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Color Shift Free Newly Two-Domain Fringe-Field Switching Mode

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The fringe-field switching (FFS) mode is a representative mode exhibiting both a wide viewing angle and high transmittance due to the in-plane rotation of the liquid crystal (LC) director. However, it shows a color shift in off-normal directions, especially along perpendicular and parallel to the director in the on state, since the LC director only rotates in one direction. To solve this problem, we suggested a new cell structure with pixel electrodes which remain in a 90° rotational symmetry. This structure allows the LCs existing in the top and bottoms halves in the center of a pixel to remain in a 90° rotational symmetry from the off state to the on state. As a result, the light that passes through the long axis of the LC in an oblique direction passes through the short axis of the LC director, and the color shift is minimized due to the ideal self-compensation. Therefore, it shows good color gamut characteristics across its range, irrespective of the applied voltage in the wide viewing directions. [DOI: 10.1143/JJAP.45.887]

KEYWORDS: fringe field switching, 90° rotational symmetry, color shift

1. Introduction

Recently, the image quality of liquid crystal displays (LCDs) has been greatly improved by the development of various LC modes. Among of them, the most common type is the twisted nematic (TN)[1] mode. This mode was generally adopted for use in notebook computers and monitors because of its simple structure, low weight, and low electric power consumption. However, it also has some disadvantages, such as a narrow viewing angle, and a slow response. With regard to visibility from the oblique direction to the LCD, the serious problems such as a reversal of the gray scale and a color shift have been noted.

In order to solve these problems, the in-plane field switching (IPS)[2,3] mode and the fringe-field switching (FFS)[4–7] mode that utilize the concept of an in-plane rotation of the LC director has been suggested and developed. They show both good electrooptic properties and a wide viewing angle characteristic. Actually when a voltage is applied to these modes, in-plane and fringe fields are generated, and the driving field is different. As a result, their electrooptic characteristics are different. Notably, the FFS mode shows much higher transmittance than the IPS mode, because the LCs at the center of the pixel electrode rotate. However, these modes with in-plane rotation of LCs show a color shift at off-normal directions, especially along perpendicular and parallel to the director in the on state, since the LC director only rotates in one direction.

This problem was greatly improved using the multi-domain technique with which the LC directors rotate in various directions when the voltage is applied. For most of them, the two domain (2D) method using wedge-shaped pixel electrodes having a 180° rotational symmetry in the top and bottom halves direction along the center axis of a pixel was the most general.[8] For this structure, two different field directions are produced inside a pixel so that with a bias voltage, the LC molecules rotate in two directions, clockwise and counterclockwise, virtually imitating a two domains.[9,10] Therefore, a much smaller color shift occurs compared with single domain (1D) structures, but the color shift is not fully compensated if the applied voltage is low because of the small angle between the LCs existing in the opposite direction. The self-compensation effect is also maximized when the LC directors are perpendicular to each other, resulting in the minimization of the color shift.

Therefore, we proposed a new 2D FFS cell structure in which the pixel electrodes remain at a 90° rotational symmetry. We also proved that it reduced the degree of color shift as the viewing direction changed, especially when a low voltage was applied and the high color range in the wide viewing directions, irrespective of the applied voltage with a three-dimensional simulation was demonstrated.

2. Simulation Results and Discussion for the New 2D FFS Mode

The normalized-light transmission of a device used a birefringent LC medium under a crossed polarizer is given by

$$T/T_0 = \sin^2(2\psi)\sin^2(\pi d\Delta n(\theta,\phi)/\lambda),$$

where ψ is the angle between one of the transmission axes of the crossed polarizers and the LC director, Δn is the birefringence of the LC medium, d is the cell gap, λ is the wavelength of incident light, and θ, ϕ represent polar and azimuthal angles in spherical coordinates, respectively. From the equation, one can understand that the wavelength showing maximum transmission can be varied depending on the value of $d\Delta n$. In other words, the white color can be shifted to bluish and yellowish as the value of $d\Delta n$ becomes smaller and larger, respectively. As already mentioned, this color shift was observed at off-normal directions, especially along perpendicular and parallel to the director in the on state for these modes with in-plane rotation only in one direction, such as the IPS mode or the FFS mode. To solve this problem, a 2D structure with a wedge-shape pixel electrode was suggested.

