A Study on Improvement of the Transmittance in the Fringe-Field Switching (FFS) Mode

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Abstract
Pixel structure of the fringe-field switching (FFS) mode to improve transmittance has been studied. New FFS structures related to the electrode structure at the edges of pixel, and the pixel electrode width and distance between electrodes was optimized. The former improves transmittance by minimizing the region of disclination lines. The latter improves it by increasing light efficiency above center of electrodes and also response time.

1. Introduction

In these days, the image quality of the liquid crystal displays (LCDs) has been improved more and more because of the development of new LC modes and optimization of each optical layer. There are several LC modes being commercialized such as in-plane switching (IPS) [1], fringe-field switching (FFS) [2-5], and multi-domain vertical alignment (MVA) [6-7]. Among them, IPS and FFS mode have a wide viewing angle intrinsically, because the LCs are aligned homogeneously at an initial state and then in-plane and fringe electric field rotate the LC almost in plane. In the IPS mode, the transmittance is much lower than FFS mode because the LCs above the center of the pixel electrode does not rotate. However, the FFS mode has a much higher transmittance than the IPS mode because LCs above electrodes rotate with low driving voltage [2]. Owing to many advantages, the FFS mode is being applied to various application fields such as mobile, tablet PC, notebook, monitor and LC-TVs.

In case of the FFS modes, both LCs with positive and negative dielectric anisotropy were commercialized. In fact, the FFS mode with positive dielectric anisotropy is rather lower than that using the LC with negative dielectric anisotropy and twisted nematic (TN) mode [5]. In addition, in the FFS mode, the LC dynamics becomes unstable near the edge of the pixel slit at a high applied voltage, where a horizontal field direction is different from that in the active region [8]. That is, in the pixel edge, strong unwanted electric field makes the LC director to twist in a reverse direction so that the disclination line (DL) at the boundary between different field direction regions is generated and thus the transmittance decreases [9]. Besides, the conventional FFS mode has electrode width large than 3㎛ so that the LC at the center of pixel or common electrode does not rotate enough and thus the transmittance is decreased. Furthermore, response time in the FFS mode is slower than VA mode relatively due to twist deformation and low operating voltage.

In this paper, we propose a new pixel structure that improves the transmittance and response time by minimizing the region with DL lines and improving light efficiency above electrode.

2. Calculation Results

To investigate the transmittance characteristic with new FFS structure, we performed a calculation using two-dimensional (Shintech, Japan) and three-dimensional simulation (Sanayi System, Korea). The motion of the LC director is calculated based on the Eriksen-Leslie theory and 2x2 extended Jones matrix is applied for an optical transmittance calculation [10]. The LC with physical properties such as $\Delta\varepsilon$ = +8.2, Δn = 0.1, K_{11} = 9.7pN, K_{22} = 5.2pN, K_{33} = 11.6pN is used. The surface pretilt angle is 2°. The cell gap is 4㎛.

2.1. Zigzag type FFS Pixel Structure

Figure 1 shows cell structure of the conventional and new (zigzag) FFS one. In the FFS mode, the pixel and common electrode exist only on one substrate. The pixel electrode exists in a slit form with electrode width (*w*) and the distance (*l*) between them, and the common electrode exists as a plane with passivation layer between pixel and common electrode. As indicated in Fig. 1(a), the LC director rotates clockwise in the active region, but the LC directors near pixel edge (regions with circle) rotate anticlockwise, generating DL lines. A new FFS cell called "Zigzag Shape FFS" connects the pixel edge, alternatively, so that the DL is reduced to the half of the conventional one.

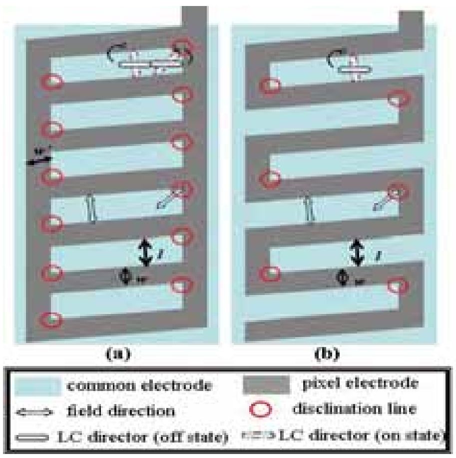

Figure 1. Pixel structure: (a) conventional FFS and (b) zigzag shape FFS.

Figure 2 shows calculated results of the transmittance according to the cell structure. The dark region due to existence of DL is reduced in the new pixel structure, compared with the conventional one. Further, in the DL regions, the LC molecules collide, each other, leading to slow response time as well as high operating voltage. Since this region is reduced in the zigzag shape FFS mode, the transmittance is increased.

