Japanese Journal of Applied Physics
Vol. 45, No. 3A, 2006, pp. 1749–1751

Brief Communication

Study on Reverse Twist Depending on Rubbing Direction for Fringe-Field Switching Mode

Mi Sook KIM[1,2*], Youn Hak JEONG[1,2], Seung Min SEEN[1], 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 September 8, 2005; accepted November 28, 2005; published online March 8, 2006)

We studied the reverse twist near the pixel edge depending on the rubbing direction for the fringe-field switching (FFS) mode. At the active region, liquid crystal (LC) dynamics and transmittance are the same, irrespective of the rubbing direction, that is, clockwise or counterclockwise with respect to the x-axis, because only one electric field direction exists. On the other hand, LC dynamics and transmittance near the pixel edge, where various field directions are generated, depend on the initial rubbing direction because the position of the reverse twist is decided by the angle between the electric field direction and LC director under a bias voltage. For example, when the rubbing angle is 7°, the reverse twist appears at the bottom of the right sharp corner of the pixel edge so that the reverse region exists far from main active region. However, when the rubbing angle is −7°, the reverse twist appears on top of the right sharp corner of the pixel edge, resulting in the region becoming closer to the main active area and the unstable disclination lines (DLs) easily intruding into the active region. Therefore, it is necessary to keep the reverse twist region far from the active region and this is possible by controlling the rubbing direction in the design of a pixel electrode. As a result, we can minimize the permeation of DLs into the main active region.
[DOI: 10.1143/JJAP.45.1749]

KEYWORDS: reverse twist, disclination lines, dynamic stability

Presently, many types of liquid crystal display (LCD) that are based on their own unique fundamentals have been proposed and developed. The most common wide-viewing type includes the LC modes such as the in-plane switching (IPS) mode[1,2)] and fringe-field switching (FFS) mode,[3–5)] where the LC director rotates almost in plane.

The IPS mode driven by this in-plane switching has the merits, such as a wide viewing angle, but intrinsically has a low transmittance. On the other hand, the FFS mode driven by the fringe electric field has good electrooptic characteristics such as a high transmittance and a wide viewing angle because LCs at the center of the pixel electrode rotate. When using LCs with positive dielectric anisotropy in the FFS mode, we must consider the acute angle between the electric field (E_y) and the rubbing direction in the active region because LCs rotate only to the electric field. In this case the clockwise or counterclockwise of the rubbing direction owing to the same transmittance and LC dynamics is not a concern.

Here, clockwise and counterclockwise indicate the position in the top and bottom directions with respect to the x-axis, respectively. However, the electric field directions near the edge of a pixel with a patterned slit are several and they are different from those in a main active area. Thus, LCs near the edge of a pixel and in the main active area do not rotate in the same direction at an applied voltage, so that LCs collide with each other under a bias voltage and then the reverse twist appears. In reverse twist regions, LCs have different orientation from those of neighboring active LCs, so that disclination lines (DLs) are formed at the boundary.[6)] Unstable DLs deeply permeate into an active region at a high applied voltage. Therefore, it is very important to decrease the area of the reverse twist region or keep it far from the main active area in the panel design. Indeed, the reverse twist depends on the rubbing direction, that is, clockwise or counterclockwise, because the reverse twist region is decided by the angle between rubbing direction and different electric fields compared with the active region in which the slit angle is 0°. That is, the position of the reverse twist region changes depending on the rubbing direction, although the rubbing angle remains the same. Consequently, rubbing direction has greatly affected on the dynamic stability of LCs near the pixel edge. In this study, we compared and analyzed the dynamic stability of DLs according to the rubbing direction by three-dimensional simulation in the FFS mode.

Figure 1 shows the top view of the FFS mode in both the off state and the on state. In the structure, the electrodes exist only on the bottom substrate. The common electrode exists in the plane form with a passivation layer. Then, the pixel electrode with a patterned slit between them exists with a width (w) of 3 µm and a distance (l') with 5 µm. LC with physical property ($\Delta n = 0.098$ at $\lambda = 589$ nm, $\Delta\varepsilon = 8.2$), was used for simulation. The initial rubbing angle (θ) is 7° with respect to the horizontal component (E_x) of the fringe electric field. The surface pretilt angle for both substrates is 2° and the cell gap (d) is 4 µm. In this case, there is an acute angle between the electric field and rubbing direction for the rotation of LCs only to the electric field. Here, transmittance at the main active region is the same irrespective of the initial rubbing direction, that is, clockwise or counterclockwise with respect to the electric field (E_x) because transmittance is decided by the angle between LC directors twisted by the electric field and the polarizer axis; so do LC dynamics. On the other hand, both transmittance and LC dynamics according to the rubbing direction are different at the pixel edge. Electric fields near the pixel edge are different from those at the active region because various electric directions exist owing to the patterned slit electrode near the pixel edge, as shown in Fig. 1. Thus, LCs near the pixel edge and in the main active area do not rotate in the same direction at applied the voltage, so that LCs collide with each other under a bias voltage and then the reverse twist appears. Consequently, LCs near the pixel edge have unstable dynamics and DLs existing at the boundary intrude into the main active region. Therefore, it is very important to

