A Single Gap Transflective Display associated with In-Plane Switching Mode

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Abstract

We have studied a single gap transflective liquid crystal display (LCD) associated with in-plane switching (IPS) mode. In the transmissive IPS cell, the transmittance of electrodes and above electrodes is different, that is, the degree of rotation of the LC director between electrodes and above electrodes is 45 ° and 22.5 °, respectively. Utilizing the different rotating angle of the LC director and in-cell retarder with a quarter-wave plate used below the LC layer, the IPS transflective LCD is realized such that the area between electrodes is used as a transmissive part and the area above electrodes is used as a reflective part.

1. Introduction

Transflective liquid crystal displays (LCDs) are widely used because they show good visibility under both strong and weak lighting conditions while keeping characteristics such as portability, good legibility and low power consumption[1]. Nowadays, many results such as homogenous cells with compensation film driven by vertical electric field (named ECB)[2,3] and driven by fringe-electric field[4,5] with dual cell gap, and single gap transflective display using multi-driving circuit[6] have been reported. In the dual gap structure, a cell gap (*d*) in transmissive (*T*) area is twice of that in reflective (*R*) area. This causes additional process and unwanted LC alignment between domains, resulting in decrease of the contrast ratio. For a transflective display with multi-driving circuit, a single cell gap is used but the cost in circuit part increases.

The in-plane switching (IPS) mode is known to exhibit wide viewing angle since the LC director rotates in plane[7]. So, reflective IPS LCD has been studied.[8,9] However, in the device, the film exists below substrate, which may cause a parallax problem.

In this paper, we propose a single gap transflective LCD associated with IPS mode. By optimizing the cell structure such as films, electrode structure and the LC retardation value, the new transflective LCD with a single gap structure and a single driving circuit is realized. Since the LC director rotates in plane in the device, high image quality in both reflective and transmissive parts is achieved.

2. Results and discussion

Fig. 1 shows cell configuration of the proposed transflective display with a single cell gap. In the device, the pixel and counter electrodes exist only on bottom substrate and are reflective metals. The in-cell retarder with $\lambda/4$[10] exists above electrodes which could be patterned. Two polarizers are crossed to each other and an optic axis of the LC coincides with one of polarizer axes.

