Zig-zag electrode pattern for high brightness in a super in-plane-switching liquid-crystal cell

Hyunchul Choi
Jun-ho Yeo (SID Student Member)
Gi-Dong Lee (SID Member)

Abstract — A novel electrode structure which can provide a high aperture ratio in a super in-plane-switching (S-IPS) liquid-crystal (LC) cell at high transmittance is proposed. To improve the aperture ratio of the S-IPS cell, a zig-zag electrode pattern was applied to the electrode edge in the active area that can effectively reduce the disclination area. In addition, a novel electrode structure was also applied to the bulk area which can reduce the cross-talk and light leakage between the pixel lines and the data lines. As a result, it was found that the proposed electrode structure could provide a higher aperture ratio than that of the conventional type by reducing the black matrix (BM) area so that a high transmittance compared to that of the conventional structure can be achieved.

Keywords — *IPS, LCD, electrode design, defect, aperture ratio.*

DOI # 10.1889/JSID17.10.827

1 Introduction

Recently, LCDs have been required to provide better electro-optical characteristics such as wide viewing angle and fast response time. In particular, horizontal-switching liquid-crystal (LC) modes such as the super in-plane-switching (S-IPS) mode[1] and the fringe-field-switching (FFS) mode[2] show high optical performance, including wide viewing angle and fast response time. Despite of their superior optical properties, optical transmittance of the S-IPS mode may be generally lower than the optical transmittance of the other LC modes such as the twisted-nematic (TN) and FFS modes because of their mechanical electrode structures and non-uniform retardation of the liquid-crystal cell due to different director profiles around the electrode. In general, the optical transmittance can be increased by optimizing the optical structure and the LC cell structure. However, an increase in the optical transmittance in the bright state can be more easily obtained by controlling the structure of the LC cell compared to controlling the optical configuration. In order to increase the optical transmittance, *Lin et al.* has proposed an electrode structure which can decrease the cross-talk over each line by controlling the thickness of the induced organic layer.[3,4]

In this paper, we propose a novel zig-zag pattern between the up and down electrodes for the edge area of the electrode, which can reduce the black-matrix (BM) area by moving the disclination to the far edge area of the S-IPS LCD. For the bulk area in the active area, we applied and optimized the electrode structure by using Lin's structure. We optimized the width and distance between each line in order to block the cross-talk between the pixel and the data lines. These can induce high optical transmittance compared to that of the conventional structure by reducing the required BM area. We calculated the director configuration of the S-IPS cell and the optical transmittance by using the *Q*-tensor method.[5–9]

2 Design of the electrode pattern for the bulk active area

Figures 1(a) and 1(b) show the conventional structure of the electrode and calculated optical intensity. The LC material with positive dielectric anisotropy (Δn = 0.0846 at λ = 589 nm and $\Delta\varepsilon$ = 8.4) was used in our experiments and simulations. The thickness of the dielectric layer is set to 3 μm and the cell gap is set to 3.4 μm. The width of the data line and the common line are set to 10 and 25 μm, respectively. The width of the pixel line is set to 3.4 μm. Voltages of 14.8 and 7 V were applied to the data line and the common line, respectively, for operation. In addition, 13.8 and 6 V were applied to the pixel line for the bright state and dark state,

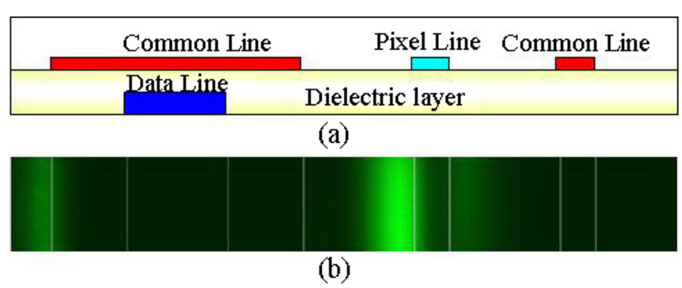

FIGURE 1 — Light leakage due to crosstalk in the conventional IPS LC cell in the dark state: (a) the electrode structure, (b) calculated optical transmittance in the dark state.

