Electronic Materials Letters, Vol. 5, No. 4 (2009), pp. 179-182
DOI: 10.3365/eml.2009.12.179

Polarity Effects of Dielectric Anisotropy on the Electro-Optical Characteristics of Fringe Field Twisted Nematic Mode

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The polarity effects of dielectric anisotropy on the electro-optical characteristics of a twisted nematic mode driven by a fringe electric field that has wide viewing angle characteristics was the focus of this study. The device used in this study was designed to be a normally black mode between parallel polarizers. The perfect polarization conversion of the incident light, which passed through a polarizer, was achieved when it passed through a twisted Liquid Crystal (LC) layer. When an electric field was applied, the LC molecules with a positive (or negative) dielectric anisotropy rotated parallel (or perpendicular) to the horizontal component of a fringe electric field as the transmittance increased. According to the calculated results, an enhanced transmittance of the Fringe Field-Twisted Nematic (FF-TN) mode with a positive dielectric anisotropy of + 8.2 was be obtained.

Keywords: FF-TN mode, fringe field, wide viewing angle, dielectric anisotropy

1. INTRODUCTION

Since a Twisted Nematic Liquid Crystal Display (TN LCD) was first commercialized, LCDs have undergone intensive research to see if they can substitute Cathode Ray Tube (CRT). In particular, the TN mode, which has high transmittance, is one of the most representative LCD modes.[1,2] However, the viewing angle of the TN mode is narrow, so that its application is limited to small size displays, such as digital watches, cellular phones and personal digital assistants. In order to improve the viewing angle of the TN mode, various LCD modes have been proposed and developed, such as In-Plane Switching (IPS) mode[3,4] and Fringe Field Switching (FFS) mode.[5-7] Although the wide viewing angle characteristics can be obtained with these modes, these modes have a lack of processing margin compared to the TN mode. This has caused the 90° twisted nematic mode driven in-plane switching (IT mode) to be proposed.[8,9] This mode has both a wide viewing angle characteristic and a wide cell gap margin, but has problems with the contrast ratio because it does not perfectly catch a dark state when it is normally white. This mode also shows a low transmittance if the opaque electrodes are used. In order to solve these problems, the electro-optical characteristics of the twisted nematic mode driven by a Fringe Field (FF-TN mode) were studied. In particular, the optical performance that depended on LC director distribution of the FF-TN mode was calculated under an electric field and results were simulated when a positive dielectric anisotropy (+$\Delta\varepsilon$) was compared with those of a negative dielectric anisotropy (-$\Delta\varepsilon$).

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2. OPERATIONAL PRINCIPLE OF FF-TN MODE

Figure 1 shows the cell structure of the FF-TN mode and its operating principle. The FF-TN cell with a glass plate as a top substrate, a LC layer, a bottom substrate that consists of a common electrode on the glass substrate, a passivation layer,[10] and a pixel electrode are located between the parallel polarizers. Initially, LC molecules with -$\Delta\varepsilon$ on the bottom substrate was oriented to be perpendicular to the pixel electrode, whereas the LC molecules with +$\Delta\varepsilon$ were parallel to the electrode. The LC directors in the LC layer were continuously twisted with an angle of 90° along the cell thickness.

Before a voltage was applied, the linearly polarized light, which passed through a polarizer, was 90° twisted when it passed through the LC layer. When the transmission axis of the analyzer was parallel to that of the polarizer, the light was absorbed by an analyzer. Therefore, it exhibited a dark state. However, when a voltage was applied, the fringe electric field, which was composed of horizontal and vertical components of the electric field, occurred. The horizontal field

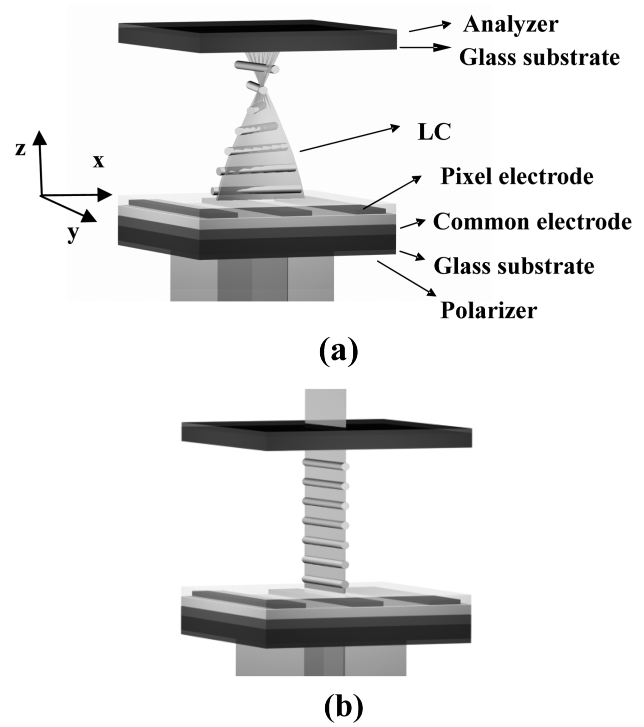


Fig. 1. Cell structure of FF-TN mode: (a) voltage-off state and (b) voltage-on state.

