Viewing Angle Characteristics of the Ultra-FFS TFT-LCD

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Abstract
We report viewing angle characteristics of the Ultra-FFS TFT-LCD. The FFS mode is known to exhibit both a wide viewing angle and high transmittance, owing to the approximated in-plane rotation of the LC director. Nevertheless, in the bright state, the device shows bluish and yellowish color parallel and perpendicular to the LC director at off-normal directions since the LC director rotates only in one direction, and in addition, the grey scale inversion exists in large oblique viewing angle. However, the Ultra-FFS shows no grey scale inversion and no color shift in wide viewing angle range.

1. Objectives and Background
Recently, the image quality of the liquid crystal displays (LCDs) has been improved greatly with development of the new LC modes. Notably, among them are both in-plane field switching (IPS)[1-3] and the fringe-field switching (FFS)[4-7] modes that utilize the concept of in-plane rotation of the LC director. When a voltage is applied, in-plane and fringe fields are generated, enabling the LC molecules to rotate in plane and almost in plane in the IPS and the FFS modes, respectively; thus, the cell appears to be white. Since the driving field is different in each device, the electro-optic characteristics of both modes are different from each other. Notably, the FFS mode shows much higher transmittance than that of the IPS mode. However, both modes show relatively good uniformity in transmittance compared with that of the twisted nematic mode, owing to the in-plane rotation of the LC director. Nevertheless, both devices 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. In addition, the grey scale inversion exists in some oblique viewing angles.

In order to solve such problems, the Ultra-FFS mode was suggested[8]. In the device, the pixel electrode has a wedge shape to generate electric fields in two directions such that the LC director rotates in two directions. In this way, the iso-contrast curve shows four-fold symmetry with high contrast in wide viewing angle range without grey scale inversion.

2. Results and Discussions
The normalized light transmission of a device with a birefringent LC medium under a crossed polarizer is given by:

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

where ψ is an angle between one of the transmission axes of the crossed polarizers and the LC director, Δn is the birefringence of LC medium, d is a cell gap, λ is the wavelength of an 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. This was observed in the IPS mode[9] and a similar effect was also observed in the FFS mode. Fig. 1 shows the top view of one pixel structure of the 1-D and 2-D (Ultra) FFS modes with a thin-film transistor (TFT) when using the LC with negative dielectric anisotropy. In the 1-D FFS mode, the pixel electrodes are patterned in a slit form such that the field direction of the horizontal component of the fringe field is horizontal. In this mode, the rubbing direction was 12° with respect to the horizontal field (E_y). Therefore, with applied voltage, the LC director rotates only in one direction clockwise. In the 2-D FFS mode, the pixel electrodes are patterned in a wedge shape such that the field directions of the horizontal component of the fringe field in a pixel are two, i.e., the direction of E_y in the top and bottom half of one pixel are symmetrically different along the center of a pixel. The rubbing direction is vertical, and the LC director has an angle of 12° with respect to E_y. In this mode, the LC molecules rotate in two opposite directions from initial alignment with applied voltage, i.e., clockwise and counterclockwise.