Revised extended version of a paper presented at the 28th International Display Research Conference (IDRC '08) held November 4–6, 2008, in Orlando, Florida, U.S.A.

H. Choi is with LG Display, Kyungbuk-do, Korea.

J-H. Yeo and G-D. Lee are with Dong-A University, Electronics Engineering, 840 Hadan2-Dong, Saha-Gu, Busan, 604-714, Korea; telephone +82-51-200-7704, fax –7712, e-mail: gdlee@dau.ac.kr.

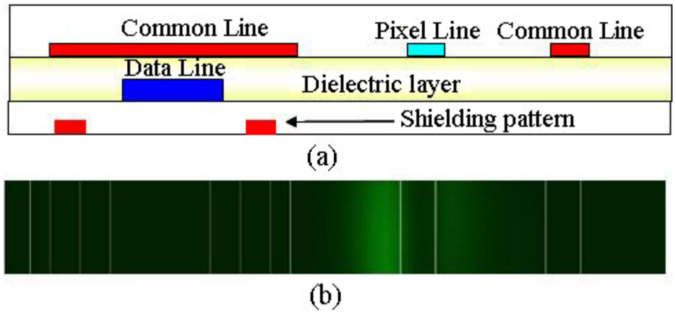

FIGURE 2 — Improved light leakage by using the proposed electrode structure for bulk active areas: (a) the electrode structure, (b) calculated optical transmittance in the dark state.

respectively. The conventional structure of the electrode exhibits serious light leakage between the data line and the common line as shown in Fig. 1(b). Therefore, we normally use the BM layer in order to block the light leakage. As for the conventional LC cell, the required width of the BM was calculated to be 36 μm for blocking the light leakage.

Figure 2(a) shows the novel structure of the electrode by introducing shielding patterns in another organic layer proposed by Lin.[3] Lin who had shown that the crosstalk can be effectively reduced by controlling the thickness of the organic layer in the proposed structure. However, it is not sufficient to prevent the cross-talk because they did not optimize the electrode structure in the cell. In order to complete the optimization that can decrease the BM area and the light leakage between the data line and the pixel, we inspected the optical characteristics of the LC cell regarding the cross-talk as functions of the width of the common line, the shielding pattern, and the pixel line. The width and depth of each electrode of the proposed structure are the same as for the conventional structure. Instead, 7 V was applied to the shielding pattern.

In order to optimize the proposed electrode structure, we observed the cross-talk and light leakage of the LC cell by changing each parameter as shown in Table 1 so that we could optimize the three parameters including the width of the common line, the shielding pattern, and the distance between the data line and shielding pattern. In the Table 1, condition *ref.* represents the conventional structure and the condition number represents the combination of conditions of the three parameters, which are the width of the common line, the width of the shielding pattern, and the distance between the data line and shielding pattern, to calculate the luminance in the dark state, the capacitance between the data line and the pixel line, and the luminance ratio of the white and the black states.

TABLE 1 — Observation conditions for inspecting the cross-talk as functions of three parameters which are the width of the common line, the shielding pattern, and the distance between the data line and shielding pattern.

Conditions	*Ref.*	1	2	3	4	5	6	7	8	9	10	11
Width of the common line	25	24	26	26	28	26	28	28	30	28	30	30
Width of the shielding pattern		3	3	3	3	4	4	4	4	5	5	5
Distance between data line and shielding pattern		2	2	3	3	2	2	3	3	2	2	3