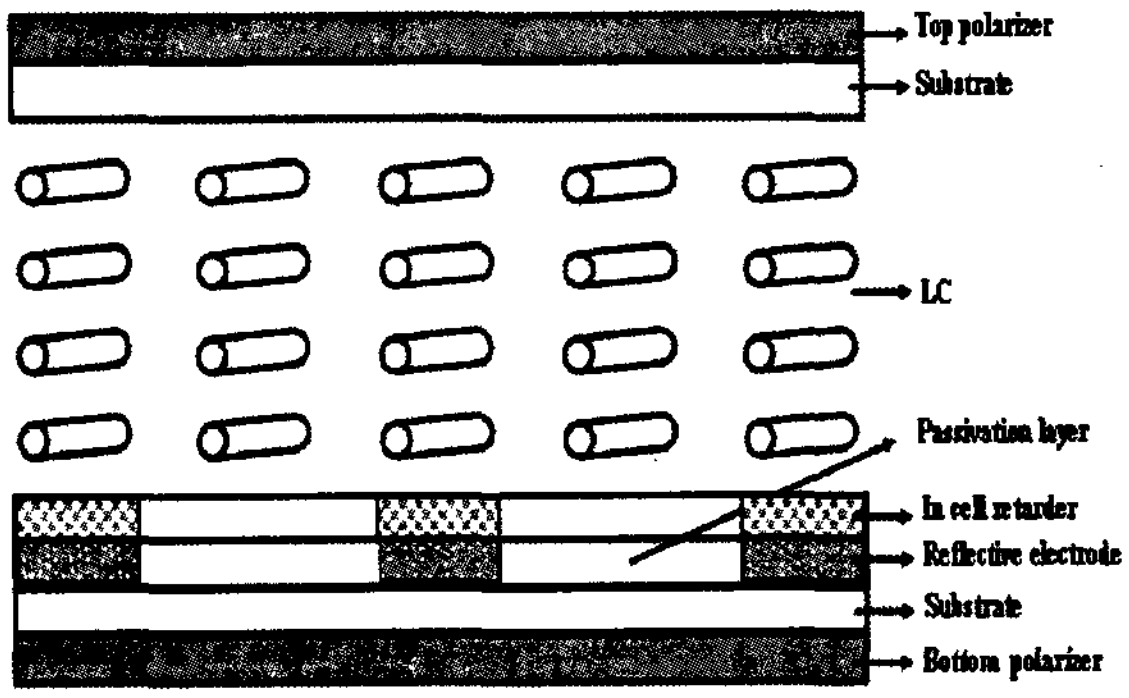


Figure 1 Schematic cell structures of the IPS transflective display.

Fig. 2 shows twist angle distribution at different position when an operating voltage is applied. At position *A*, the LC is twisted by 45° in average from initial alignment. However, at position *D* that is at the center of electrode, the LC is twisted by in average by 23° and 29° in

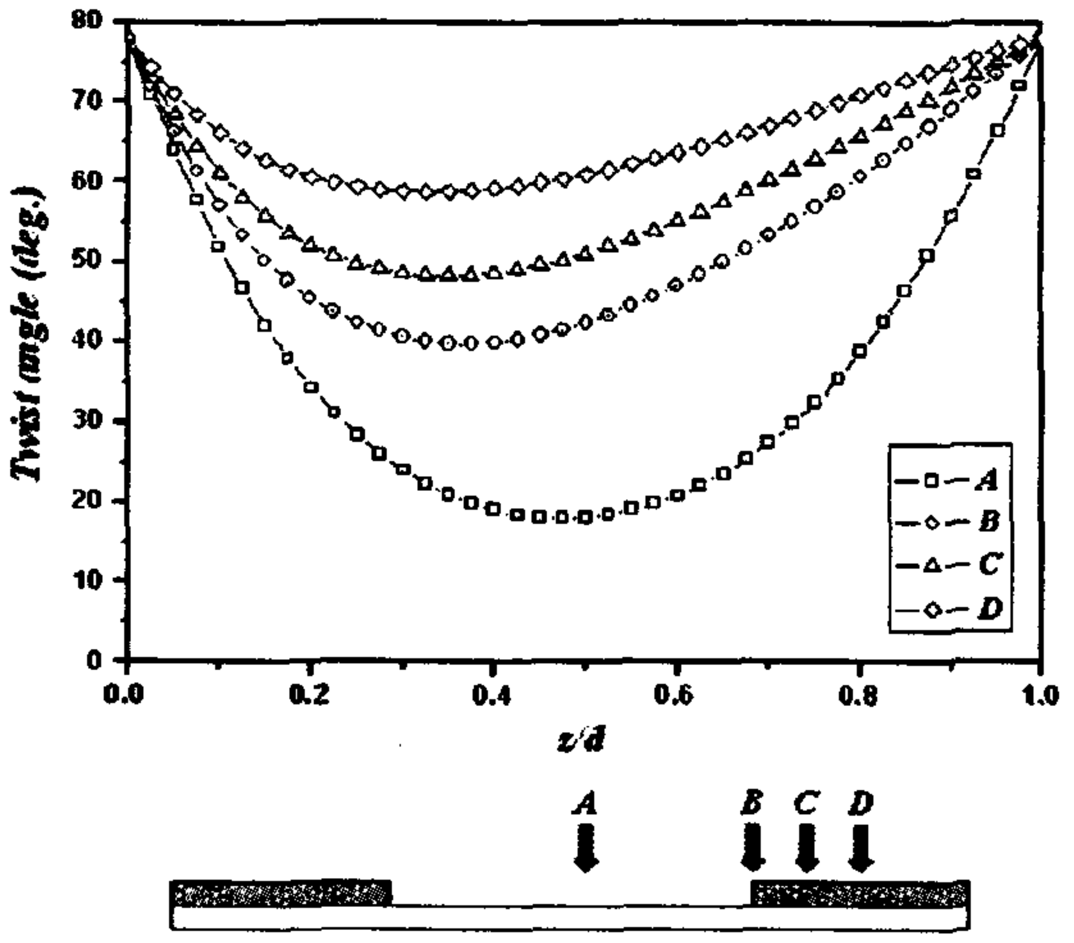
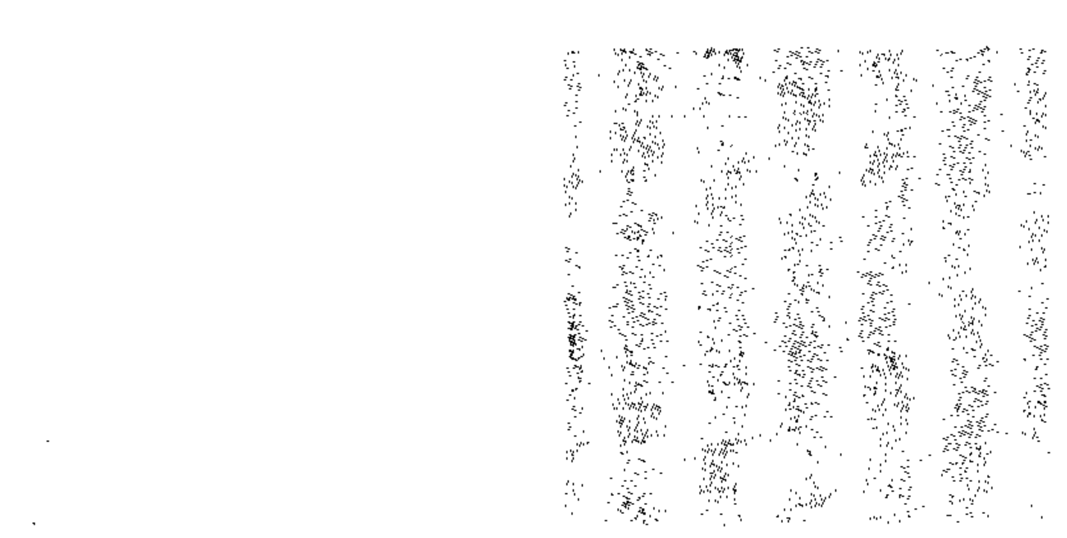


