Japanese Journal of Applied Physics
Vol. 45, No. 2A, 2006, pp. 883–886

Dynamic Stability of Disclination Lines in Fringe-Field Switching Mode with a Wedge-Shaped Common Electrode

Mi Sook KIM[1,2*], Seung Min SEEN[1], Youn Hak JEONG[1,2], Hyang Yul KIM[1], Seo Yoon KIM[1], Young Jin LIM[1] and Seung Hee LEE[2]

[1]*SBU Development Center, BOE_TFT_LCD_SBU, San 136-1, Ami-ri, Bubal-eup, Ichon-si, Kyungki-do 467-701, Korea*
[2]*School of Advanced Materials Engineering, Chonbuk National University, Chonju-si, Chonbuk 561-756, Korea*

(Received July 1, 2005; accepted November 10, 2005; published online February 8, 2006)

We investigated the dynamic stability of disclination lines (DLs) generated near pixel edges for fringe-field switching (FFS) mode with a wedged shape common electrode. Actually, in the FFS mode with a liquid crystal (LC) of positive dielectric anisotropy, the LC dynamic is very unstable near pixel edges. There are strong field competitions between the adjacent active region and the pixel edge with a patterned slit at a bias voltage so that DLs are observed at the boundary. A reverse twist force near the pixel edges is strong at a high voltage and pushes DLs into the active region, resulting in a decreased transmittance in the panel. Thus, to solve this problem, another force is needed to make DLs remain near the pixel edges. In this study, we proposed an advanced FFS structure with a wedge-shaped common electrode. This structure produces a strong horizontal electric field due to the wedge-shaped common electrode extended near the data bus line. As a result, it can reduce portions of the reverse twist force in the panel and make DLs remain near the pixel edges. Also, it eliminates the distortion of pixel and data signals preventing the complete extension of a common electrode through the use of a wedge-shaped electrode.
[DOI: 10.1143/JJAP.45.883]

KEYWORDS: dynamic stability, disclination line, horizontal electric field

1. Introduction

Recently, many types of liquid crystal displays (LCDs) that have their own unique properties have been proposed and developed. The most common wide viewing LCDs are the LC modes such as in-plane switching (IPS)[1,2] and fringe-field switching (FFS) modes,[3–5] where the LC director rotates almost in plane.

The IPS mode driven by in-plane switching has a advantages such as a wide viewing angle, however, it has an intrinsically low transmittance because the LCs at the center of the pixel electrode do not rotate. To solve the problem, FFS mode driven by the fringe electric field has been proposed. FFS mode has good electro-optic characteristics such as a high transmittance and a wide viewing angle. In this FFS mode, we must consider the LC dynamic stability near pixel edges. Actually, the electric field direction near the edge of a pixel with a slit pattern is different from that in a main active area. Consequently, the LCs near the edge of a pixel and in the main active area do not rotate in the same direction at the applied voltage, thus, the LCs collide with each other with bias voltage and then the reverse twist regions appear. In the reverse twist regions, the LCs have a different orientation compared with neighboring active LCs, so that the disclination lines (DLs) are formed at the boundary.[6] The stability of DLs also depends on the dielectric anisotropy of the LCs and the applied voltage.[7] Particularly, when using the LC with positive dielectric anisotropy, DLs become unstable at a high applied voltage and deeply permeate into the main active area. Therefore, it needs another force to make DLs remain near the pixel edge even if a high voltage or an external pressure is applied. Actually, DLs have dynamic stability when the horizontal electric field generated between the data bus line and common electrode is larger than that of the reverse twist field. Moreover, the horizontal field increases as the distance between them decreases. However, there is a limit as how close a common electrode can get to the data line with the alternating voltage due to the RC delay of data and pixel signals. To overcoming these problems, we proposed an advanced FFS structure with a wedge-shaped common electrode, for which only the common electrode near the pixel edges producing the reverse twist region extends to the data signal, causing the load in the panel to decrease by one-half compared with the complete extension of the common electrode. Moreover, it obtains a dynamic stability of DLs near the pixel edges due to the wedge-shaped common electrode that extended to the data line. In this study, we observed the dynamic stability of DLs near the pixel edges and the electro-optic properties for the advanced FFS structure through three-dimensional simulations.