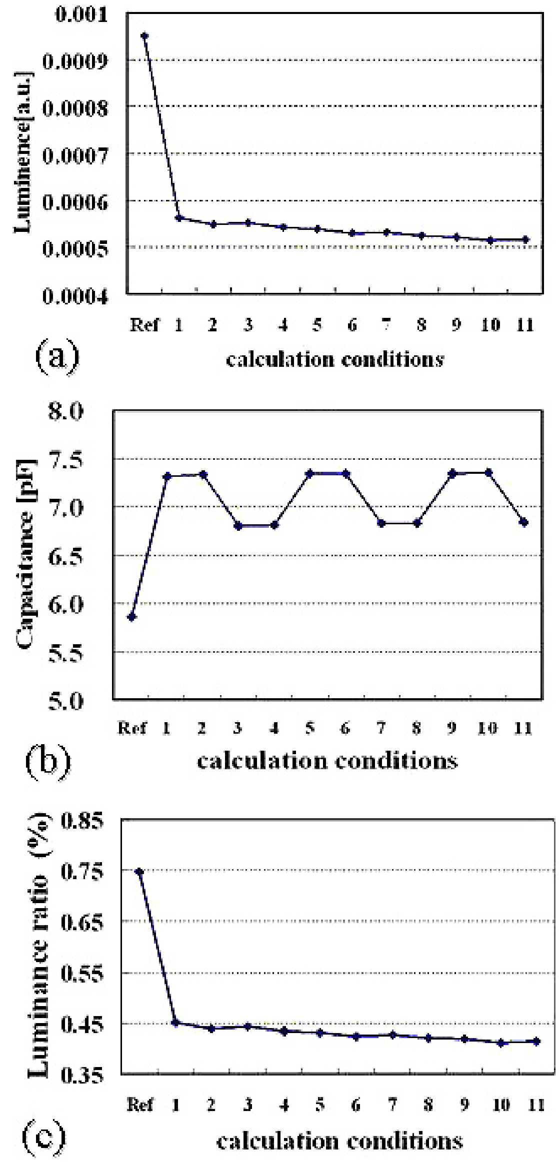

FIGURE 3 — Calculated electro-optical properties related to the cross-talk: (a) light luminance in the dark state, (b) capacitance between the data line and the pixel line, (c) luminance ratio of the white and the black state.

Optimization of the width of the electrodes has been performed by evaluating the three electro-optical properties related to the cross-talk and the light leakage, which are light luminance in the dark state, capacitance between the data line and the pixel line, and the luminance ratio of the white and the black states by using the software TechWiz LCD (developed by Sanayi system, Korea). From the calculation of the three electro-optical properties, we can optimize the electrode structure by selecting the condition that has a low value of the three electro-optical properties which implies little cross-talk and light leakage.

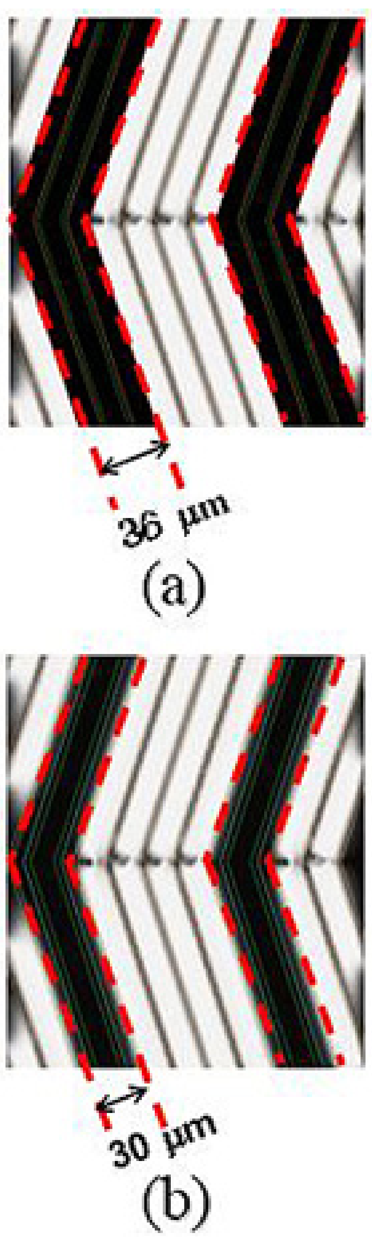

FIGURE 4 — Comparison of the calculated optical intensity between the conventional LC cell and the proposed LC cell: (a) the calculated optical intensity of the conventional LC cell, (b) the calculated optical intensity of the proposed LC cell. Dashed lines imply the required BM area for blocking the light leakage.