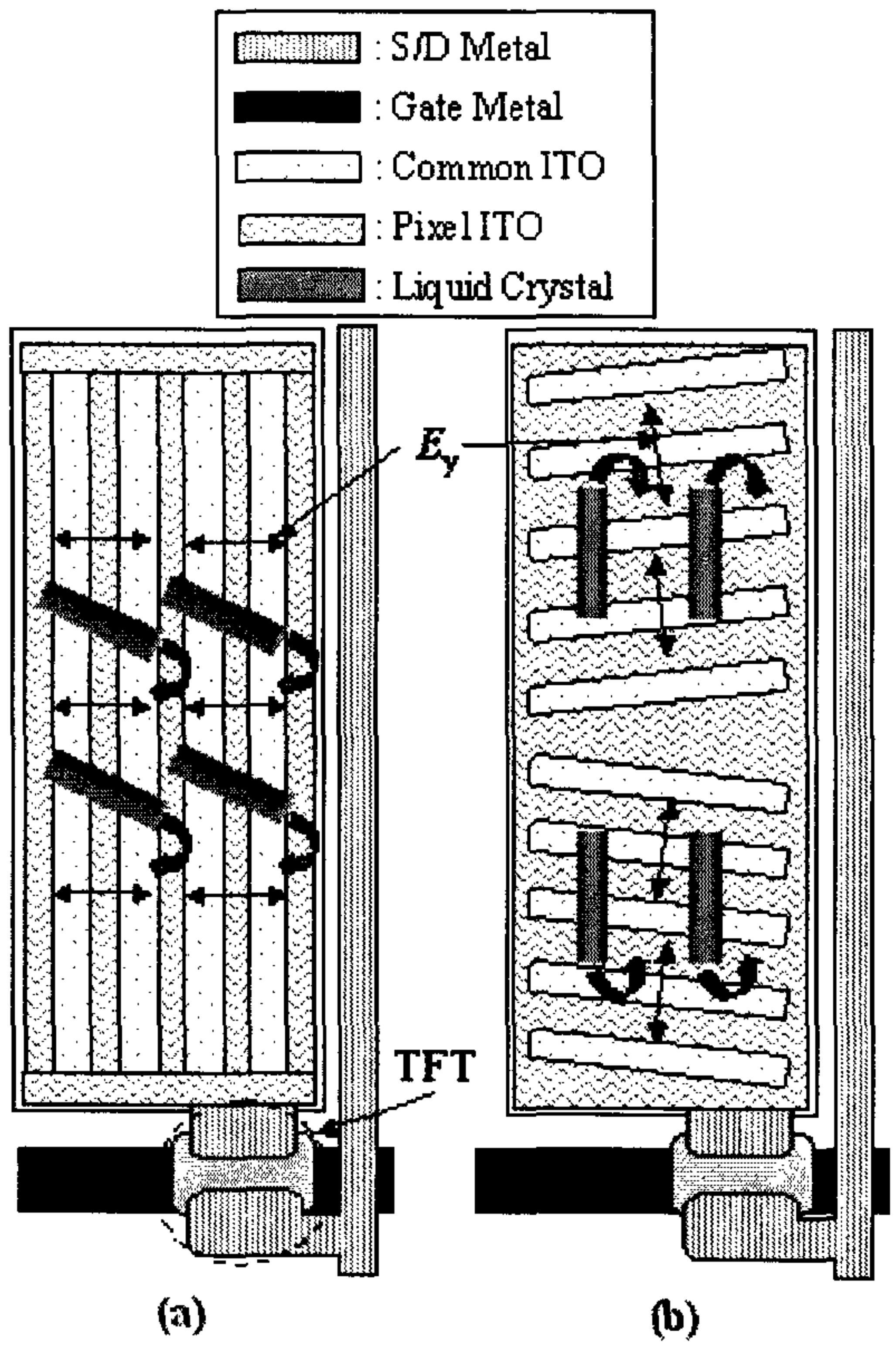

Figure 1. One pixel structure of the FFS device with TFT for (a) 1-D and (b) 2-D.

Fig. 2 describes a configuration of the LC director in the off and on state for the FFS mode with 1-D and 2-D. In the 1-D device, although the degree of rotation of the mid-director is dependent on horizontal position as described previously, the LC director rotates in one direction so that the normally directed white color shifts to a bluish or yellowish color in oblique directions along parallel and perpendicular planes with respect to the LC director in the on state. This coloration effect occurs because the $d\Delta n$ along parallel and perpendicular to the LC director become smaller and larger than that at a normal direction. However, in the 2-D device, such a behavior is not observed since the LC director rotates in two opposite directions and in the white state, the LC directors are perpendicular to each other. The light that passed through the long axis of the LC director in an oblique direction passes through the short axis of the LC director, i.e., the $d\Delta n$ in the directions that show color shift in the 1-D device become the same in the 2-D device. Consequently, the color shift is minimized due to a self-compensation effect.