Figure 2 Twist angle distribution of LC director at four different positions.

average, resulting in twist angle of about 22.5° in average. From this, one can understand that the degree of LC's twist angle between electrodes is two times of that above electrode.

Next, a test cell is evaluated to confirm the feasibility. Figure 3 shows microphotographs of the reflective mode cell in voltage of mid-grey state (a) and voltage of white-grey state (b). The cell with compensation film and reflector below substrate is observed under polarizing microscope as a reflective mode. When a voltage of mid-grey in which the LC director rotates by 22.5° between electrodes is applied, the reflectance is maximal between electrodes and is much brighter than that above electrode. However, when a voltage of white-grey in which the LC director rotates by 45°between electrodes is applied, the reflectance becomes maximal above electrodes while the reflectance between electrodes decreases, indicating the LC director above electrode rotates by about 22.5°. This is in good agreement with the calculated results and indicates that a single cell gap transflective display with a single driving circuit is possible.



(a) (b)

Figure 3 Optical microphotographs of the reflective mode cell in voltage of mid-grey state (a) and voltage of white-grey state (b).

To optimize electro-optic characteristics of the proposed transflective LCD, a simulation was performed by LCD master (Shintech, Japan) and an optical calculation was based on the 2 X 2 extended Jones matrix methods[11]. For the simulation, the thickness of in-cell retarder is 1.8 μm and the d is 4 μm. Here, the elastic constant of the LC, K_1, K_2 and K_3 are 11.7 pN, 5.1 pN and 16.1 pN, respectively. The dielectric anisotropy ($\Delta\varepsilon$) of the LC is 7.4. The surface tilt angle of the LC is 2° with an initial rubbing direction of 78° with respect to its horizontal field. The cell retardation value ($d\Delta n$) is varied to find out an optimal value by changing birefringence (Δn) of the LC. For calculations, the transmittances for the single and parallel polarizers are assumed to be 41% and 35%, respectively.