Figure 1 shows the top view of conventional and new 2D FFS cell structures in the off state and the on state, respectively. In the conventional structure, the pixel electrodes with a patterned slit have a 180° rotational symmetry

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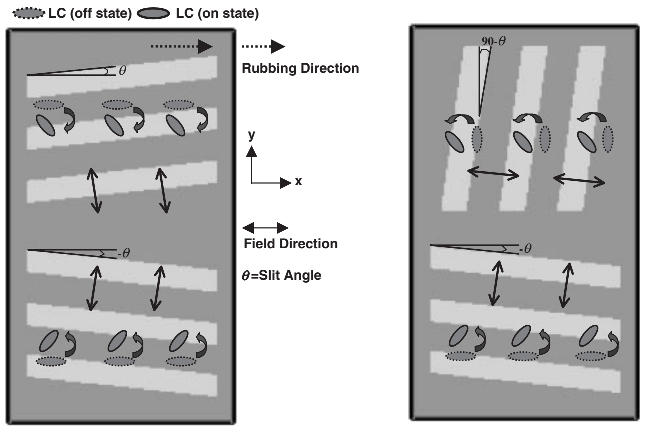

Fig. 1. Top view of structure for the different 2D FFS structures with the off state and the on state: (a) the conventional structure, (b) the newly designed structure.

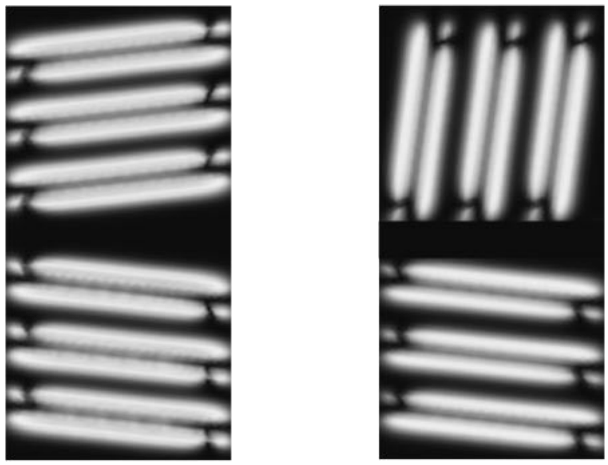

Fig. 2. Transmittance for the different 2D structures: (a) the conventional structure and (b) the newly designed structure.

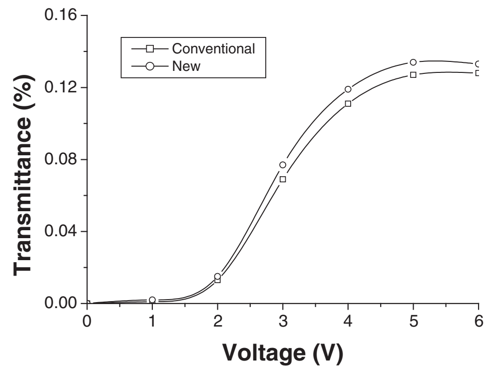

Fig. 3. The V–T curve for the different 2D structures: (a) the conventional structure and (b) the newly designed structure.

in the top and bottom halves along the center of a pixel, where the slit angles of the pixel electrode at the top and bottom are θ and $-\theta$, and θ is 7°. The rubbing angle is 0° with respect to the horizontal field (E_x). When a bias voltage is applied, the LCs rotate in two opposite directions, clockwise and counterclockwise. At that time, because LC directors rotate in two opposite directions and, in the white state, the LC directors are perpendicular to each other, the light that passes through the long axis of the LC in an oblique direction passes through the short axis of the LC director. As a result, the color shift is dramatically reduced due to the self-compensation effect. But, since the effect is greatest when the angle between the LC directors which exist in the opposite direction, is 90°, the color shift increases as the applied voltage is decreased.

On the other hand, in the new 2D structure, the pixel electrodes have a 90° rotational symmetry in the top and bottom halves along the center in a pixel, where, the slit angles of the pixel electrode at the top and bottom are $(90 - \theta)$ and $-\theta$, and θ is 7°. The rubbing angles at the top and bottom are 90 and 0°, respectively. Multi rubbing is possible, using the rubbing methods such as the photoalignment and ion beam. When a bias voltage is applied, the LCs rotate only in one direction, counterclockwise, with a 90° rotational symmetry, as shown in Fig. 1(b). This indicates that for the newly designed 2D structure LCs from the off state to the on state are fully perpendicular to each other so that the color shift is minimized due to an ideal self-compensation effect, irrespective of the applied voltage.

For the detailed analysis of electrooptic or color characteristics for the newly designed 2D FFS structure, we used the commercially available software "Techwiz LCD" (Sanayisystem, Korea), where the motion of the LC director is calculated on the basis of the Eriksen–Leslie theory and a 2×2 Jones matrix[11] is applied to calculate optical transmittance. The electrode design used in the FFS mode was the same as in the previous paper.[12] The surface pretilt angle generated by rubbing was 2° and the cell gap was 4.0 μm. The LCs with positive dielectric anisotropy ($\Delta n = 0.1$ at $\lambda = 589$ nm, $\Delta\varepsilon = 8.0$ at 1 kHz) were used in the simulation.