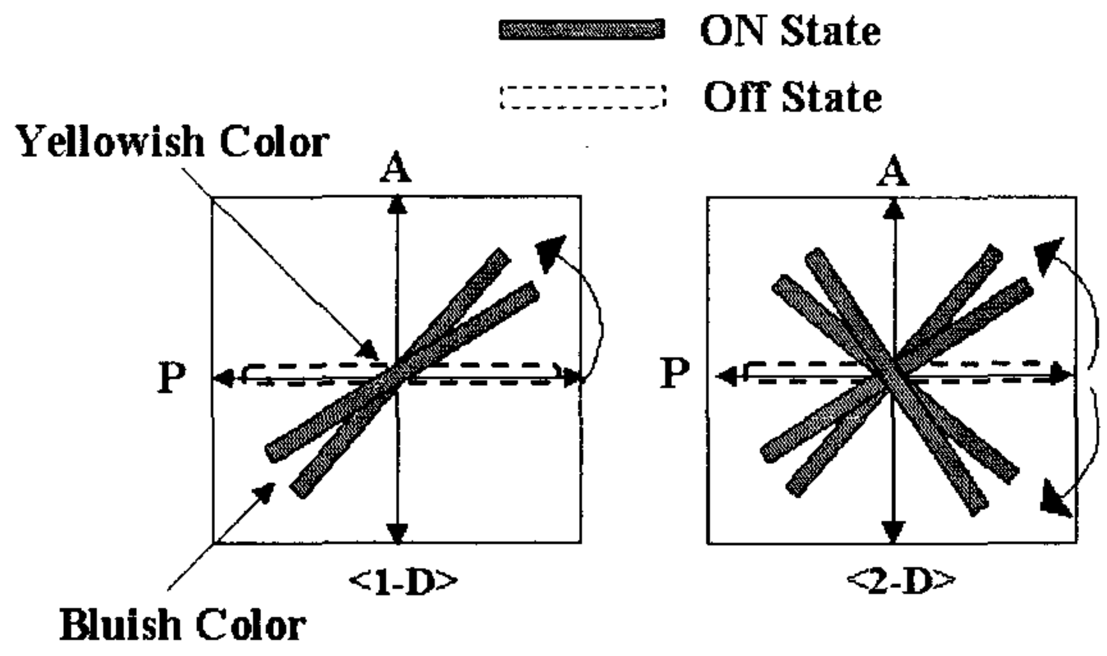

Figure 2. Configuration of the LC director in the off and the on states in the FFS mode with 1-D and 2-D.

Experimentally, we investigated the difference between the 1-D and the 2-D devices in terms of iso-luminance and iso-contrast curves, and color shift. All data were obtained by increasing the polar angle up to 70° with an increasing step of 10° in all azimuthal angles with an increasing step of 15°. Fig. 3 shows the iso-luminance curves of the FFS mode with 1-D and 2-D at transmissions of 50% (mid-grey) and 100% (white) with respect to maximum transmission at a normal direction. At mid-grey state, the shape of the iso-luminance curves in the 2-D device is much more axially symmetrical than those in the 1-D device, meaning that the viewing angle dependency of the light transmission is stronger in the 1-D device than in the 2-D device. In the white state, this phenomenon is reduced in both devices, and the shape of the iso-luminance curves in the 1-D device is elliptic; however, they are almost axially symmetrical in the 2-D device, meaning that in the 2-D device, the displayed image at an arbitrary polar angle is about the same, even though the viewing direction changes in all directions. Fig. 4 shows iso-contrast curves of the FFS device with 1-D and 2-D. In the 1-D device, the region where the contrast ratio is smaller than 10 exists in certain directions with a polar angle over 60 °, and the region where the contrast ratio is greater than 100 is not axially symmetrical. In the 2-D device, the CR is higher than 10 in all directions with a polar angle up to 70°; a CR over 100 extends to the region over 70° of polar angle in vertical and horizontal directions. Furthermore, it has four-fold symmetry. Conclusively, the 2-D device has a better viewing angle in terms of the CR. We have also checked if the grey scale inversion exists or not using 9 grey levels in the sectional plane from 24° to 204° of the azimuthal direction.