Figure 3 shows the calculated results in each condition listed in Table 1. In Fig. 3, we can observe that the shielding electrode effectively blocks the cross-talk and light leakage compared to that of the conventional structure. In particular, we can also observe that large width of the common electrode and shielding pattern, and the large distance between the data line and shielding line can reduce the cross-talk and light leakage as shown in Fig. 3. Therefore, the optimized condition of the electrode structure can be obtained by applying 30 μm of the width of the common line, 5 μm of the width of the shielding pattern, and 3 μm of the distance between data line and shielding pattern from the results of the Fig. 3. Figure 2(b) shows the calculated light intensity of the IPS LC cell with the optimized electrode structure in the bulk active area. By comparing the light leakage between Figs. 2(b) and 1(b), we can confirm that the light leakage of the IPS LC cell can be effectively reduced by applying the optimized structure. Figure 4 shows a comparison between the optical intensity of the Super IPS LC cell between the conventional structure and the optimized proposed structure. In Fig. 4, we could recognize that the required width of the BM can be reduced to 30 μm from 36 μm by applying the optimized proposed LC structure so that the optical transmittance increased to 4.3% by calculation in the single-dot area.

3 Design of the electrode pattern for edge area

In general, S-IPS LC cells can store high strain energy in a very small area at the edge of the electrode, so we can observe intrinsic unstable dynamic behavior of the LC director around the edge of the electrode. Therefore, the instability of the LC director around the edge causes disclination on the edge of the electrode, and we need to reduce the disclination area that requires cover by using the BM. Figures 5(a) and 5(c) show the conventional shape of the electrode edge in the super IPS LC cell and the optical intensity,

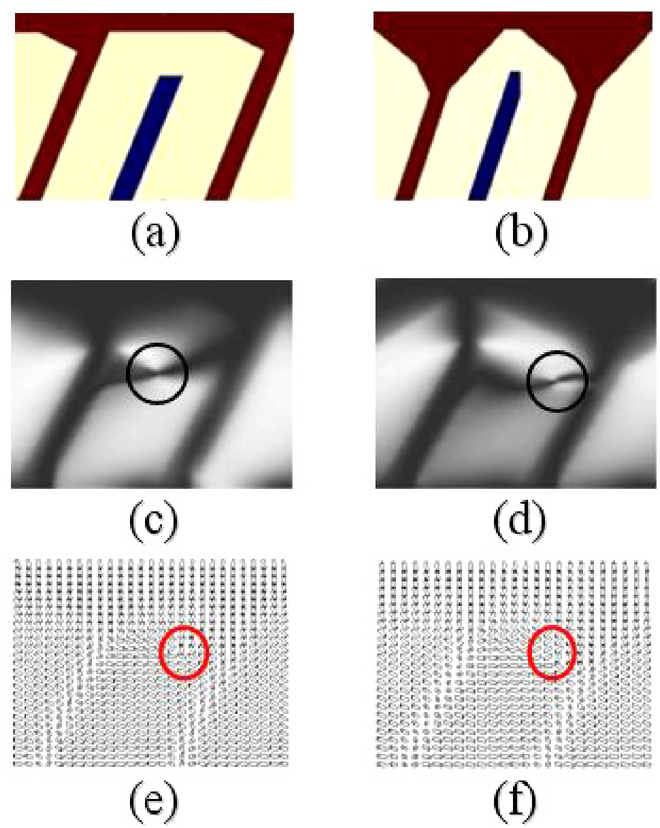

FIGURE 5 — The shape of the electrode edge and the calculated optical transmittance: (a) the conventional structure, (b) the proposed structure, (c) the optical transmittance of the conventional structure, (d) the optical transmittance of proposed structure, (e) the calculated director profile around the edge of the conventional electrode, and (f) the calculated director profile around the edge of the proposed electrode.

respectively. In Fig. 5(c), the solid circle shows the generated defect around the edge. In order to block the non-uniform light intensity, another BM is needed around the edge.

