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A Novel Fringe Field Switching Mode with 3-partition Pixel Slit

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We proposed a novel fringe field switching (FFS) liquid crystal (LC) mode with a 3-partition pixel slit. In this mode, a pixel branch is partitioned into 3 areas, namely, two edges and a center, where the edge slit angle is larger than the center slit angle. Thus the reverse twist region in the pixel edge is reduced and the LC dynamics in this region becomes very stable. Also, when an external pressure is applied to the panel at the operating voltage, the disclination line is barely extended into the active area. Consequently, this mode exhibits a high external pressure resistance with a wide viewing angle and is attractive for pen-based touch panels such as personal digital assistants (PDAs) and tablet personal computers (PCs).
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KEYWORDS: 3-partition pixel slit, fringe field switching, reverse twist, disclination line

1. Introduction

Thin-film-transistor liquid crystal displays (TFT-LCDs) have been widely used in notebook personal computers (NBPCs) and desktop PCs. Nowadays, their application field has reached pen-based systems, such as mobile phones, personal digital assistants (PDAs) and tablet PCs.[1)] For pressure-sensitive pen-based displays, the dynamics of the LC directors should be stable with the application of an external pressure or a high voltage because a pen directly applies the pressure. A mode driven by a vertical field such as the twisted nematic (TN) mode is very unstable when an external pressure is applied to the panel.[2)] On the other hand, fringe field switching (FFS) mode,[3–5)] which is driven by a fringe electric field, is very stable with the application of an external pressure or a high voltage. However, for the FFS mode, the direction of the electric field at the edge of a pixel slit differs from the active direction at the pixel center. Moreover, the LC directors placed at these locations differ in alignment with there neighboring directors, i.e., a reverse twist area and a disclination line are formed. Since this area is very unstable, it easily extents into an adjacent pixel area.

For the design of a pixel electrode in the FFS mode, the reverse twist region decreases as the slit angle of the edge at the pixel electrode increases. Thus, the unstable area at the pixel edges decreases, but so does the transmittance at the panel.

To overcome this problem, we designed a novel FFS mode with a 3-partition pixel slit, which has desirable characteristics such as a high external pressure resistance and a high transmittance. In this study, we have investigated the electrooptic characteristics and dynamic stability of the LC director in this mode by 3D simulation.

2. Simulation and Experimental Results

Figure 1 shows the cell structure of the FFS mode. First, an indium/tin oxide (ITO) layer with a thickness of 400 Å was deposited on the bottom glass substrate, and then a passivation layer, SiO_2, with a thickness of 3000 Å was coated by chemical vapor deposition. Finally, another ITO layer with a thickness of 400 Å was deposited and patterned as interdigital electrodes. The width of the second ITO layer electrodes is 3 μm and the distance between the electrodes is 5 μm. There is no electrode on the top glass substrate. In this case, the first and second ITO layers function as common and pixel electrodes, respectively, and there is no distance between the first and second ITO layers such that fringe field lines are generated instead of in-plane field like that in the conventional IPS mode with a bias voltage. The alignment layer AL-16139 (Japan Synthetic Rubber Co.) was coated on both substrates and rubbing was performed in antiparallel directions. The rubbing angle (α) is defined as the angle with respect to the horizontal component of the fringe field. The pretilt angle generated by the rubbing is 2°. The two glass substrates were then assembled to provide a cell gap (d) of 3.6 μm. The liquid crystal with a positive dielectric anisotropy ($\Delta n = 0.098$ at $\lambda = 589$ nm, $\Delta\varepsilon = 8.2$) from Merck Co. was used for our experiments and simulations.

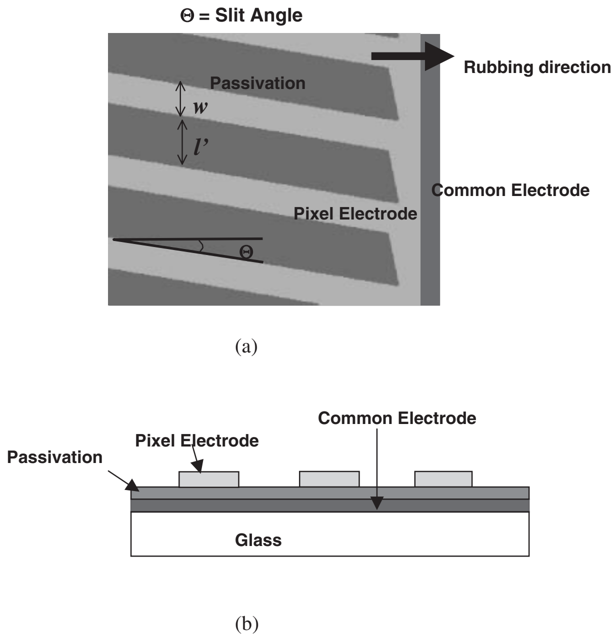

Fig. 1. Schematic diagrams of FFS cell structure: (a) top view and (b) side view of electrodes.