2. Experiment and Simulational Results

Figure 1 shows the side view of the FFS mode with a fringe field line. In the structure, the electrodes exist only on the bottom substrate. The common electrode exists in a plane form with the passivation layer. The pixel electrode with patterned slits has with a width (w) of 3 μm and a distance (l') of 5 μm between them. Liquid crystal with physical properties ($\Delta n = 0.098$ at $\lambda = 589$ nm, $\Delta\varepsilon = 8.2$), was used for the experiment and simulation. Here, the strong anchoring of LC to the surface is assumed. The surface pretilt angle for both substrates is 2°, the initial rubbing angle is 0° with respect to the horizontal component (E_x) of the fringe electric field and the cell gap (d) is 3.6 μm.

First, we observed the inner panel after a high voltage was applied for analyzing LCs having unstable dynamic properties near the pixel edge in the FFS mode. As shown in Fig. 2, DLs occur at the operation voltage (V_{op}) of approximately 4 V, Furthermore, unstable DLs extend into the main active region at the high applied voltage of 5.5 V. Actually, there were the field competitions near the V_{op}. Moreover, the unstable force that generated the reverse twist near the pixel edge was larger than the twist force near an adjacent active

*E-mail address: misuk7287@boehydis.com

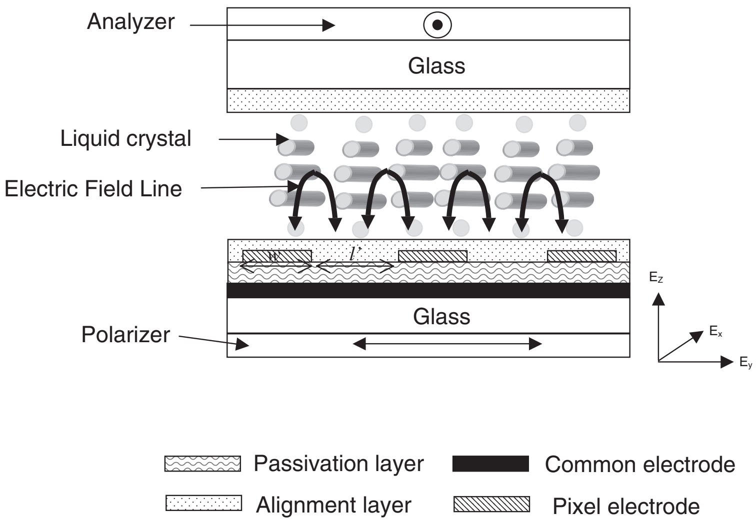
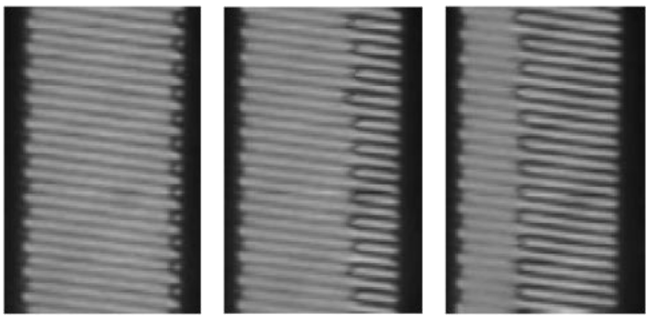


Fig. 1. Schematic diagram of the side view in the FFS mode.

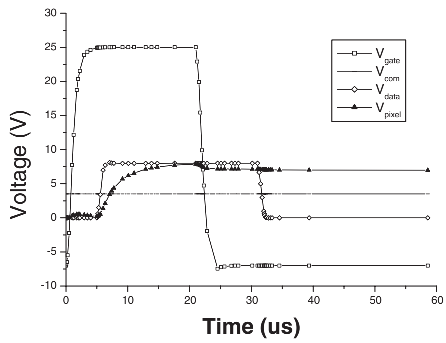


(a) (b) (c)