In order to reduce the required BM area for the edge electrode, we optimized the shape of the electrode edge as shown in Fig. 5(b). The optimized edge structure applies the alternative peak to the valley structure between the up and down electrodes. This structure can permit the zig-zag pattern between the up and down electrodes so that we can reduce the required BM area. In addition, the optimized shape of the electrode edge permits the generated disclination on the edge to move to the far edge area of the electrode in the pixel so that it will also help the required BM area to be reduced. Figure 5(d) shows the optical intensity of the S-IPS LC cell with proposed shape of the edge electrode as shown in Fig. 5(b). A solid circle in the figure shows the calculated defect area. Compared to the conventional structure, the generated defect of the proposed structure gets closer to the electrode edge. Figures 5(e) and 5(f) shows the calculated LC director profiles, including the defects around the edge area of the conventional and the proposed electrode. The shape of the edge electrode makes non-uniform potential distribution when we apply the voltage, so that defects can occur around the edge. The solid lines in Figs. 5(e) and 5(f) show the generated defects around the edge electrode due to the applied voltage.

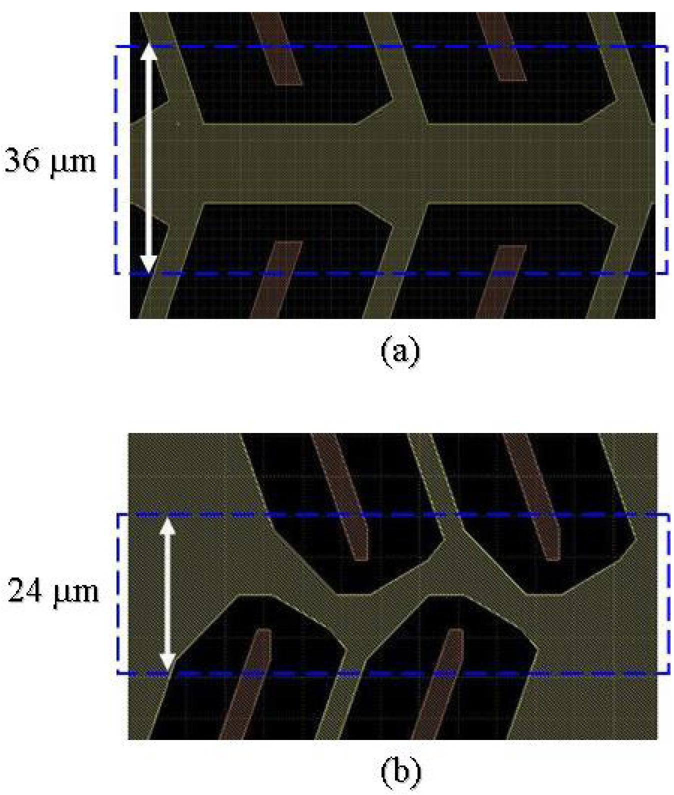

FIGURE 6 — The structure of the electrode of the edge: (a) the conventional pattern, (b) the proposed zig-zag electrode pattern. The rectangular area with the blue line represents the required area for covering disclination. Dashed rectangle represents the required BM area.