Two polarizers are oriented to cross each other with one

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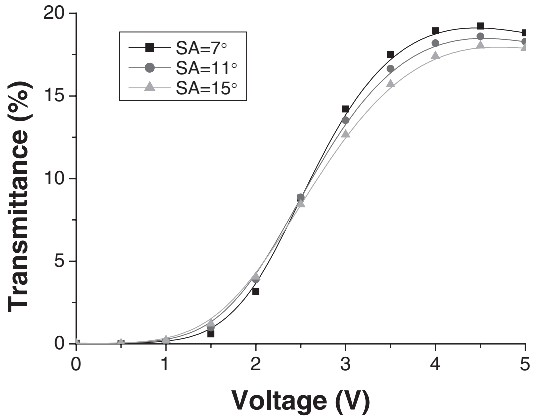


Fig. 2. Calculated V–T curve in FFS mode for various slit angles.

Table I. Simulation conditions.

Electrode width, w (μm)	3
Electrode distance, l' (μm)	5
Cell gap (μm)	3.6
Pretilt angle (°)	2
Slit angle (°)	7, 11 and 15
LC properties (from Merck)	
K_{11} (pN)	9.6
K_{22} (pN)	5.8
K_{33} (pN)	11.6
Δn at 589 nm	0.099
$\Delta\varepsilon$	8.2

of them aligned parallel to the rubbing direction. In this case, the normalized transmission of light is given by

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

where Ψ is an angle between a polarizer and the liquid crystal director, and T_o is the intensity of the transmitted light through a pair of parallel polarizers. Therefore, the FFS mode is a normally black mode, and the transmission becomes maximal when the LC director is rotated by 45° by an applied voltage, given the birefringence of the LC medium.

First, we performed a computer simulation to investigate the voltage-dependent transmittance (V–T) characteristics as a function of slit angle[6] with respect to the in-plane field direction, as shown in Fig. 2. We used the commercially available software "Techwiz LCD" (Sanayisystem, Korea), where the motion of the LC director is calculated based on the Eriksen-Leslie theory and a 2×2 Jones matrix[7] is applied for optical transmittance calculation. The simulation conditions are given in Table I.

The calculated results show that the threshold voltage (V_{10}) decreases and the operation voltage (V_{op}) at which the maximum transmittance occurs increases as the slit angle of the pixel electrode increase, and the maximum transmittance decreases as the slit angle changes from 7° to 15°. The reason for this is as follows: A strong fringe electric field is induced near the pixel electrodes while the operation voltage is increased by increasing the slit angle. Consequently, the LC directors near this area are overtwisted by the horizontal component of the fringe electric field and tilted upward from the substrate by the vertical component of this field.

Next, we performed a simulation to demonstrate the dynamic stability of the LC director at the edge of a pixel slit. Figure 3 shows the transmittance of the pixel electrodes with an applied operation voltage. The disclination line barely extents into the adjacent pixel area with the increase in slit angle from 7° to 15°. We analyzed the profile of the