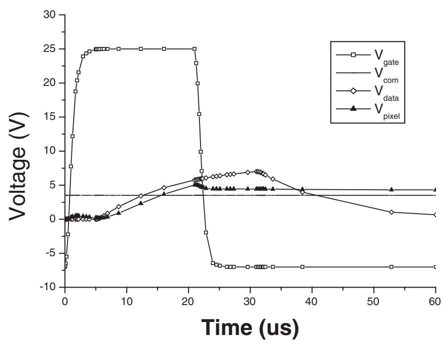
Fig. 2. Transmittance in panel according to applied voltage: (a) 4, (b) 4.8, and (c) 5.5 V.

area at a high voltage. As a result, DLs were deeply pushed into the main active areas. At that time, if another force existed to make the DLs remain near the pixel edge, we could have reduced the portion of the reverse twist force in the panel and obtained a dynamic stability of the DLs. This is possible through use of a strong horizontal electric composition (E_x), such as the electric field induced between the data bus line and common electrode. The horizontal field increases as the horizontal distance between the common electrode and data line decreases. However, there are limits as to how close the common electrode can get to the data line with an alternating signal. If the common electrode is very close to or overlaps to the data bus line for the horizontal field, data and pixel signal delay occurs in the panel and there is distortion of their signals.

Figures 3(a) and 3(b) show time-dependent signal variation of the gate, data, common and pixel electrode before and after the whole extension of the common electrode near the data line in the pixel. As has been shown, the gate voltage of 20 V is applied for the initial 20 μs and the applied data voltage with alternating signal is changed to 0 and 8 V before the whole extension of the common electrode, whereas it is only changed to 0 and 5 V after the whole extension of the common electrode, a similar behavior is seen in pixel electrodes. It shows that data and pixel signal delays occur in the panel when the common electrode is very



(a)



(b)

Fig. 3. Calculated results of time-dependent signal variations before and after whole extension of common electrode in pixel: (a) before whole extension of common electrode, and (b) after whole extension of common electrode.

close to the data line with alternating signal, causing their signals to distort, as shown in Fig. 3(b). This phenomenon is notable for medium or large applications such as monitors or television products. Therefore, it is impossible to extend the whole common electrode near the data line for the strong horizontal field near the pixel edge. For preventing the distortion of signals in the panel and maintaining the strong field near the pixel edge, we proposed the advanced FFS structure with a wedge-shaped common electrode, as shown in Fig 4. Here, only the common electrode near the pixel edge producing the reverse twist is enlarged near the data

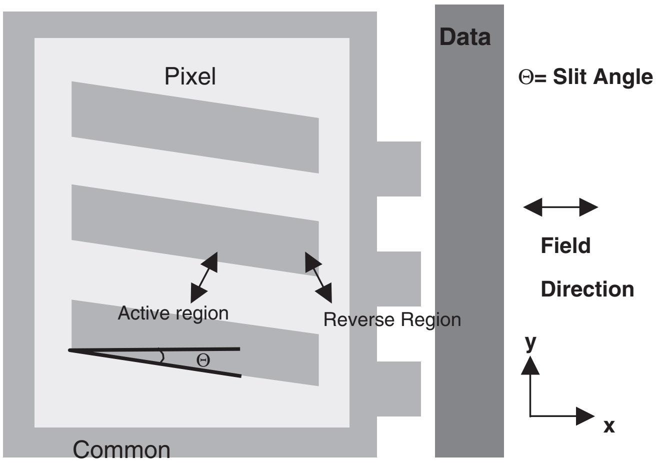


Fig. 4. Schematic diagram of top view in the advanced FFS structure with a wedge-shaped common electrode.

line so that the common electrode has a wedge shape. The slit angle of the pixel electrode (θ) is 7°.

For the detailed analysis of the horizontal electric field affecting the DL dynamic stability in this structure, we performed a computer simulation. For the simulation, we used the commercially available software "Techwiz LCD" (Sanayi System, Korea), where the motion of the LC director is calculated basis of the Eriksen–Leslie theory and the 2×2 Jones matrix[8] is applied for optical transmittance calculation.

Figures 5(a) and 5(b) represent the simulation transmittances of a conventional structure without a wedge-shaped common electrode and an advanced structure with a wedge-shaped common electrode, respectively. As shown in Fig. 5, the structure with a wedge-shaped common electrode that extended to the data line barely generates transmittance by the reverse twist domain compared with the conventional structure at V_{op}. Moreover, the DLs do not permeate into the active region unlike the conventional structure. It shows that LC dynamic stability near the pixel edge of the advanced structure is better than that of the conventional structure.

