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Brief Communication

Effect of Horizontal Electric Field Generated by Data Signal on Disclination Lines near Pixel Edge in Fringe Field Switching Mode

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We have studied the dynamic stability of a liquid crystal (LC) in an adjacent active region near the edge of a pixel slit according to the horizontal electric field generated by the data signal for the fringe field switching (FFS) mode. The horizontal component of a fringe electric field becomes strong as the distance between the common electrode and the data bus line decreases. Therefore, the disclination lines (DLs), which are formed near the pixel edge, barely intrude an active region. Moreover, the LC director existing in this region becomes stable and has a large twist angle. This indicates that the LC dynamic stability near the pixel edge is markedly affected by the horizontal electric field of a strong data signal.

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Image qualities of liquid crystal displays (LCDs) have been markedly improved by the development of new conceptual LC modes such as the in-plane switching (IPS) mode[1,2] and fringe-field switching (FFS) mode,[3–5] where LC directors rotate almost in plane.

The IPS mode driven by this in-plane switching has a merit such as a wide viewing angle but it has an intrinsically low transmittance. On the other hand, the FFS mode was the first mode that has both a high transmittance and a wide viewing angle. In this mode, the dynamic stability of a LC is very important in obtaining good electrooptic characteristics such as a high transmittance and a fast response.

In the thin-film-transistor (TFT)–LCDs using the FFS mode, the electric field direction at the edge of a pixel with a patterned slit is different from that in the 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 when a bias voltage is applied; thus, the LCs collide with each other and then a reverse twist appears. In reverse twist regions, the LCs have a different orientation from neighboring active LCs; thus, the disclination lines (DLs) are formed. The stability of DLs also depends on the dielectric anisotropy of the LCs and the applied voltage.[6] In particular, when using a LC with positive a dielectric anisotropy, DLs become unstable at a high applied voltage. Actually, these DLs can be controlled by the horizontal electric field generated between the common electrode and the data bus line.

In this study, we investigated the LC dynamic stability near the pixel edge and the electrooptic characteristics according to the horizontal electric field by the three-dimensional simulation.

Figure 1 shows the side view of the FFS mode. First, an indium tin oxide (ITO) layer with a thickness of 400 Å was deposited on a bottom glass substrate and then a passivation layer with a thickness of 3000 Å and a data bus line with a thickness of 1000 Å, were coated by chemical vapor deposition. Another passivation layer with a thickness of 2000 Å was coated on the data bus line by chemical vapor deposition. Finally, the second ITO layer with a thickness of 400 Å was deposited and patterned as interdigital electrodes. The width of the second ITO electrodes was 3 µm and the distance was 5 µm between them. There was no electrode on the top glass substrate. In this case, the first and second ITO layers served as the common and pixel electrodes, respectively, and there was no distance between the first and second ITO layers. The horizontal distance between the common electrode and the data bus line with respect to the x axis was defined as H. The alignment layer was coated on both substrates, and rubbing was carried out in antiparallel directions. The rubbing angle was defined as an angle with respect to the horizontal component of a fringe field. The pretilt angle generated by rubbing was 2°. The cell gap (d) was 3.6 µm. A liquid crystal with a positive dielectric anisotropy ($\Delta n = 0.098$ at $\lambda = 589$ nm, $\Delta\varepsilon = 8.2$) was used for simulations. Polarizers crossed each other and one of them was parallel to the rubbing direction. In this case, the normalized transmission of light was

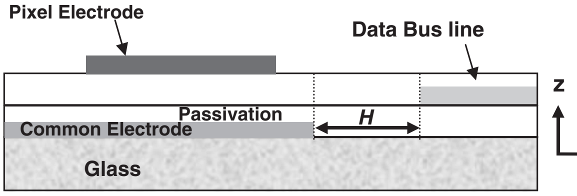

Fig. 1. Schematic diagram of side view of FFS mode.

$$T/T_o = \sin^2(2\psi)\sin^2(\pi d\Delta n/\lambda),$$

where ψ is an angle between the crossed polarizer and the liquid crystal, Δn is the birefringence of the LC medium, and λ is the wavelength of the incident light. Therefore, the FFS mode is a normal black mode, and the transmission becomes maximal when the LC director rotates by 45° due to the applied voltage, given the birefringence of the LC medium.