Since the twist and tilt of the LC depend on the horizontal position, largely between electrodes and above electrodes, the transmittance and reflectance according to applied voltage is calculated as a function of $d\Delta n$ as shown in Fig. 4. As indicated, the reflectance is almost the same when $d\Delta n$ is between 0.24 μm and 0.36 μm, while the transmittance is relatively dependent on the $d\Delta n$. The operating voltage (V_{op}) was about the same when it is between 0.32 μm and 0.36 μm. Therefore, in order to realize a single driving circuit, we choose an optimal cell retardation value of 0.32 μm.

Figure 5 shows the voltage-dependent reflectance and transmittance curves in this cell condition. The result shows that the threshold and driving voltages of both reflective and transmissive area are same and thus this display can be displayed with a single driving circuit. In addition, the LC director rotates almost in plane such that it shows wide viewing angle, as shown in Fig. 6. In reflective area, the region where the contrast ratio larger than 5 is larger than 50° of polar angle in all directions. In transmissive area, the region in which the CR is large than 10 exists over 70° of polar angle in all directions.

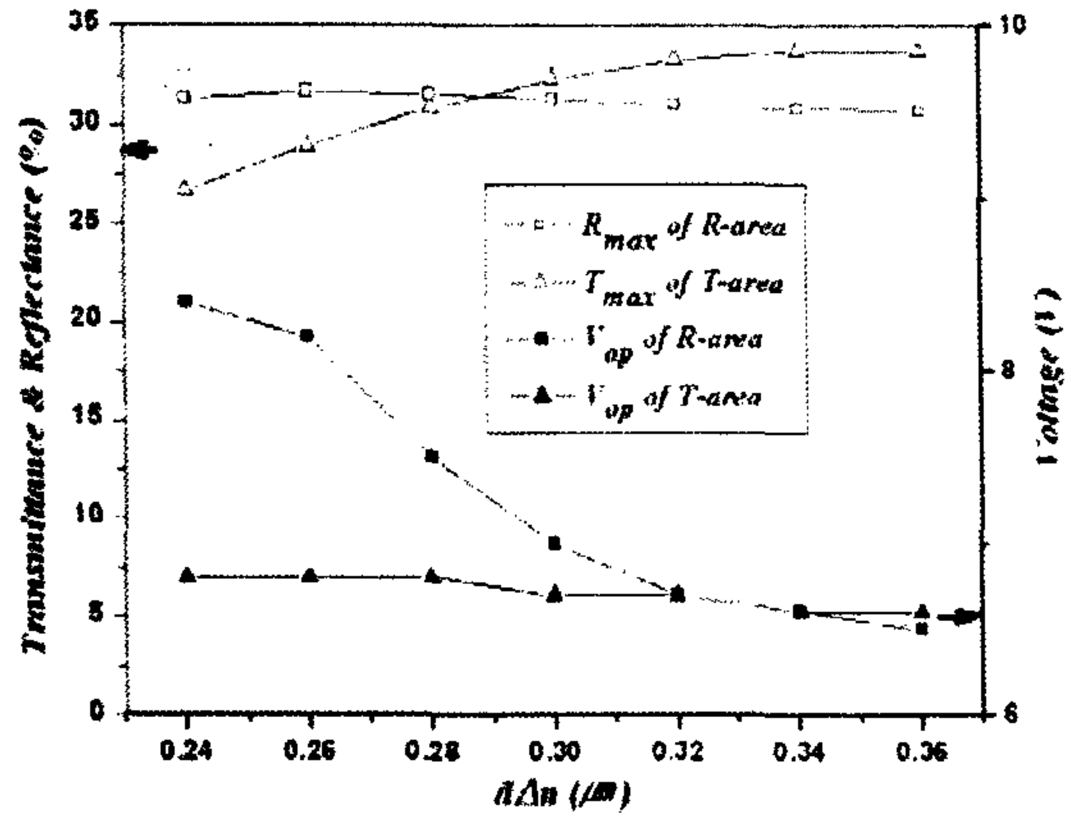


Figure 4 The Maximum reflectance, transmittance and operating voltages of each area as a function of $d\Delta n$.