Figure 2 shows the transmittance for the different 2D FFS structures with an operation voltage. Here, Figs. 2(a) and 2(b) show the conventional 2D structure and the new 2D structure, respectively. As it appears, the white state is similar for these structures, and the aperture ratio of the new structure is larger than that of the conventional structure due to the vertically aligned top pixel electrodes. Figure 3 shows the calculated voltage–dependent transmittance (V–T) curves for the different 2D FFS structures. As already mentioned, the maximum transmittance of the new 2D FFS structure with a wide aperture region is about 4% higher compared with the conventional 2D structure, while their V–T characteristics are similar. But, for the color characteristics, the new 2D FFS structure with a 90° rotational symmetry of LCs in both the off state and the on state is more favorable compared with the conventional structure.

Figure 4 shows the color gamut range according to the voltage for the different 2D structures. Here, the azimuthal angle was fixed to 45°, at which angle the color shift is clearly observed, and also the polar angle changed from 0 to the 80° with increasing steps of 20°. In the conventional structure as shown in Fig. 4(a), the color range dramatically decreases as the applied voltage decreases. The color gamut is less than 11% at 0° in the polar direction when the applied voltage is 1 V because the angle between the LCs which

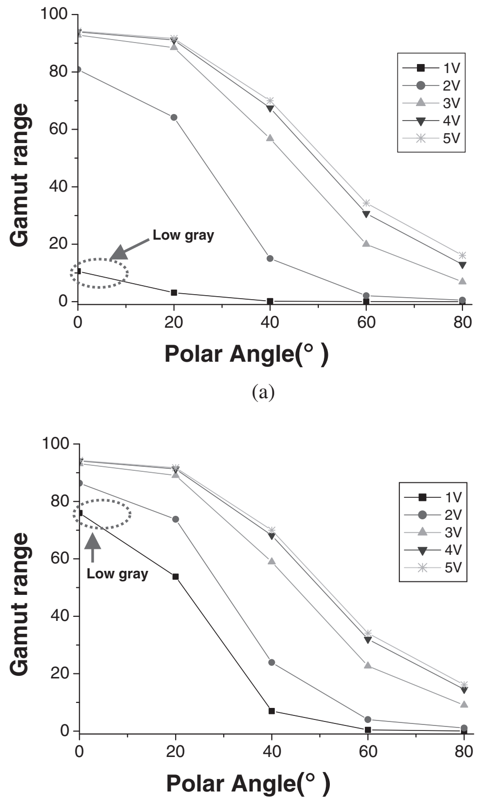

Fig. 4. Color gamut according to the applied voltage for the different 2D structures: (a) the conventional structure and (b) the newly designed structure.

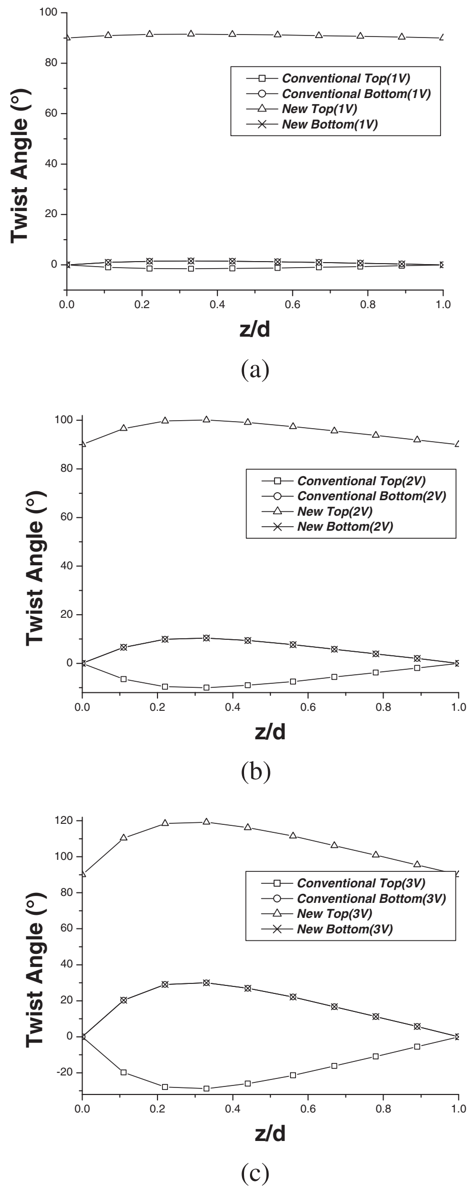

Fig. 5. Profile of the twist angle of the LC according to the applied voltage for different 2D structures: (a) 1, (b) 2, and (c) 3 V.

exists in the opposite direction, is very small, generating a large color shift. The color gamut also increases as a high voltage is applied. On the other hand, the color gamut remains as high as 76% of NTSC standard, at 0° in the polar direction, although a low voltage of 1 V is applied to the new 2D structure as shown in Fig. 4(b). The results show that for the newly designed 2D structure, the self-compensation effect is very excellent as the LC directors become perpendicular to each other from the dark state to the white state. As a result, the color shift is minimized and the high color gamut appears, even if the applied voltage is decreased.