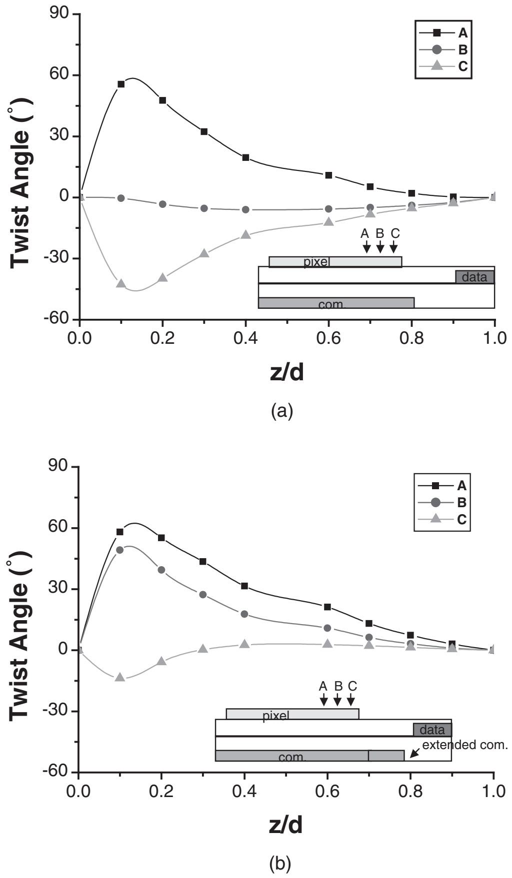


Fig. 6. LC director profile according to shape of common electrode: (a) without a wedge-shaped common electrode, and (b) with a wedge-shaped common electrode.

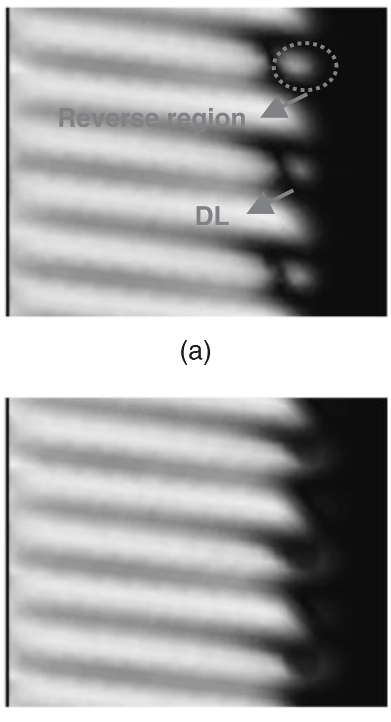


Fig. 5. Calculated transmittance according to shape of common electrode: (a) without a wedge-shaped common electrode, and (b) with a wedge-shaped common electrode.

Next, we observed the profile of the LC director for the different structures for the detail analysis of LC dynamic stability. Figures 6(a) and 6(b) show the twist angle of the LC for the structures without and those with a wedge-shaped common electrode along the vertical axis in the *z*-direction, respectively. Here, A, B, and C represent simulation positions for analyzing the LC dynamic stabilities and they are 10, 8, and 6 µm from the data bus line, respectively. The distance between the common electrode and the data line for the conventional structure is 5 µm, the distance between the extended common electrode and the data bus line for the advanced structure is 1 µm. In the case of the conventional structure, LC in the A position twists by 60° near $z/d = 0.1$. LC in the B position barely twists, where the dark DLs exist. LC in the C position reverse twists by $-45°$ near $z/d = 0.1$. This shows that there are strong field competitions between the adjacent active area and pixel edge so that the DLs exhibit at the boundary. On the other hand, in the advanced structure with a wedge-shaped common electrode, LC in the A and B positions twists more than 45° near $z/d = 0.1$.