First, we performed a computer simulation to investigate transmittance characteristics according to the distance between the common electrode and the data bus line (H), as shown in Fig. 2. For this simulation, we used the commercially available software "Techwiz LCD" (Sanayi System, Korea), where the motion of the LC director is calculated

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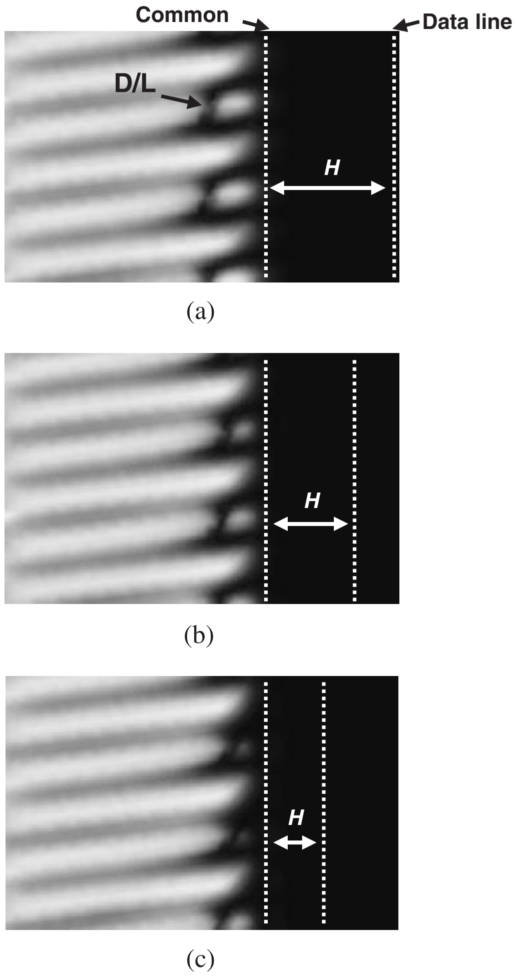
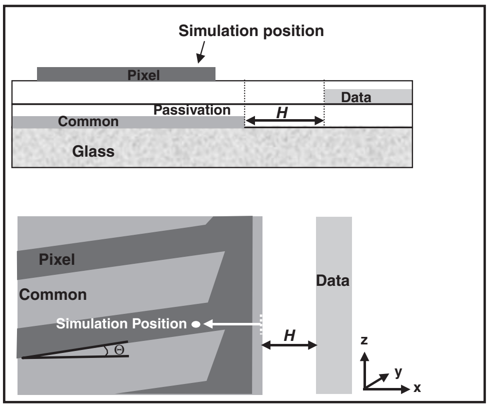


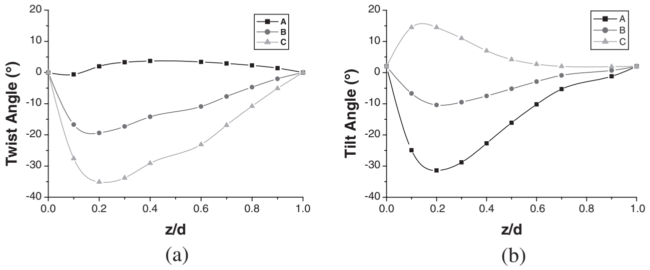
(a)

(b)

(c)

Fig. 2. Transmittance according to distance between common electrode and data bus line (H): (a) 10, (b) 7.5 and (c) 5 µm.





(a) (b)

Fig. 3. LC director profile according to H: (a) twist angle and (b) tilt angle.

based on the Eriksen–Leslie theory and the 2 × 2 Jones matrix[7)] is applied for optical transmittance calculation.

Figures 2(a)–2(c) show the transmittance changes for the H values of 10, 7.5, and 5 µm, respectively. The results indicate that the DLs that are formed due to the different field directions between the edge of the pixel with a slit and the active region barely extend into the active area when the H is close.

Next, we observed the profile of the LC director according to the H for detailed analysis. Figures 3(a) and 3(b) show the twist angle and tilt angle of the LC along the vertical axis, that is, the z direction, where A, B and C indicate the H values of 10, 7.5, and 5 µm, respectively. And, the simulation position is the pixel edge in an adjacent active region, which is 4 µm away with respect to the x axis from the common electrode, in which the slit angle (θ) of the pixel electrode is 7°. As shown in Fig. 3(a), the LC in A barely twists. That is, DLs are formed in a neighboring active area. The LC in B twists by 20° near $z/d = 0.2$, while the LC in C twists by 35° near $z/d = 0.2$. The results indicate that the horizontal electric field generated by the data signal is strong when the H is close, maintaining the DLs near the edge of the pixel slit. Therefore, the DLs barely intrude an adjacent active region, and the LC existing in this region exhibits dynamic stability and has a large twist angle. Furthermore, the LC in A has a large tilt angle from the substrate and is very unstable. That is, the horizontal electric field induced by the strong data signal markedly affects the stability of DLs and adjacent active area.