To analyze this phenomenon in detail, we observed the profile of the LC director. Figures 5(a)–5(c) show the twist angles of the LCs along the vertical axis, which is the z direction according to the voltage for the 2D FFS structures, where, the voltage was applied up to 3 V corresponding to the mid gray state (the maximum transmittance of 50%). When applying 1 V, the maximum twist angle between the LCs which exist in the opposite direction along the center of one pixel is less than 4° near 0.3 of z/d for the conventional structure; in comparison it remains 90° for the new structure. Next, in the case of 2 V, the maximum twist angle between the LCs which exists in the opposite direction along the center of one pixel is more than 20° near 0.3 of z/d for the conventional structure; in comparison it remains constant at 90° for the new structure. Finally, in the case of 3 V, the maximum twist angle between the LCs which exist in the opposite direction along the center of one pixel is about 60° near 0.3 of z/d for the conventional structure; in comparison it also remains constant at 90° for the new structure. This result shows that the maximum twist angle between LCs existing in the opposite direction becomes large as the applied voltage increases for the conventional 2D structure, resulting in becoming close to 90°, while it always remains 90° for the new 2D structure, irrespective of the applied voltage.

Therefore, the newly designed 2D FFS structure exhibits a good color gamut range of about 76% at the 0° in the polar direction and 45° in the azimuthal direction, even at the low applied voltage of 1 V, because the color shift is minimized due to the ideal self-compensation effect.

3. Conclusions

Generally, the FFS mode exhibits a color shift due to the in-plane rotation of LCs only in one direction, in off normal directions, especially along perpendicular and parallel to the director in the on state. To solve this problem, we suggested a newly designed two domain FFS structure with pixel electrodes which remain at 90° rotational symmetry. The structure allows the LCs existing in the top and bottoms halves along the center in a pixel to remain counterclockwise at a 90° rotational symmetry from the off state to the on state, so that a color shift is minimized due to the ideal self-compensation, unlike the behavior of the conventional 2D structure. Therefore, it has characteristics of a good color gamut range above 76% at 0° in the polar direction and at 45° of the azimuthal direction, irrespective of the applied voltage. We can also predict that the newly designed 2D FFS structure is very useful for applications in need of true color characteristics such as LCD-television products.

1) H. Mori and P. J. Bos: SID Int. Symp. Dig. Tech. Pap. **29** (1998) 830.
2) S.-K. Lee, Y. H. Jeung and D. S. Seo: Trans. EEM **4** (2003) 7.
3) H. Y. Kim, I. S. Song and S. H. Lee: Trans. EEM **4** (2003) 24.
4) S. H. Hong, I. C. Park, H. Y. Kim and S. H. Lee: Jpn. J. Appl. Phys. **39** (2000) 527.
5) H. Y. Kim, S. H. Hong, J. M. Rhee and S. H. Lee: Liq. Cryst. **30** (2003) 1287.
6) J. D. Noh, H. Y. Kim, J. M. Kim, J. W. Koh, H. S. Park and S. H. Lee: Proc. 2nd IDMC, 2002, p. 447.
7) H. Y. Kim, S. H. Nam and S. H. Lee: Jpn. J. Appl. Phys. **42** (2003) 2752.
8) H. Y. Kim, G. R. Jeon, M.-H. Lee and S. H. Lee: Jpn. J. Appl. Phys. **41** (2002) 2944.
9) S. Aratani, H. Klausmann, M. Oh-e, M. Ohta, K. Ashizawa, K. Yanagawa and K. Kondo: Jpn. J. Appl. Phys. **36** (1997) L27.
10) S. H. Hong, H. Y. Kim, M.-H. Lee and S. H. Lee: Liq. Cryst. **29** (2002) 315.
11) A. Lien: Appl. Phys. Lett. **57** (1990) 2767.
12) M. S. Kim, Y. H. Jung, S. M. Seen, H. Y. Kim, S. Y. Kim, Y. J. Lim and S. H. Lee: Jpn. J. Appl. Phys. **44** (2005) 3121.