix methods [8]. For the simulations, two polarizers are set to be parallel with each other and the cell gap was 3.1μm. The used nematic LC has the material parameters as follows : 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.

In PVA structure, orientation LCs in the presence of applied voltage is perpendicular to the angle of electrode structure. When the patterning angles of electrodes are 45° and 22.5° for the transmissive and reflective part, respectively, EO characteristics and threshold voltage are well matched each other at the bright and dark state. This coincides with the result of optical path analysis depicted in Fig. 2 by using poincare sphere representation and 2 X 2 extended Jones matrix methods. But, in the gray scale range, there still exists mismatch of the EO characteristics between transmissive and reflective part. To solve this mismatch the different driving schemes of LC cell for each part are required. One solution can be fine tuning of the patterning angle of electrode in reflective part. In this method, EO curve of the reflective part was down to that of the transmissive part, thus EO characteristics were well matched two regions in the gray scale range.

We found that the patterning angle of 19° in reflective part was optimized to match gray level of the transmissive part, as shown in Fig. 3. Although the saturated optical signal is different due to the optical loss, this problem is not so significant because the intensity of source light for each part is different and even human eye is not so sensitive in bright state compared to dark state observation.

To confirm the simulated results, we made a test sample. Microscopic textures of our transflective LC cell under parallel polarizer are illustrated in Fig. 4. Figure 4 (a), (c) are obtained in the presence of applied voltage of 0V, 11V, respectively, at the transmissive part. Under the same applied voltages,



(a) (b)

(c) (d)

Figure 4. Polarizing microscopic images of our transflective cell.

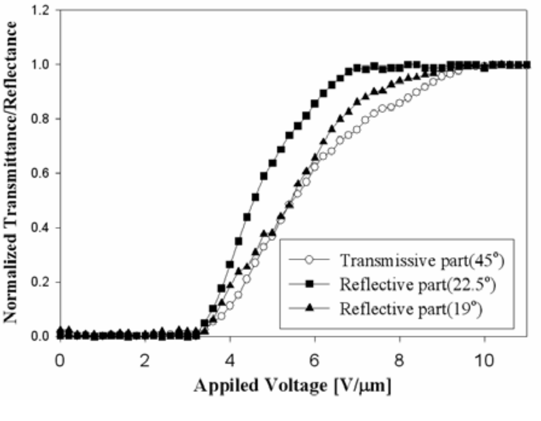


Figure 5. The mesured EO characteristics of our transflective cell

Textures at the reflective part are shown in Fig. 4(b), (d). As we respected, 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 measured EO characteristics, where reflectance and transmittance are normalized to examine the essential features of each part. 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 response time as shown in Fig. 6. Note that almost identical response characteristics were obtained in both part. The rising and falling times of reflective part were found to be 9.5 msec and 6.1 msec, respectively, and that of transmissive part got the 10.1 msec and 6.2 msec, respectively. Low dielectric anisotropy ($\Delta\varepsilon = -3.1$) and rather wide width of electrode pattern (180μm) induced slightly slow rising time. This problem can be overcome easily by changing LC and electrode size. In conclusion, the switching time of our cell is fast enough for moving picture applications.

5. Conclusion

We have investigated a transflective liquid crystal display (LCD) with a single cell gap in a patterned vertically aligned mode. A novel transflective LCD with a single cell gap shows that EO characteristics in each part are well matched each other over the whole gray scale range. Moreover, it is single cell gap and mode, which is greatly important in massive fabrication. This suggested structure can play a critical role for fabricating an enhanced performance transflective LCD.

6. Acknowledgements

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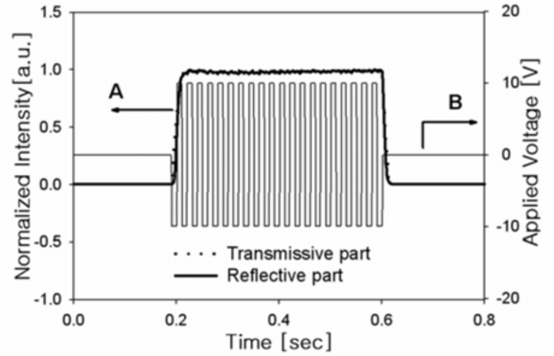

Figure 6. The response time of our transflective LCD. The graph A and B are represent the normalized EO response and the input pulse , respectively.

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7. References

[1] K. Fujimori, Y. Narutaki, Y. Itoh, N. Kimura, S. Mizushima, Y. Ishii, and M. Hijikigawa, SID Symposium Digest 1382 (2002).

[2] S. H. Lee, K.-H. Park, J. S. Gwag, T.-H. Yoon, and J. C. Kim, Jpn. J. Appl. Phys. 42, 5127, (2003).

[3] M. Kubo, S. Fujioka, Y. Narataki, T. Shinomiya, Y. Ishii, and F. Funada, International Display Workshops 183, (1999).

[4] H.-I. Baek, Y.-B. Kim, K.-S. Ha, D.-G. Kim, and S.-B. Kwon, International Display Workshops 41, (2000).

[5] C.-J. Yu, D.-W. Kim, and S.-D. Lee, SID Symposium Digest 35, 642, (2004).

[6] Y. Y. Fan, et al., SID Symposium Digest 35, 647, (2004).

[7] J. E. Bigelow, and R. A. Kashnow, Appl. Opt. 16, 2090, (1977).

[8] Lien, Appl. Phys. Lett. 57, 2767, (1990).