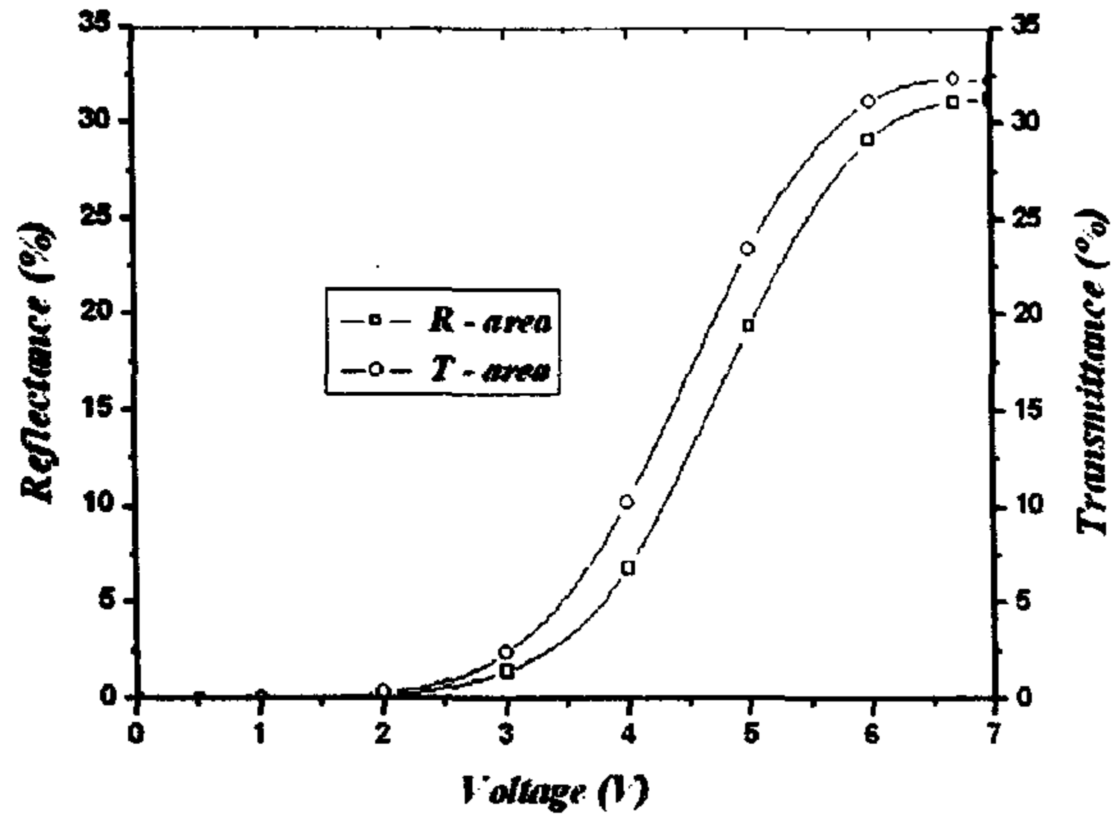
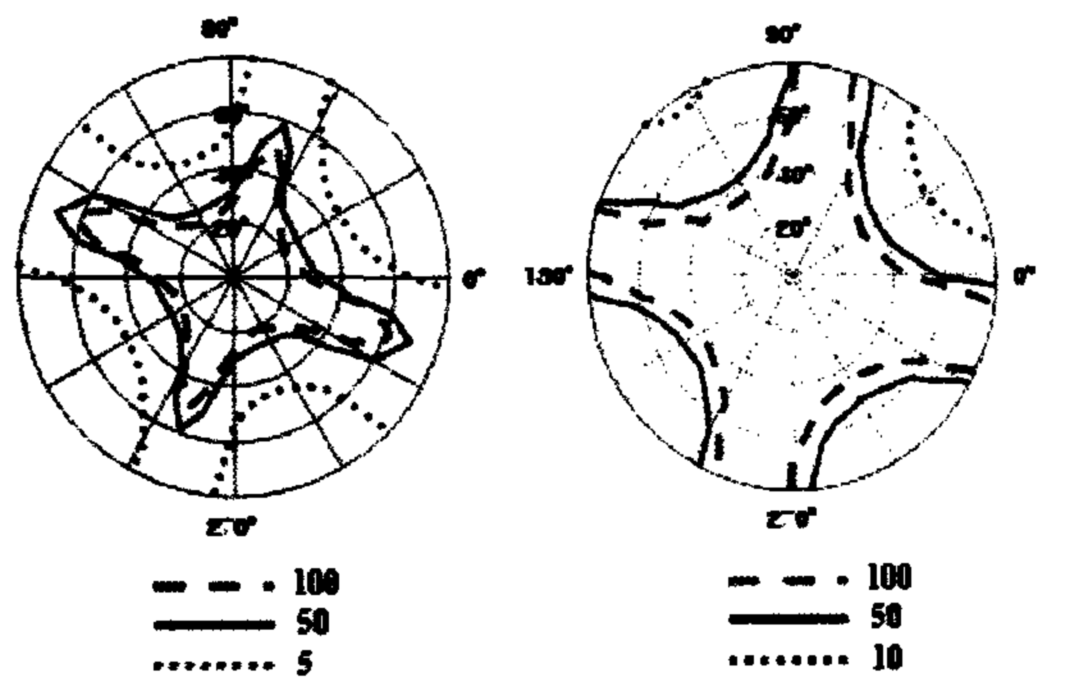


