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Enhancing transmittance of fringe-field switching liquid crystal device by controlling perpendicular component of dielectric constant of liquid crystal

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In this paper, we briefly report the effect of the magnitude of the perpendicular component ($\varepsilon_\perp$) of the dielectric constant of liquid crystals with a positive dielectric anisotropy on the transmittance of a fringe-field switching liquid crystal device. The larger the $\varepsilon_\perp$, the more the tilt angle of the liquid crystal director near the edges of electrodes is reduced, thereby increasing the twist angle above the center of electrodes. Consequently, the transmittance of the device is significantly improved by controlling $\varepsilon_\perp$ of the liquid crystal.

The image quality of liquid crystal displays (LCDs) has been greatly improved owing to the development of various liquid crystal (LC) modes such as the film compensated twisted nematic (TN),[1] in-plane switching (IPS),[2,3] fringe-field switching (FFS),[4–7] and multi-domain vertical alignment (MVA)[8–10] modes. Recently, the display resolution has become increasingly higher to realize high image quality, and the FFS mode has been generally acknowledged to be suitable for such a high-resolution and high-performance display.[11] In general, the light efficiency of most commercialized LCDs is less than 10%, owing to the use of absorptive optical layers, such as color filters and polarizers, and also because of the limited aperture ratio and insufficient light efficiency of the LC layers. In addition, the aperture ratio decreases as the resolution increases, resulting in a deterioration of the transmittance. Therefore, maximizing the light efficiency in the LC layer is crucial for achieving high-transmittance and low-power-consumption LCDs.

The light efficiency in the FFS mode is well known to be dependent on many cell parameters such as electrode structure,[12–15] rubbing direction,[16] retardation value of the LC layer,[17,18] cell gap,[19,20] and sign and magnitude of dielectric anisotropy.[21–23] In general, the light efficiency of a LC layer with a negative dielectric anisotropy ($\Delta\varepsilon < 0$) is higher than that of the LC with a positive dielectric anisotropy ($\Delta\varepsilon > 0$). However, devices adopting LC with $\Delta\varepsilon > 0$ are dominant in the market owing to the crucial advantages of low operating voltage and short response time. In order for LCs with $\Delta\varepsilon > 0$ to show better performance, the light efficiency in the FFS mode with $\Delta\varepsilon > 0$ should be improved. In this study, we investigate the improvement of light efficiency by optimizing the perpendicular component of the dielectric constant ($\varepsilon_\perp$) of LCs for devices with positive dielectric anisotropy ($\Delta\varepsilon > 0$) LC material.

In the FFS mode, the LC is homogeneously aligned in the initial state with its optic axis coincident with one of the crossed polarizers so that the LC cell appears to be black in the voltage-off state. Figure 1 shows a cross-sectional view of the LC cell and director profile in the voltage-on state. As indicated by red and dark blue colors, two transparent electrodes are vertically separated by the thin passivation layer such that the common electrode is formed as a thin continuous layer beneath the orange passivation layer and the pixel electrode is patterned in a slit form with t electrode width w and distance l between the patterned electrodes. For the simulation, w, l, and passivation layer thickness have been chosen to be 3.0, 4.5, and 0.29 µm, respectively. The surface

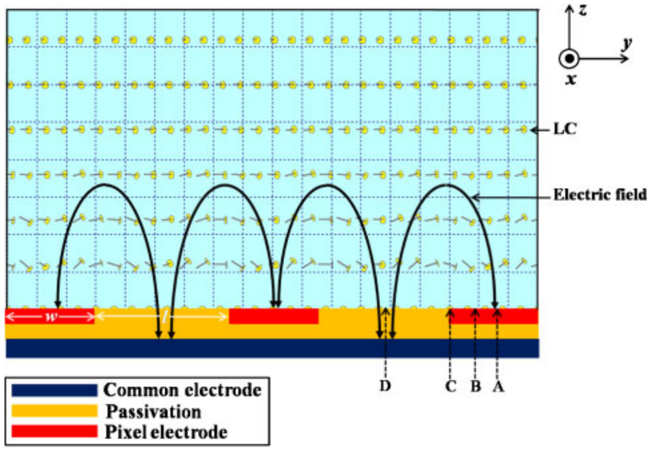

Fig. 1. (Color online) Cross-sectional view of the FFS cell with electrode structures, field direction and LC director profile in the voltage-on state.