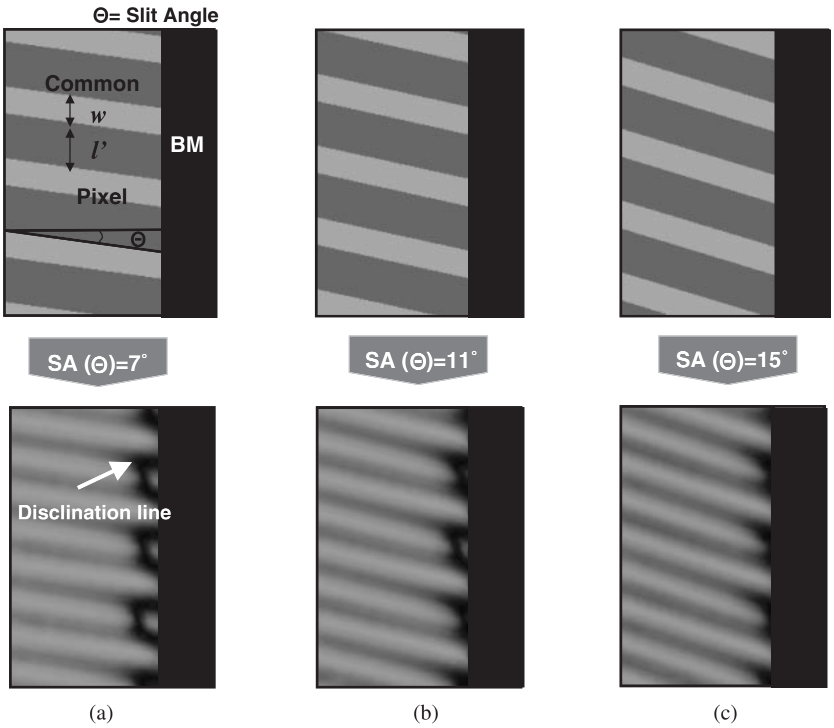
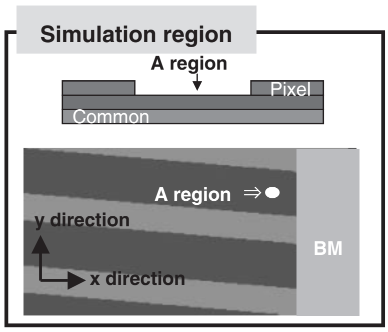
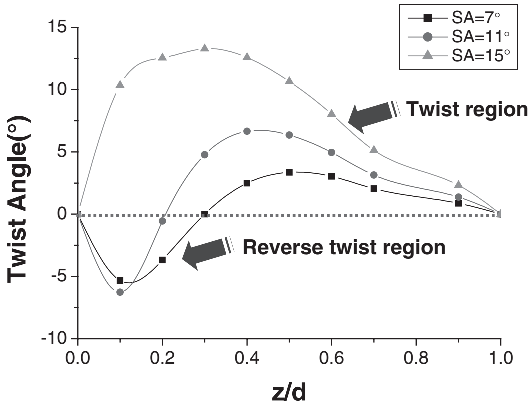
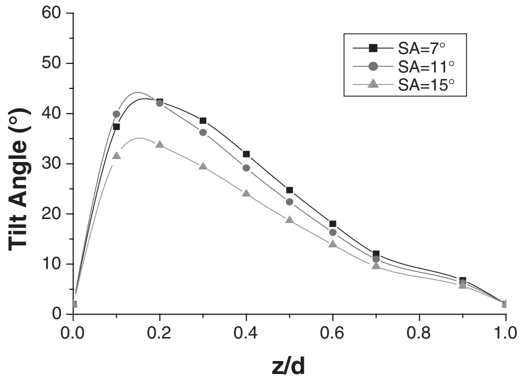


Fig. 3. Transmittance for various slit angles: (a) 7°, (b) 11° and (c) 15°.





(a)



(b)

Fig. 4. LC director profile for various slit angles: (a) twist angle and (b) tilt angle.

LC director at the A position to observe the edge of the pixel slit in detail. The A position is 2 μm away from the black matrix (BM) in the x direction and midway between two pixel electrodes in the y direction, as shown in Fig. 4. Figure 4(a) shows the twist angle of the LC as a function of slit angle. When the slit angle is 7°, the reverse twist region is up to 0.3 of z/d, where z is the position in the vertical direction and d is the cell gap, and the area of the reverse twist is 1.802. When the slit angle is 11°, the reverse twist range is up to 0.2 and the area of the reverse twist is 1.362. There is no reverse twist area in the case when the slit angle is 15°. This result indicates that the reverse twist area at the edge of a pixel slit decreases as slit angle increases, and so does the area of the unstable region. The total areas of the curves are 2.228, 3.6305 and 7.8625 for pixel edge slit angle of 7°, 11° and 15°, respectively. Also, this shows that transmittance is minimal when the slit angle is 7° because the total area of the curve represents the degree of twist angle of the LC molecules, and transmittance is maximal when the twist angle is 45°. Through the transmittance drop at an adjacent pixel when the slit angle is 7°, we can see that the disclination line is easily extends into an adjacent pixel as slit angle decreases. Figure 4(b) shows the tilt angle of the LC as a function of slit angle. Tilt angle decreases with increasing slit angle. This indicates that the unstable region at the edge of a pixel slit decreases as slit angle increases because it is unstable with an applied external pressure and operation voltage as the LC molecular tilt upward from the substrate. That is, the LC directors at the edge of a pixel slit are unstable and show a low transmittance at the adjacent pixel when the slit angle is 7°.