played a role in twisting aligned LC directors while the vertical field held down the LC directors for the –Δε and erected the LC directors for the +Δε by the dielectric interaction. Therefore, the LC directors on the bottom substrate that formed an arbitrary angle with a horizontal electric field were twisted in a vertical direction of the electric field. Then, the electric field turned into a white state since the linearly polarized light was transmitted through the analyzer without changing the polarization state.

3. ELECTRO-OPTICAL CHARACTERISTICS OF FF-TN MODE

The deformation of LC directors by a fringe field, which depends on the polarity of dielectric anisotropy, plays an important role in modulating the polarization state of incident light. The polarity effects of dielectric anisotropy on the switching of the FF-TN mode were investigated. In the calculation, the pre-tilt angle of the LC molecules and cell gap, d, were 2° and 6 μm, respectively. The optical anisotropy, Δ n, was 0.08 and thus the retardation, d Δ n, was 0.48 μm, which was the first optimal condition of the TN mode. A negative dielectric anisotropy of -4 and a positive dielectric anisotropy of + 8.2 were used. The elastic constant K_{11}, K22, K33 were 13.5 pN, 6.5 pN, and 15.1 pN, respectively. The width (ω) and length (ℓ) were 3 μm and 4.5 μm. The calculation of optical transmittance was obtained by using the 2×2 extended Jones matrix for the wavelength of 550 nm.[11]

Figure 2 shows the voltage-dependence on the transmittance curves of the FF-TN mode. When a voltage increased continuously, the transmittance started to occur around 1 V and increased up to 88% and 78% for the +Δε and the –Δε, respectively. In addition, the transmittance did not fall down when the voltage was increased further. This result implies that the maximum transmittance occurred when the LC was twisted with an angle of 90°, and the LC directors on the bottom substrate were strongly anchored by a surface anchoring energy that tried to orient themselves to be as near to 90° with increasing voltage. Compared to the –Δε, the transmittance for the cell with the +Δε was higher than 10%. As for the +Δε, the LC directors on the bottom substrate were tilted up to 90° at a high voltage, and thus the transmittance above the center of the electrodes increased.

Figure 3 shows the director profile of the FF-TN mode along the electrode and corresponding transmittance when the transmittance was maximal. As shown in Fig. 3(a), for the -Δε, the transmittance was maximized, but it fell down on the electrode center and between the electrodes because the LC directors were not fully twisted by 90°, except near the edge of electrodes. However, for the +Δε, the dependency of transmittance on the electrode position was reduced, as shown in Fig. 3(b), because the LCs near the bottom surface and above the center of electrodes were tilted about 90° parallel to the vertical electric field, and thus, light was transmitted.

In order to understand a detailed profile of the LCs, the twist and tilt angle inside the cell were calculated. Figure 4 shows the director profiles of the twist angle for the white state of the FF-TN mode at three different electrode positions. Here, d, e, and f represent the position at the center of the electrode, between the center and edge, and the edge of the electrode, respectively. As shown in Fig. 4(a), the LC directors with -Δε on the bottom substrate was twisted less than the other position due to the strong anchoring energy. However, going up to the top substrate at which the z/d was