pretilt angle at both surfaces is 2° and the cell gap has been chosen to be 4.0 µm. The physical properties of LC have been given as follows: dielectric anisotropy ($\Delta\varepsilon$) = 8.0 ($\varepsilon_{//}$ = 12.0, $\varepsilon_\perp$ = 4.0 at 1 kHz), birefringence (Δn) = 0.1 at 550 nm, and three elastic constants K_{11} = 9.7, K_{22} = 5.2, K_{33} = 13.3 pN.

Considering the electrode structure and electric field lines in the FFS mode shown in Fig. 1, the horizontal electric field (E_y), which enforces rotation of the LC director by dielectric torque, is not uniform along the y-direction so that the intensity of E_y is much higher at the edge of the electrode (position C) than ate position B, and it is zero at positions A and D in Fig. 1. The field distribution indicates that the LC director at positions A and D cannot be rotated by dielectric torque at all, giving rise to zero transmittance at these positions because the transmittance in the FFS mode is proportional to $\sin^2(2\Psi)$, where Ψ is the voltage-dependent azimuthal angle between the LC director and the transmission axis of the crossed polarizer. According to our previous studies,[19] the LC director at position A can be rotated by the elastic torque originating from nearby LCs at position B. Owing to the larger Ψ at position B and elastic distortion, Ψ at position A becomes larger, resulting in significant transmittance even at the electrode position A. In the conventional FFS cell with the above mentioned cell parameters, a lower transmittance at position A than at electrode positions B and C is observed when a LC with $\Delta\varepsilon$ = 8.0 is used, as shown in Fig. 2. This confirms that the LC director at position B,

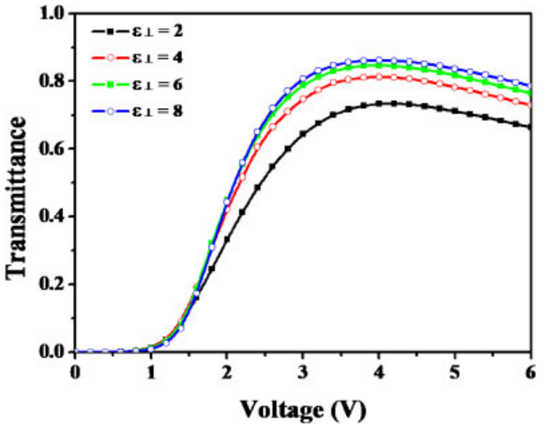

Fig. 2. (Color online) Voltage–dependent transmittance curves of the FFS cells with different magnitudes of perpendicular component of dielectric constant ($\varepsilon_\perp$) of the LC at the $\Delta\varepsilon = 8.0$.

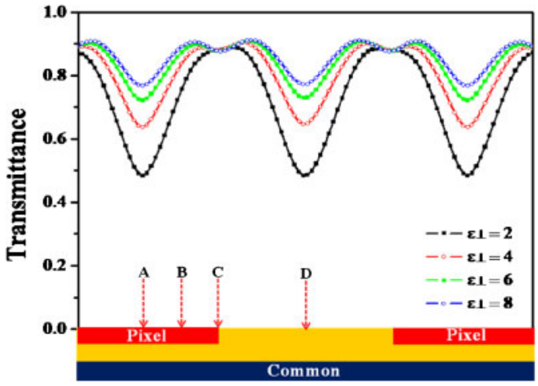

Fig. 3. (Color online) Variations of transmitted light intensity at different locations with respect to the electrodes. Graphs for four different values of the perpendicular component of the dielectric constant are presented for the dielectric anisotropy fixed at 8.0.