*E-mail address: misuk7287@boehydis.com

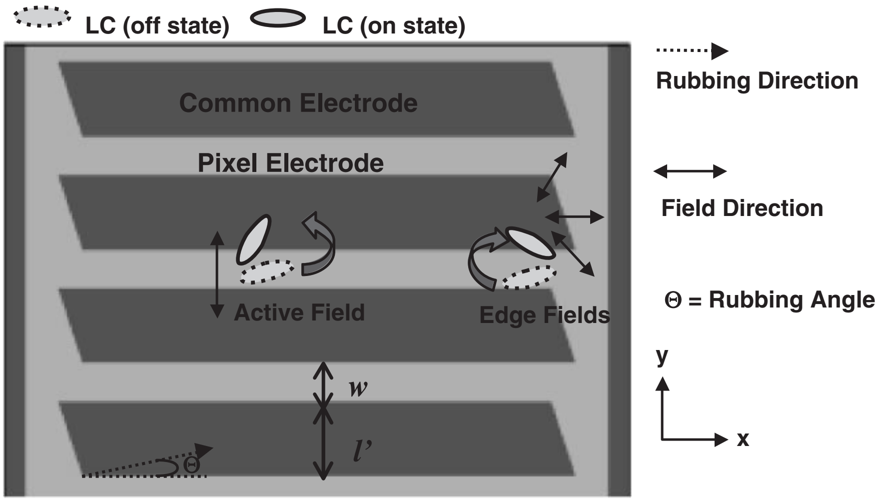


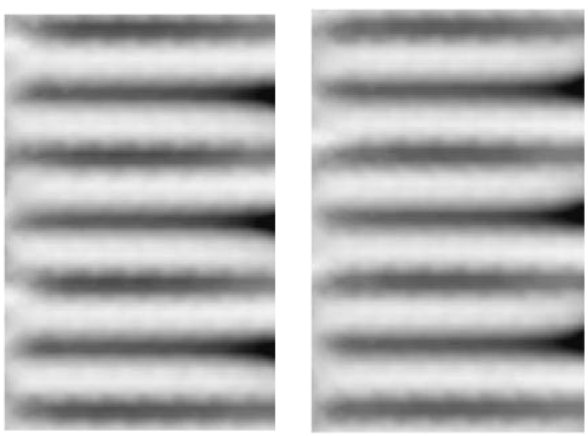
Fig. 1. Schematic diagram of the top view in the FFS mode.

reduce the reverse twist region near the pixel edge or keep it far from the active region. This is possible by controlling the rubbing direction for the FFS mode.

To analyze this phenomenon in detail, we performed a computer simulation. For the simulation, we used commercially available software "Techwiz LCD" (Sanayi System, Korea), where the motion of the LC director is calculated on the basis of the Eriksen-Leslie theory, and the 2×2 Jones matrix[7)] is applied for optical transmittance calculation.

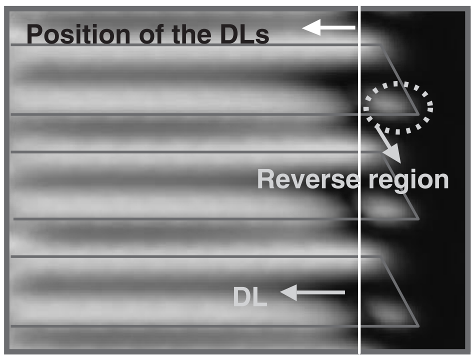
First, we observed transmittance change according to the rubbing direction in the active region. Figure 2 shows the calculated transmittance according to the rubbing direction at a bias voltage. The rubbing angles (θ) in the Figs. 2(a) and 2(b), are 7 and -7° with respect to the x-axis of the electric field, respectively. As shown, the transmittance results at the active region are the same, irrespective of the rubbing direction, that is, clockwise or counterclockwise. It indicates that transmittance for the FFS mode with the in-plane rotation of LCs, is proportional to the angle between the LC director and polarizer axis, irrespective of the rotation direction of the LC owing to the presence of only one field direction at the active area. On the other hand, the transmittance result near the pixel edge with the several field directions is not the same as that in the main active region.

Figure 3 shows the transmittance results according to the rubbing direction near the pixel edge. Here, the white line indicates the position of DLs. When the rubbing angle is 7°, the reverse twist region appears at the bottom of the right sharp corner at the pixel edge, as shown in Fig. 3(a). However, when the rubbing angle is -7°, the reverse twist region exists on top of the right corner at the pixel edge, as shown in Fig. 3(b). It shows that the position of the reverse twist is different when the rubbing direction changes owing

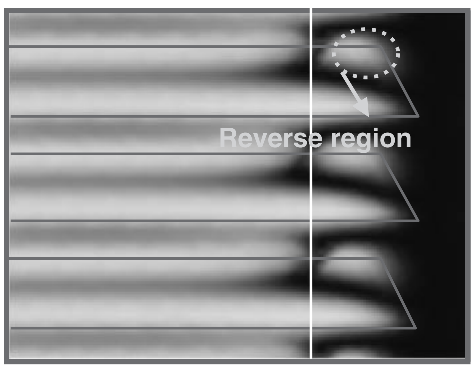


(a) (b)

Fig. 2. Transmittance according to the rubbing direction at the active region: (a) 7° and (b) -7°.