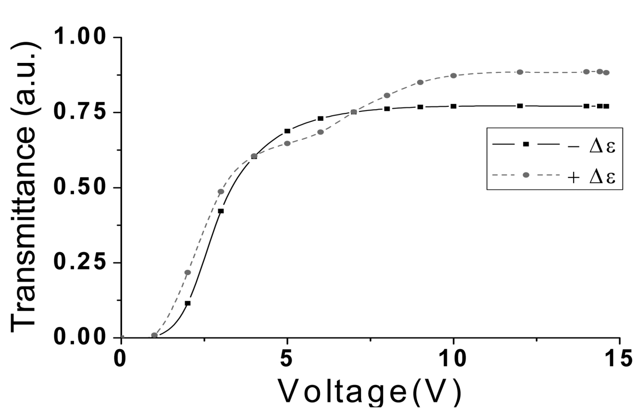
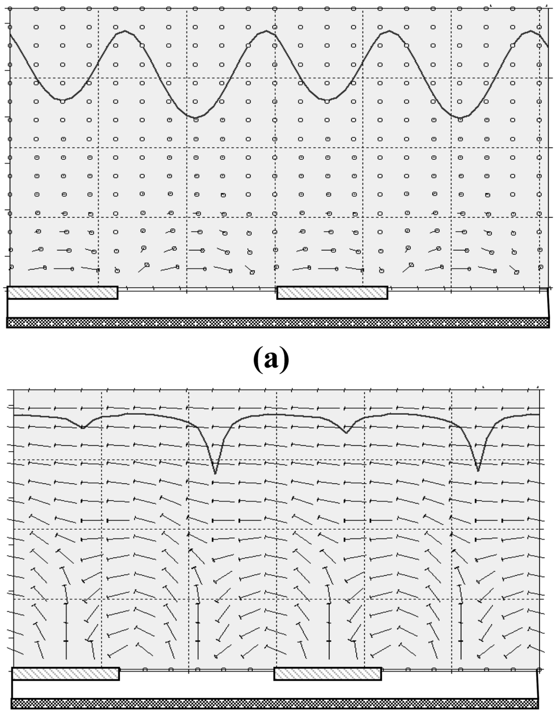


Fig. 2. Calculated V-T curve of FF-TN mode.



(a)

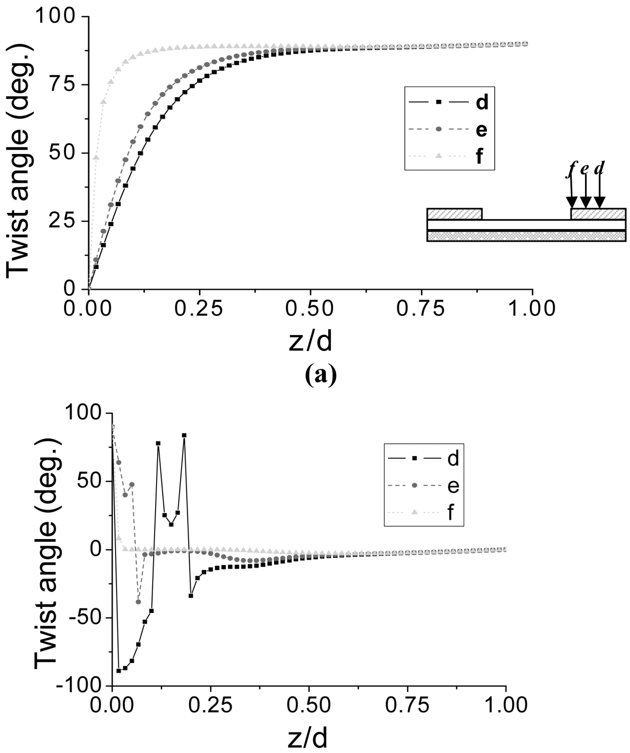
(b)

Fig. 3. Director profiles with (a) -Δε and (b) +Δε for electrode position at maximum transmittance.

larger than 0.5, the twist angle increased nearly to 90°. In particular, there was stronger horizontal field intensity at point f than at any other position. Therefore, the LC directors with -Δε twisted more than other positions, giving rise to the highest transmission. Figure 4(b) shows the twist angle of the LC directors with +Δε. At Point f, the similar deformation occurred with the –Δε. However, at Points e and d, the variation of the LC directors was very large since the LC directors tried to orient itself parallel to the vertical component of a fringe field along a vertical distance.

Figure 5 shows the director profile of a tilt angle for the white state at the three positions. For the LC directors with –Δε that oriented itself perpendicular to the electric field, it was near 0° when z/d was above 0.5, but near the bottom surface, at Positions e and f, the tilt angle occurred. Therefore, for the LC directors with –Δε, the degree of tilt angle was not so high that the transmittance along electrode position was dominated by the twist angle. For the +Δε, the LC directors on the bottom substrate were drastically tilted to nearly 90°, at Position d, which had the strongest vertical field. At Positions e and f, a large amount of tilt angle existed, indicating that the cell retardation value at normal direction decreased, which caused increasing transmittance.