where both E_y and E_z coexist, is not rotated sufficiently to give a large Ψ at position A, resulting in relatively low transmittance compared with other regions. On the basis of this principle, we found that controlling the physical properties of LC either by reducing the dielectric anisotropy of the LC with $\Delta\varepsilon > 0$ or using the LC with $\Delta\varepsilon < 0$ would improve the transmittance at position C by suppressing the field-induced director tilt at position B. In particular, when the LC with $\Delta\varepsilon < 0$ and a larger value of $\varepsilon_\perp$ is employed, the LC director tends to reorient perpendicularly to the field direction from the initial homogenous alignment. Therefore, the director tilt at position B is greatly reduced, resulting in a larger in-plane component of the LC optic axis and subsequent high transmittance at position A compared with the case of using LC with $\Delta\varepsilon > 0$. This also implies that the LC with a larger value of $\varepsilon_\perp$ is advantageous in achieving a high transmittance, since it decreases the tilt angle at position B.

Although the LC with a negative dielectric anisotropy is favored for high transmittance in the FFS mode, the magnitude of $\Delta\varepsilon$ for a commercialized LC mixture with $\Delta\varepsilon < 0$ is relatively low, close to or below |4| so that the operating voltage is higher than that ($\Delta\varepsilon > 8$) of the LC with $\Delta\varepsilon > 0$ in mobile LCDs. On the other hand, the rotational viscosity of the material with $\Delta\varepsilon < 0$ is higher than that of the LC with $\Delta\varepsilon > 0$, indicating that the response of the FFS mode becomes slower when the LC with $\Delta\varepsilon < 0$ is used. For these reasons, the LC with a positive dielectric anisotropy is still mainly employed in the FFS mode.

Then, the question of how to improve the transmittance in the FFS mode using the LC with $\Delta\varepsilon > 0$ while keeping the magnitude of dielectric anisotropy high arises. One possible approach is to dope the LC with $\Delta\varepsilon < 0$ into the LC with $\Delta\varepsilon > 0$. When the target value of $\Delta\varepsilon$ for a positive anisotropy is 8.0, the LC with $\Delta\varepsilon > 8.0$ is selected and then the LC with a negative anisotropy is doped into the positive one, giving rise to $\Delta\varepsilon = 8.0$. In this case, however, the value of $\varepsilon_\perp$ for the new mixture should be increased while the value of $\varepsilon_\parallel$ should be either decreased or increased by a smaller amount than the increase in the $\varepsilon_\perp$ value. In order to confirm whether the increased value of $\varepsilon_\perp$ of the LC mixture with $\Delta\varepsilon > 0$ affects transmittance or not, simulations have been performed using the commercially available program (Two-Dimensional LCD Maters by Shintech). Four different LCs with the value of $\Delta\varepsilon$ fixed at 8.0 and the values of $\varepsilon_\perp$ corresponding to 2.0, 4.0, 6.0, and 8.0 have been tested because a typical value for a conventional commercialized LC mixture is about 4. Figure 2 shows voltage–dependent transmittance (V–T) curves with various magnitudes of $\varepsilon_\perp$. As clearly observed, the shapes of V–T curves are similar to each other. Also, the operating voltages at which the maximal transmittance occurs are the same because the operating voltage is proportional to $(\Delta\varepsilon)^{-1/2}$. However, the variation of transmittance is obviously significant. As $\varepsilon_\perp$ varies from 2.0 to 8.0, the transmittance increases from 0.73 to 0.86. The improvement ratio of transmittance is 17.5%. The origin of transmittance improvement has been investigated by examining the transmittance in relation to the electrode positions along the y-direction at the applied voltage for the maximum transmittance in each case. As seen in Fig. 3, the transmittance at position C is the same in all cases; however, the difference in transmittance at positions A, B, and D becomes larger as $\varepsilon_\perp$ increases. It is evident that increasing the value of $\varepsilon_\perp$ while maintaining the magnitude of $\Delta\varepsilon$ improves the transmittance of the FFS cell with the LC with $\Delta\varepsilon > 0$ at a fixed operating voltage.