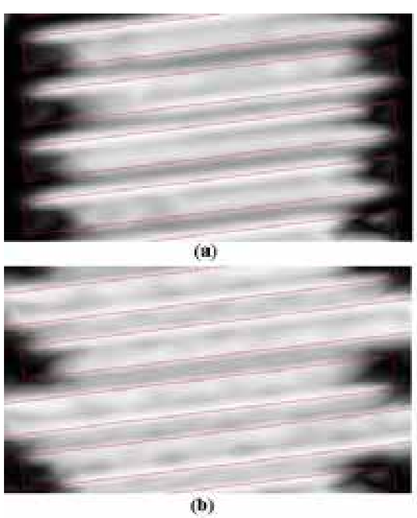

Figure 2. Calculated transmittance of (a) conventional and (b) zigzag shape FFS.

Next, we analyzed the transmittance according to time to know the transmittance difference quantitatively. As shown in Figure 3, "Zigzag Shape FFS" structure increases by about 11% compared with conventional FFS.

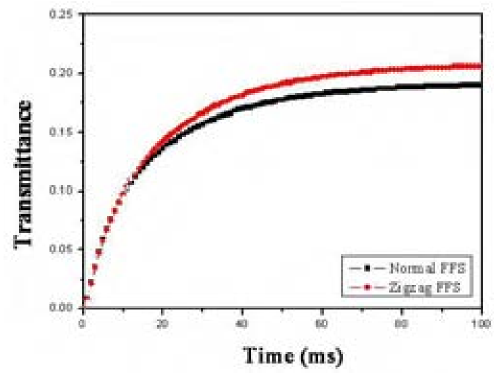

Figure 3. Time-dependent transmittance of (a) conventional and (b) zigzag shape FFS.

Figure 4 represents the LC director at the V_{op} according to the cell structure. The conventional FFS mode generates reverse twist of the LC director at the pixel edge due to strong unwanted electric field (see cicrcles). This generated DLs decrease transmittance and response time in the panel. In the "Zigzag Shape FFS" structure, the region for connecting pixel pattern is reduced to a half and the region with reverse twist is reduced to one half.

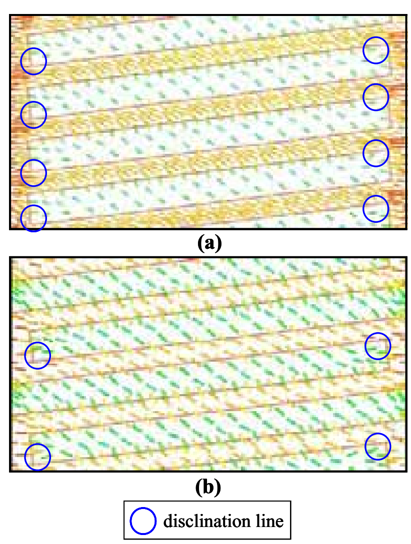

Figure 4. LC director according to cell structure; (a) conventional and (b) zigzag shape FFS.

2.2. Electrode structure optimization

To improve the transmittance in the FFS mode, we investigate electrode structure with positive LC by optimizing electrode design. We consider two ways; active region and inactive region of the pixel structure. First, at a point of active region, as the pixel electrode width (*w*) decreases from 3㎛ to 1㎛ with optimized distance between them (*l*), the region with horizontal field intensity increases so that the LCs rotate fully above whole electrode surface, giving rise to transmittance along electrodes as high as the LC cell with negative LC. [11]

Figure 5 shows the light efficiency and operating voltage (V_{op}) for three different electrode conditions. When *w* = 3㎛, *l* = 4.5㎛, the light efficiency is 0.79 and the V_{op} is 4V. However, as *w* and *l* decreases to 1㎛ and 1.5㎛, the light efficiency reaches 0.9, which is about the same value as that using the negative LC. When *w* and *l* decrease, light efficiency is almost independent of the electrode position due to increase of the region with horizontal field intensity. However, the narrow electrode width increases V_{op}.

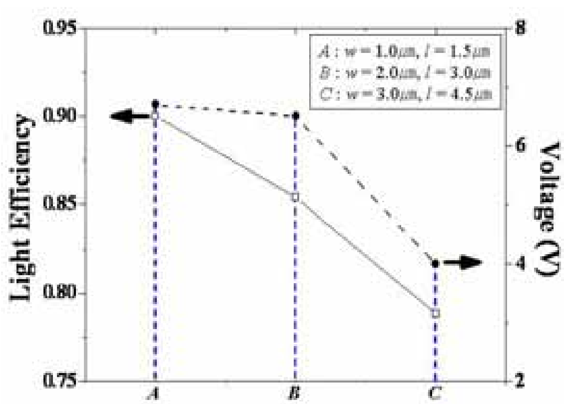

Figure 5. Light efficiency at operating voltages for different electrode conditions.