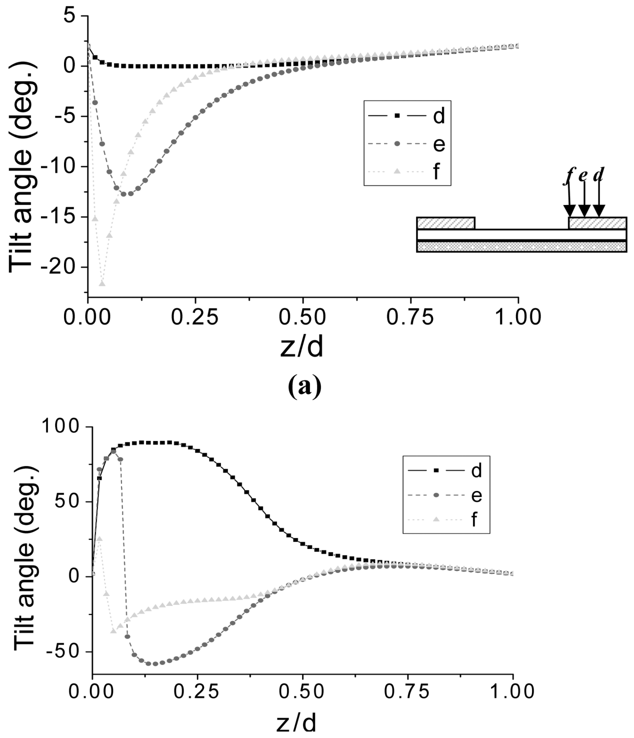
Therefore, for the +Δε, the transmittance was affected by the tilt angle, as well as by the twist angle. Figure 6 shows the iso-contrast ratio contour of the FF-TN mode. As shown



(a)

(b)

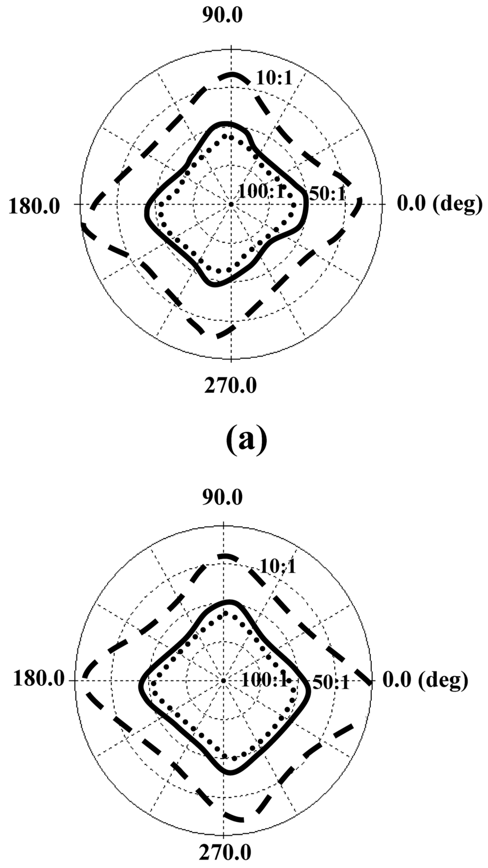
Fig. 4. Director profile of twist angle with (a)–Δε and (b) +Δε at three different positions.



(a)

(b)

Fig. 5. Director profile of tilt angle with (a) –Δε and (b) +LC at three different positions.



(b)

Fig. 6. Iso-contrast ratio contour for FF-TN mode with (a) –Δε and (b) +Δε.

in Fig. 6, both the –Δε and the +Δε showed a symmetric viewing angle and a contrast ratio greater than 10 existed over a polar angle of 50° in all directions. In this paper, the normally black mode was described only. However, by lowering the azimuthal anchoring energy from 10^{-4}J/m^2 to 10^{-6}J/m^2 or lower, the normally white mode with this configuration also became possible.[10]

4. SUMMARY

The polarity effects of dielectric anisotropy on the electro-optical characteristics of a twisted nematic mode driven by a fringe electric field, that has wide viewing angle characteristics were studied. The device was designed to be a normally black mode between parallel polarizers. The perfect polarization conversion of incident light, which passed through a polarizer, was achieved when it passed through the twisted Liquid Crystal (LC) layer. If an electric field was applied, the LC molecules with a positive (or negative) dielectric anisotropy rotated parallel (or perpendicular) to the horizontal component of a fringe electric field as the transmittance increased. The calculated transmittance with the +Δε was 10% higher than that of the –Δε, owing to the tilt up of the LC directors above the center of electrodes.

ACKNOWLEDGMENT

This work was supported by Korea Technology and Information Promotion Agency for Small& Medium Enterprises.

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