(a)



(b)

Fig. 3. Transmittance according to the rubbing direction at the pixel edge: (a) 7° and (b) -7°.

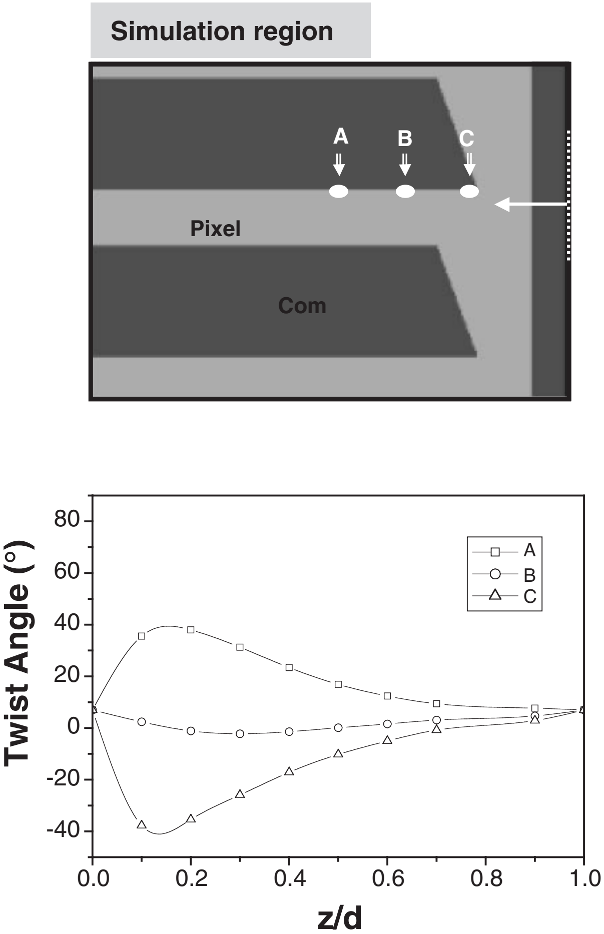


Fig. 4. LC director profile when the rubbing angle is 7°.

to the various field directions near the pixel edge with the patterned slit electrode, although the rubbing angle remains the same. Moreover, we can observe that the LC dynamics near the pixel edge is more stable if the reverse region is far from the main active region, as shown in Fig. 3(a). Thus, DLs less intrude into the adjacent active region. They intrude less than 3 μm into the active region when the rubbing angle is 7° as compared with the case when the rubbing angle is −7°.

Next, we observed the profile of the LC director for the detailed analysis of LC dynamics. Figure 4 shows the twist angle of LC along the vertical axis with z direction when the rubbing angle is 7°. Here, A, B, and C represent simulation positions for analyzing the LC dynamics, which are 10, 8, and 6 μm from the common electrode, respectively. As shown, LC in the A position twists by 45° near $z/d = 0.1$. LC in the B position is barely twisted, where the dark DLs exist. LC in the C position reverse twists by −40° near $z/d = 0.1$. This shows that there exist different field directions between the adjacent active area and pixel edge so that the rotation direction of the LC at the pixel edge is not the same as that at the active region. Consequently, the reverse twist appears at the pixel edge and the unstable DLs exhibit at the boundary. Therefore, it is necessary to decrease the area of the reverse twist region or keep it far from the main active area in the design of the pixel. This is possible by controlling the rubbing direction such that the rubbing angle is 7°.

We studied the reverse twist near the pixel edge depending on the rubbing direction for the FFS mode. At the active region, LC dynamics and transmittance are the same, irrespective of the rubbing direction, that is, clockwise or counterclockwise because only one electric field direction exists. On the other hand, near the pixel edge, the result is different. Near their edge with several electric field directions owing to the patterned slit electrode, LC dynamics and transmittance depend on the initial rubbing direction because the position of reverse twist is decided by the angle between the electric direction and the LC director under a bias voltage. For example, when the rubbing angle is 7°, the reverse twist appears at the bottom of the right sharp corner of the pixel edge so that the reverse region exists far from the main active region. However, when the rubbing angle is −7°, the reverse twist appears top of the right corner of the pixel edge, resulting in the region becoming closer to the main active area and unstable DLs easily intruding into the active region.

Therefore, it is necessary to keep the reverse twist region far from the main active region by controlling the rubbing direction such that the rubbing angle is 7° in the pixel design. As a result, we can minimize the permeation of DLs into the main active region.

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) A. Lien: Appl. Phys. Lett. **57** (1990) 2767.