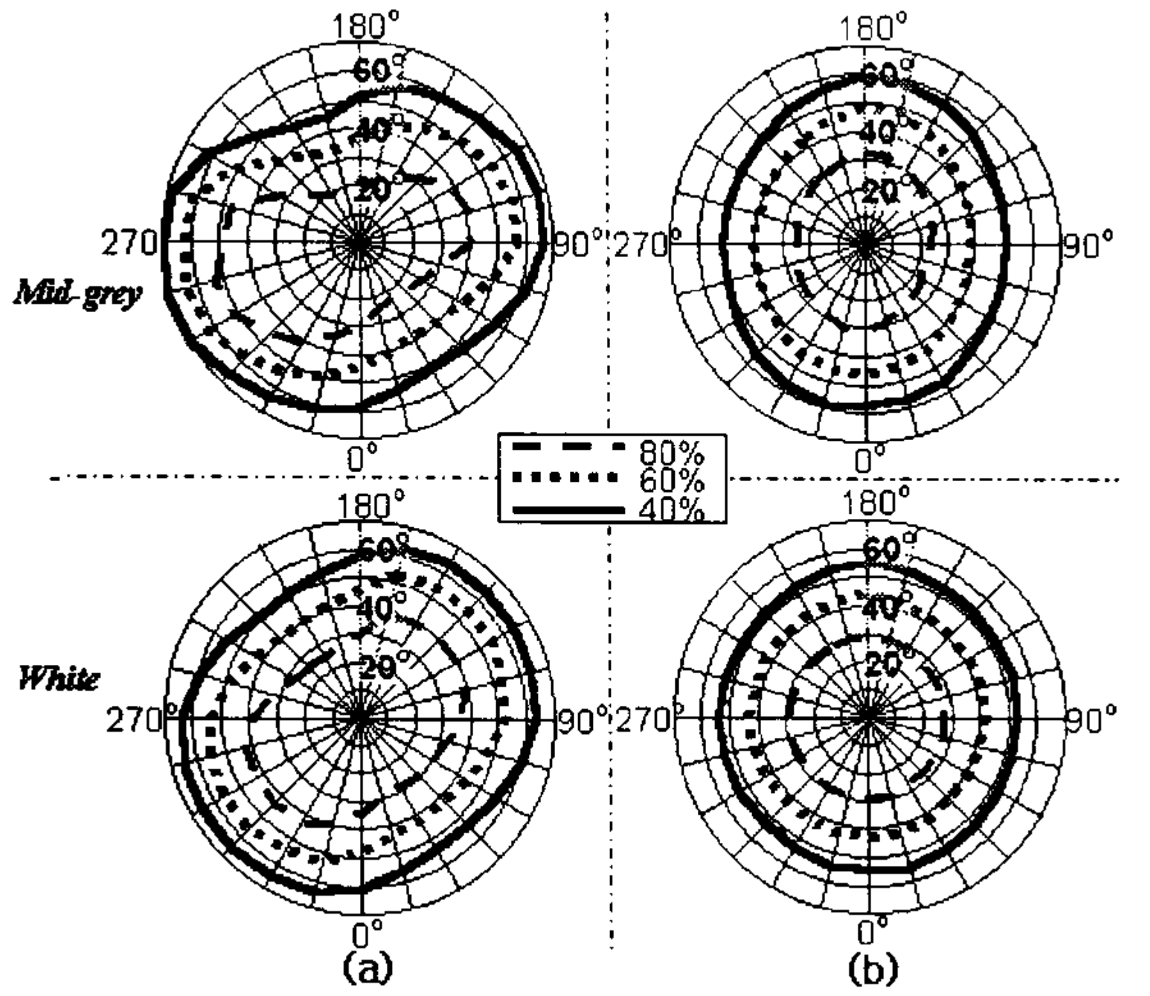

Figure 3. Iso-luminance contour of the FFS mode with (a) 1-D and (b) 2-D at mid-grey level and white state. Here, the numbers in the boxes indicate light transmission in % with respect to maximum transmission at normal direction.