Next, we analyzed the horizontal component of the fringe electric field at the simulation position, where the horizontal component between the common electrode and the pixel electrode in the neighboring active region is located. Actually, LC directors twist to the vector position of the x and y axes. In this case, the total horizontal electric field is

$$E_{\text{total}} = E_x + E_y,$$

where E_x and E_y are the horizontal electric components in the x and y directions, respectively. As shown in Fig. 4, the horizontal direction of the original field becomes −83° with respect to the x axis when the slit angle (θ) is 7°. E_{total} has the

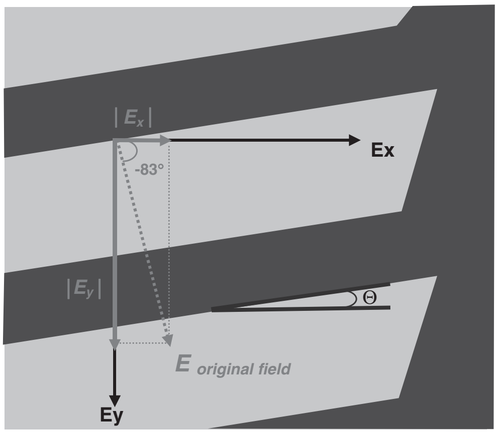
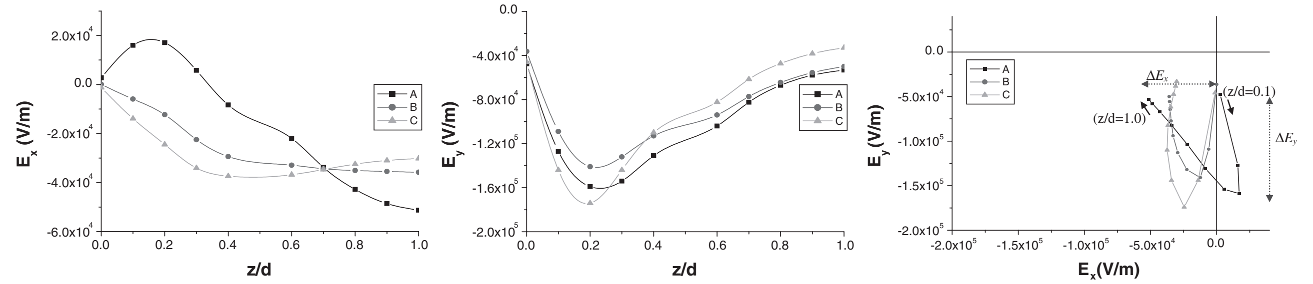


Fig. 4. Schematic diagrams of the original electric field in neighboring active region.



(a) (b) (c)

Fig. 5. Distribution of horizontal electric field according to H in neighboring active region: (a) horizontal electric field in x direction, (b) horizontal electric field in y direction and (c) the range of changes in x and y direction.

intensity and direction of the original field, if $|E_x|$ is 1 and $|E_y|$ is 8.14. Here, $E_{\text{original field}}$ is defined as the ratio of $|E_x|$ to $|E_y|$. In the FFS mode, the twist force used for rotating the LC becomes strong when the E_{total} at the active region is close to that of the original field, thus the twist angle of the LC at the active area increases.

Figure 5 shows the horizontal component of the fringe electric field according to the H. Figures 5(a) and 5(b) show the horizontal components according to the z/d in the x and y directions, respectively. Figure 5(c) shows the range of changes in the electric field according to the z/d. That is, $|\Delta E_x|$ and $|\Delta E_y|$ in A are 68.4 and 111, $|\Delta E_x|$ and $|\Delta E_y|$ in B are 35.9 and 104.5, and $|\Delta E_x|$ and $|\Delta E_y|$ in C are 36.1 and 140.8, respectively. Therefore, E_{total} values in A, B and C are 1.6, 2.9, and 3.9, respectively, where E_{total} indicates the ratio of $|E_x|$ to $|E_y|$ and increases as it goes from A to C. The results indicate that DLs near the edge of the pixel with a patterned slit exhibit dynamic stability when the horizontal electric field generated between the common electrode and data bus line is strong; thus, the LCs at the adjacent active region have little effect on the unstable reverse twist area near the pixel edge. Therefore, LCs can be twisted using the field intensity similar to the original field intensity. In summary, the LC dynamic stability in the adjacent active region is markedly affected by the horizontal electric field between the common electrode and the data bus line.

We have studied the dynamic stability of the LC at the adjacent active region near the edge of a pixel with a slit according to the horizontal electric field induced by the data signal for the FFS mode. The horizontal electric component of the fringe electric field becomes strong and maintains the DLs near the edge of the pixel slit, as the distance between the common electrode and the data bus line decreases. Therefore, DLs barely extend into an adjacent active region. Moreover, the LC at the neighboring active area becomes stable and has a large twist angle. This indicates that the LC dynamic stability in this region is markedly affected by the horizontal electric field generated between the common electrode and the data bus line.

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