Figure 5 Calculated voltage-dependent reflectance and transmittance curves.



(a) (b)

Figure 6 Iso-contrast curves at a wavelength of 550nm: (a) R-area and (b) T-area.

3. Conclusion

We have proposed a novel single gap transflective display associated with a homogenous alignment to in-plane switching of the LC director, utilizing a different degree of rotation on the reflective and transmissive area. Owing to the in-plane orientation of the LC director, the device exhibits a wide viewing angle without the occurrence of a grey scale inversion over a wide range of viewing angles, in both the reflective and transmissive areas and can be generated with a single driving circuit since the threshold and driving voltages are the same for an optimized cell structure.

4. Acknowledgements

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5. References

[1] H-I. Baek, Y-B. Kim, K-S. Ha, D-G. Kim, S-B. Kwon, IDW'00, 41, (2000).

[2] T. Uesaka, E. Yoda, T. Ogasawara and T. Toyooka, IDW'02, 417, (2002).

[3] K. Fujimori, Y. Narutaki, Y. Itoh, N. Kimura, S. Mizushima, Y. Ishii and M. Hijikigawa, SID'02 Dig. 1382, (2002).

[4] S. H. Lee, S. L. Lee and H. Y. Kim, Appl. Phys. Lett., **73**, 2881, (1998).

[5] T. B. Jung, J. C. Kim and S. H. Lee, Jpn. J. Appl. Phys., **42**, 464, (2003).

[6] J. C. Kim, C. G. Jhun, K. H. Park, J. S. Gwag, S. H. Lee, G. D. Lee and T. H. Yoon, IMID'03, 283, (2003).

[7] M. Oh-e and K. Kondo, Appl. Phys. Lett., **67**, 3895, (1995).

[8] G. D. Lee, G. H. Kim, S. H. Moon, J. D. Noh, S. C. Kim, W. S. Park, T. H. Yoon, J. C. Kim, S. H. Hong and S. H. Lee, Jpn. J. Appl. Phys., **40**, 221,)2000).

[9] S. H. Lee, S. H. Hong, H. Y. Kim, D. S. Seo, G. D. Lee and T. H. Yoon, Jpn. J. Appl. Phys., **4**, 5334, (2001).

[10] C. Doornkamp, B. M. I. van der Zander, S. J. Roosendaal, L. W. G. Stofmeel, J. J. van Glabbeek, J. T. M. Osenga, and J. A. M. Steenbakkers, IDW'03, 685, (2003).

[11] A. Lien, Appl. Phys. Lett., **57**, 2767, (1990).