In summary, the LC director at the edge of a pixel slit becomes more stable with increasing slit angle, but the transmittance at the active region decreases. To solve this problem, we proposed a novel FFS mode with a 3-partition pixel slit in this paper. The mode is very pressure-resistant and has a transmittance similar to that of a conventional FFS mode. The pixel slit is partitioned into 3 areas, as shown in Fig. 5. The center slit angle (θ) is smaller than the edge angle (θ'). The slit angles in this study were chosen such that θ is 7° and θ' is the 11°. The results show that the reverse twist region at a pixel edge decreases and the LC director at this location becomes stable because the edge slit angle is

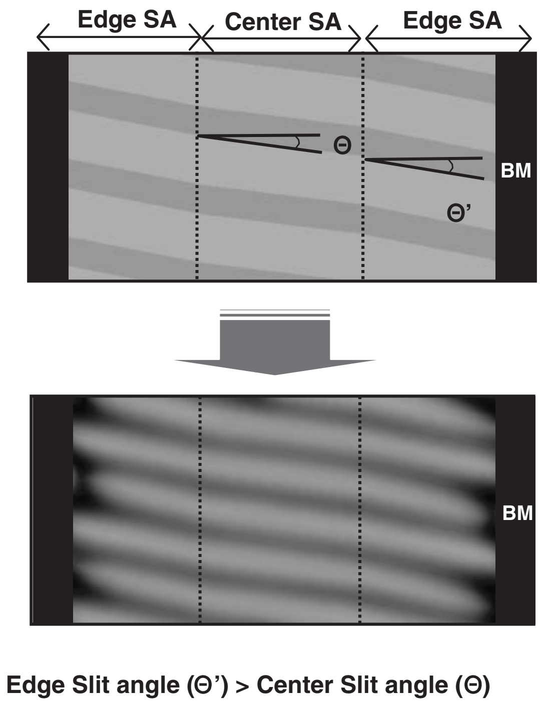
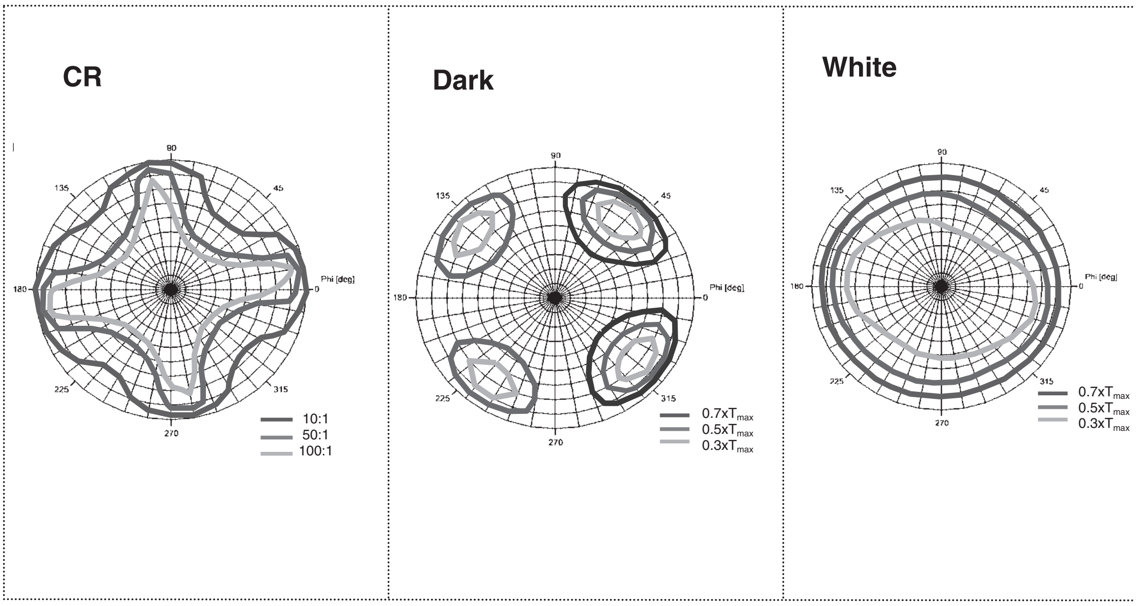


Fig. 5. Transmittance for 3-partition pixel slit structure.