The method for enhancing the transmittance of FFS-LCD using the LC with positive dielectric anisotropy has been investigated. Increasing the perpendicular component of the dielectric constant of the LC mixture with $\Delta\varepsilon > 0$ improves the transmittance. The proposed concept will help the enhancement of the light efficiency of the FFS-LCD incorporating the LC material with positive dielectric anisotropy while maintaining the operating voltage the same.

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1) H. Mori, J. Disp. Technol. **1**, 179 (2005).
2) M. Oh-e and K. Kondo, Appl. Phys. Lett. **67**, 3895 (1995).
3) M. Ohta, M. Oh-e, and K. Kondo, Asia Display, 1995, p. 707.
4) S. H. Lee, S. L. Lee, and H. Y. Kim, Appl. Phys. Lett. **73**, 2881 (1998).
5) S. H. Lee, S. L. Lee, and H. Y. Kim, Asia Display, 1998, p. 371.
6) S. H. Lee, S. L. Lee, H. Y. Kim, and T. Y. Eom, SID Symp. Dig. Tech. Pap. **30**, 202 (1999).
7) S. H. Lee, S. H. Hong, J. M. Kim, H. Y. Kim, and J. Y. Lee, J. Soc. Inf. Disp. **9**, 155 (2001).
8) A. Takeda, S. Kataoka, T. Sasaki, H. Chida, H. Tsuda, K. Ohmuro, T.

Sasabayashi, Y. Koike, and K. Okamoto, SID Symp. Dig. Tech. Pap. **29**, 1077 (1998).
9) S. H. Lee, S. M. Kim, and S.-T. Wu, J. Soc. Inf. Disp. **17**, 551 (2009).
10) K. Miyachi, K. Kobayashi, Y. Yamada, and S. Mizushima, SID Symp. Dig. Tech. Pap. **41**, 579 (2010).
11) S. H. Lee, S. S. Bhattacharyya, H. S. Jin, and K.-U. Jeong, J. Mater. Chem. **22**, 11893 (2012).
12) S. H. Lee, S. L. Lee, H. Y. Kim, and T. Y. Eom, J. Korean Phys. Soc. **35**, 1111 (1999).
13) I. H. Yu, I. S. Song, J. Y. Lee, and S. H. Lee, J. Phys. D **39**, 2367 (2006).
14) J. W. Park, Y. J. Ahn, J. H. Jung, S. H. Lee, R. Lu, H. Y. Kim, and S.-T. Wu, Appl. Phys. Lett. **93**, 081103 (2008).
15) H. J. Yun, M. H. Jo, I. W. Jang, S. H. Lee, S. H. Ahn, and H. J. Hur, Liq. Cryst. **39**, 1141 (2012).
16) S. H. Hong, I. C. Park, H. Y. Kim, and S. H. Lee, Jpn. J. Appl. Phys. **39**, L527 (2000).
17) S. H. Jung, H. Y. Kim, S. H. Song, J.-H. Kim, S.-H. Nam, and S. H. Lee, Jpn. J. Appl. Phys. **43**, 1028 (2004).
18) S. M. Oh, S. J. Kim, M.-H. Lee, S. H. Lee, J.-Y. Hwang, and D.-S. Seo, Mol. Cryst. Liq. Cryst. **433**, 97 (2005).
19) S. H. Jung, H. Y. Kim, M. H. Lee, J. M. Rhee, and S. H. Lee, Liq. Cryst. **32**, 267 (2005).
20) S. J. Kim, H. Y. Kim, S. H. Lee, Y. K. Lee, K. C. Park, and J. Jang, Jpn. J. Appl. Phys. **44**, 6581 (2005).
21) H. Y. Kim, S.-H. Nam, and S. H. Lee, Jpn. J. Appl. Phys. **42**, 2752 (2003).
22) J. W. Ryu, J. Y. Lee, H. Y. Kim, J. W. Park, G.-D. Lee, and S. H. Lee, Liq. Cryst. **35**, 407 (2008).
23) S. H. Lee, J. H. Jung, K. S. Ha, M. Chae, A. K. Srivastava, S.-E. Lee, and H. K. Lee, J. Korean Phys. Soc. **56**, 548 (2010).