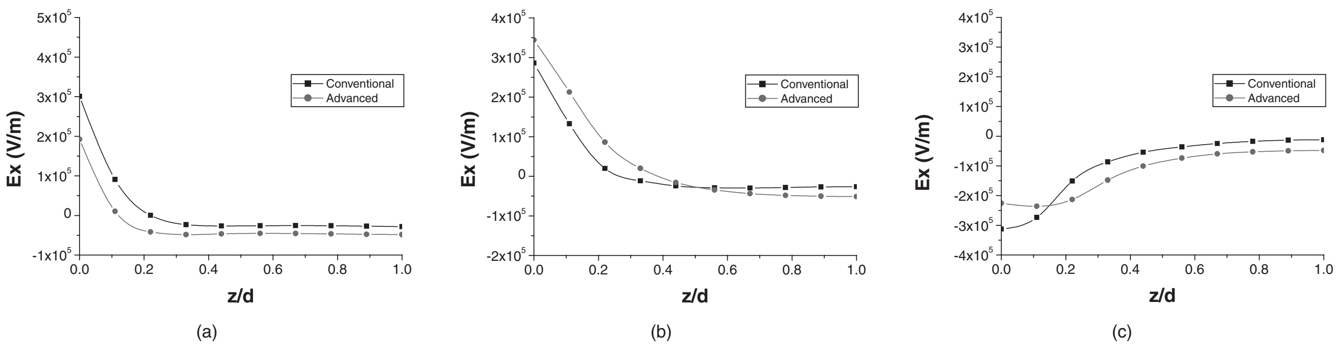


Fig. 7. Distribution of horizontal electric field according to shape of common electrode: (a) A position, (b) B position, (c) C position.

Moreover, the LC in the C position reverse twists approximately -15° near $z/d = 0.1$. This shows that the reverse twist force for the advanced structure is less than that for the conventional one, therefore, DL dynamic near the pixel edge is very stable and DLs remain near the pixel edge.

Next, we analyzed the horizontal component of the fringe electric field with respect to the *x*-axis at the simulation positions. Figures 7(a)–7(c) show the horizontal electric field along the vertical axis with respect to the *z*-direction at A, B, and C positions, respectively. As shown, the horizontal electric field for the advanced structure is larger than that for the conventional one except for the A position, which is a remote distance from the data line. Therefore, we find that the dynamic stability of DLs for the advanced structure with a wedge-shaped common electrode is excellent.

3. Conclusions

We investigated the dynamic stability of DLs generated near the pixel edge for the FFS mode with a wedge-shaped common electrode. Near the pixel edge, there are field competitions between an adjacent active region and the pixel edge with a patterned slit at the V_{op} so that DLs are formed. The reverse twist force near the pixel edge is strong at a high voltage, causing the DLs to be pushed into the active area. As a result, the transmittance in the panel decreases. To solve this problem, another force is needed to make the DLs remain near the pixel edge even if a high voltage is applied. In this study, we proposed an advanced FFS structure with a wedge-shaped common electrode. This structure produces a strong horizontal electric field due to the wedge-shaped common electrode enlarged near the data bus line. The field decreases the portion of the reverse twist force in the panel and maintains DLs near the pixel edges. Therefore, DLs near a pixel edge have dynamic stability.

Also, because only the common electrode near the pixel edge generating the reverse twist region extends to the data signal in this structure, the load in the panel decreases by one-half compared with the complete extension of the common electrode, thus it prevents the distortion of pixel and data signals.

1) S.-K Lee, Y. H. Jeung and D. S. Seo: Trans. EEM **4** (2003) 7.
2) H. Y. Kim, I. S. Song and S. H. Lee: Trans. EEM **4** (2003) 24.
3) S. H. Lee, S. L. Lee and H. Y. Kim: Appl. Phys. Lett. **73** (1998) 2881.
4) S. H. Hong, I. C. Park, H. Y. Kim and S. H. Lee: Jpn. J. Appl. Phys. **39** (2000) L527.
5) H. Y. Kim, S. H. Hong, J. M. Rhee and S. H. Lee: Liq. Cryst. **30** (2003) 1287.
6) M. S. Kim, Y. H. Jung, S. M. Seen, H. Y. Kim, S. Y. Kim, Y. J. Lim and S. H. Lee: Jpn. J. Appl. Phys. **44** (2005) 3121.
7) H. Y. Kim, S. H. Nam and S. H. Lee: Jpn. J. Appl. Phys. **42** (2003) 2752.
8) A. Lien: Appl. Phys. Lett. **57** (1990) 2767.