Table II. Transmittance charge with slit angle.

SA	7°(ref.)	11°	15°	3-partition structure
V_{op}	4.4 V	4.5 V	4.6 V	4.5 V
Transmittance	19.24%	18.60%	18.11%	18.94%
Transmittance change	100%	96.7%	94.1%	98.4%



(a) (b) (c)

Fig. 6. Viewing angle characteristics: (a) isocontrast ratio contour, (b) isoluminance contour at V_{on} and (c) isoluminance contour at V_{off}.

larger than that at the center. Also, it is possible for the transmittance drop at the active region to reach one-half. Moreover, the transmittance of the novel FFS structure is 98.4% in comparison with the reference (at SA = 7°), as shown in Table II. This indicates that the new mode shows both a good transmittance and stable slit edge characteristics. Next, we observed the viewing angle characteristics. Figure 6(a) shows isocontrast ratio (CR) curves. Figures 6(b) and 6(c) show the isoluminance curves at V_{on} and V_{off}, respectively. The curves correspond to 30%, 50% and 70% with respect to the maximum transmission at a normal direction. The isocontrast ratio curves are almost axially symmetrical in all directions for CRs less than 100 : 1, as shown in Fig. 6(a). Also, the dark characteristic for the novel FFS mode is good and the isoluminance curves at V_{on} are axially symmetrical in all directions even at 50% with respect to the maximum transmission at a normal direction, as shown in Figs. 6(b) and 6(c). That is, the mode exhibits wide viewing angle characteristics in all directions. Next, we observed the transmittance at the panel.

Figure 7 shows the experimental V–T curves. V_{op} decreases as the slit angle changes from 3° to 11°. In the case of 3°, the transmittance at the panel drops below 1% because disclination lines easily extend into the active region. Figure 8 shows microscopy images depicting how disclination lines progress as the slit angle changes with an applied external pressure at the operation voltage. Figures 8(a)–8(c) show the images corresponding to the slit angles of 3°, 7°

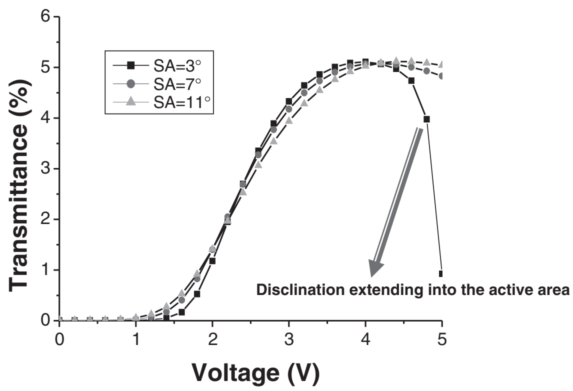


Fig. 7. Measured V–T curve in FFS mode for various slit angles.

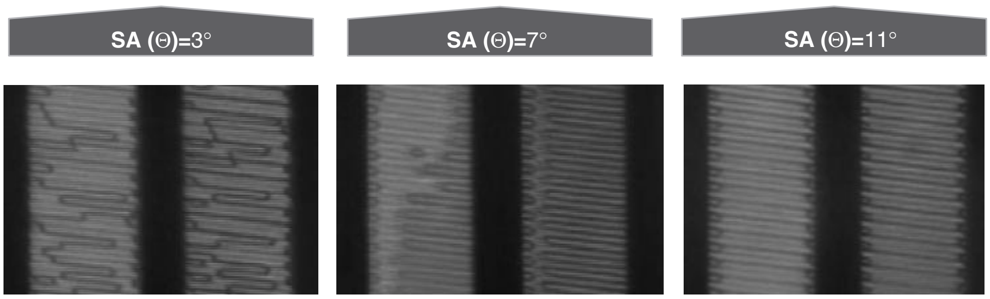


Fig. 8. Microscopy images showing how disclination lines progress with slit angle.

and 11°, respectively. The result shows that LC molecules at the edge of a pixel slit are stable when the slit angle is 11° because the area of the reverse twist region decreases as slit angle increases.

3. Summary

In this study, we proposed a novel FFS mode with a 3-partition pixel slit, which has desirable characteristics such as a high external pressure resistance and a high transmittance. In the structure, the reverse twist region at a pixel edge decreases and the LC director at this location becomes stable. Moreover, it is possible for the transmittance loss to be reduced to as much as one-half by increasing the slit angle.

Therefore, the new mode is suitable for applications in external pressure-sensitive touch displays such as PDAs and table PCs.

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