To know how the reduction of the pixel electrode width improves the transmittance of the FFS mode, we calculated a twisted angle at three electrode positions. As indicated Fig. 6, when *w* = 3㎛, the maximal twist angle from the initial position is strongly dependent on electrode position such that the LC near bottom surface and around mid-layer twists most at the edge and center of electrodes, respectively. From these director profiles, we know that the light modulation does occur using polarization rotation effect (position a_1) and phase retardation effect (position a_3) in the conventional FFS mode. However, as the *w* and *l* decrease, the maximum twist angle exists near bottom substrate in all electrode positions. This means that only polarization rotation effect plays a role of light modulation in this structure. Further, the light efficiency is maximized in all electrode positions.

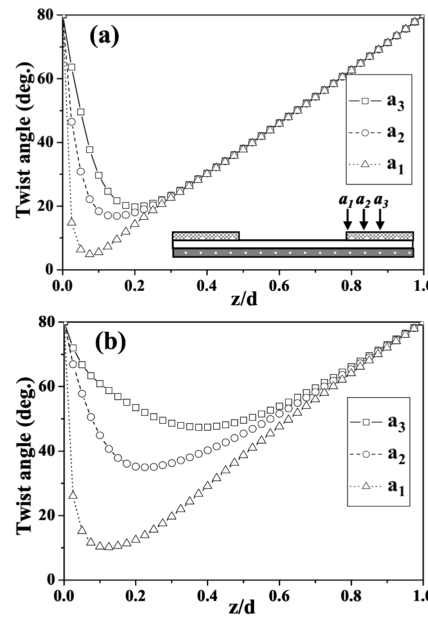

Figure 6. Director profile of twist angle at three different electrode positions; (a) *w* = 1.0 ㎛, *l* = 1.5 ㎛, (b) *w* = 3.0 ㎛, *l* = 4.5 ㎛.

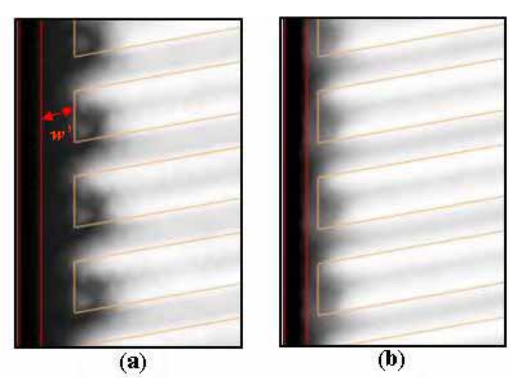

Figure 7. Transmittance depending on the pixel edge width (*w'*): (a) *w'* = 3㎛ (b) *w'* = 1㎛.

By considering changing the pixel edge width (3㎛) to the narrow electrode width, the region in which the LC director does not rotate can be reduced and thus the transmittance can be increased at the pixel edge region. Here, we define the pixel edge width, *w'* (See Fig. 7). As *w'* decreases, the dark regions decreased and thus the transmittance increased. As the *w'* decreases 3㎛ to 1㎛, the transmittance increases by about 14.2% due to the reduction of dark regions and increase of the active region (See Fig. 8).

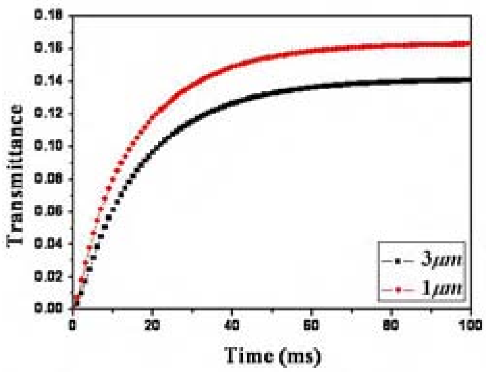

Figure 8. Time-dependent transmittance curve depending on the pixel edge width (*w*').

Next, we calculated the response time with optimized electrode structure. When *w* and *l* decrease, rise time decreases by about 58% (27ms → 11ms), and decay time also decrease by about 47% (31ms → 16ms). When the *w* and *l* decrease, horizontal electric field intensity increases and thus the LCs are influenced by strong dielectric torque in all electrode positions, giving rise to improved rising time remarkably. Decaying time is also improved because highly twisted LC director at the bottom surface relaxes back to high force of restitution due to surface effect. Further, for LC-TV applications, the high applying voltage (V_{op}) is advantageous to achieve a fast response time.

Table 1. Response time dependent on electrode condition.

w, l		3.5, 5.5㎛	1, 1.5㎛
V_{op}		3.6V	6.1V
τ_{on} (ms)	90%	27	11
	80%	25.5	10.5
τ_{off} (ms)	90%	31	16
	80%	23	12

3. Summary

In this study, we proposed efficient ways to improve the light efficiency of the FFS cell with positive LC. Newly proposed "Zigzag Shape FFS" minimized DLs generated at the edge of a pixel. In the FFS mode, the narrower the electrode width, the more the transmittance and response time are improved.

4. Acknowledgements

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