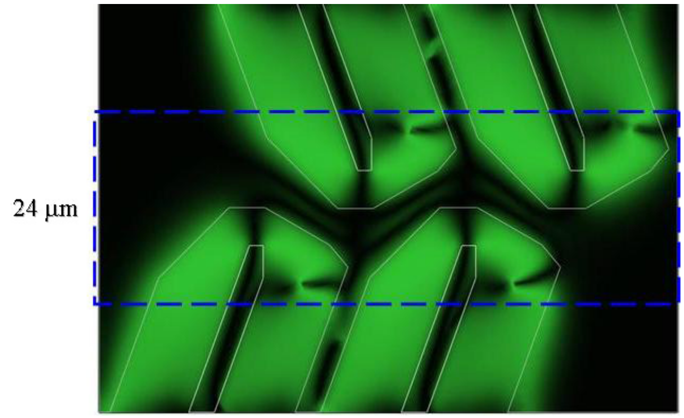

FIGURE 7 — Calculated optical intensity on the proposed electrode pattern. Dashed rectangle represents the required BM area.

The calculation for the optical characteristic of the proposed electrode and the conventional structure was performed by using the *Q*-tensor method instead of the vector method because of the calculation of the LC director field with disclinations around the edge of the electrode.[5–9]

By using the electrode pattern as shown in Fig. 5(b), we designed a zig-zag electrode pattern which can reduce the BM area as shown in Fig. 6. Figure 6(a) shows the conventional electrode around the edge that should keep the 36 μm of the BM height in order to block the disclination and cross-talk between the up and down active area. By using the zig-zag electrode pattern as shown in Fig. 6(b), however, we could reduce the BM height to 24 μm. The calculated area between the up and down active area is considered to be cross-talk free. Figure 7 shows the calculated optical intensity of the S-IPS LC cell with the proposed edge-electrode pattern. As a result, the calculated optical intensity of the proposed edge structure increased 35% compared to that of the conventional structure in the single-dot area.

4 Conclusions

We propose a novel electrode pattern for both the bulk and edge area in the S-IPS LCcell in order to increase the aperture ratio and the optical transmittance. We optimized the electrode structure with a shielding pattern as well as data and common lines in the bulk active area by inspecting the electro-optic characteristics. In addition, we also proposed a zig-zag electrode pattern on the edge area in the S-IPS LC cell that can effectively reduce the required BM area. From the calculation, we found that the active area can be increased to about 35% compared to that of the conventional structure by reducing the required BM area which blocks the disclination area.

Acknowledgment

This study was supported by research funds from Dong-A University.

References

1 M. Oh-e and K. Kondo, "Electro-optical characteristics and switching behavior of the in-plane switching mode," *Appl. Phys. Lett.* **67**, 3895 (1995).

2 S. H. Lee *et al.*, "Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching," *Appl. Phys. Lett.* **73**, 2881 (1998).

3 J.-S. Lin *et al.*, "High transmittance pixel- and common-electrode structures design for in-plane switching mode with low crosstalk," *Jpn. J. Appl. Phys.* **43**, 4276 (2004).

4 J.-S. Lin *et al.*, "A high-aperture-ratio and low-crosstalk pixel structure design for in-plane-switching-mode TFT-LCDs," *J. Soc. Info. Display* **12**, 533 (2004).

5 P. G. de Gennes and J. Prost, *The Physics of Liquid Crystals,* 2nd edn. (Clarendon Press, Oxford, 1993), pp. 166–168.

6 H. Mori *et al.*, "Multidimensional director modeling using the Q tensor representation in a liquid crystal cell and its application to the π cell with patterned electrodes," *Jpn. J. Appl. Phys.* **38**, 135 (1999).

7 J. H. Lee *et al.*, "Static configuration of the super in-plane switching liquid crystal director on the electrode," *ILCC '06,* MODLP-48 (2006).

8 G.-D. Lee *et al.*, "Fast Q-tensor method for modeling the dynamics of defects in a liquid crystal director field," *Phys. Rev. E* **67**, 041715 (2003).

9 H.-C. Choi *et al.*, "Improvement of IPS mode structure using the fast Q-tensor method," *IMID/IDMC '06,* 1597 (2006).