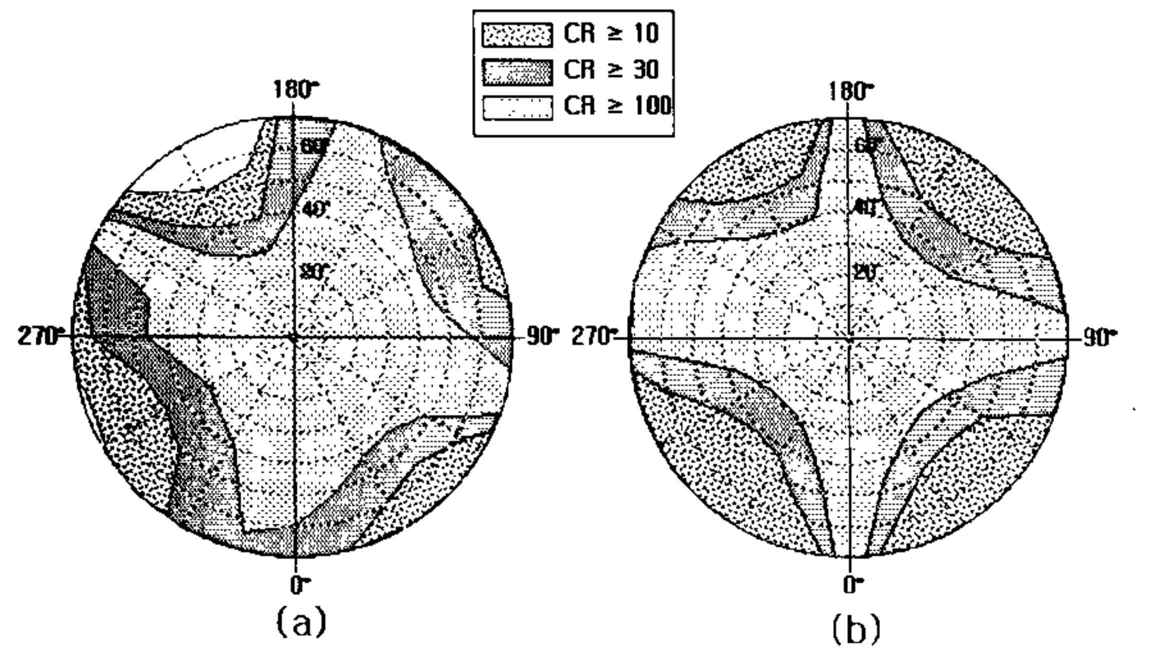

Figure 4. Iso-contrast contour of the FFS mode with (a) 1-D and (b) 2-D.

As shown in Fig. 5, for 1-D device, it starts to occur over a 30° polar angle but for the 2-D device, it does not exist at all even at a 70° polar angle. The results indicate that the FFS device only with 2-D can realize the CRT-like image. Finally, we investigated the color characteristics when the surface luminance is 50% and 100% of maximum transmission at a normal direction. As already was mentioned, the bright state of the 1-D device shows color change in certain viewing directions when observed by the naked eye. We measured the color coordinates of both devices by changing viewing directions, as shown in Fig. 5. In the 1-D device at mid-grey, the color coordinate (x, y) at a normal direction is (0.333, 0.366) but shifts strongly with a maximum difference of about (0.2, 0.1) as the viewing direction changes. However, the color shift of the 2-D device is much smaller than that in the 1-D device. In the white state, the color coordinate (0.326, 0.371) at normal direction still shifts quite strongly in the 1-D device, but in the 2-D device, the color shift does not occur almost at all. The degree of dispersion of the data proves it well.

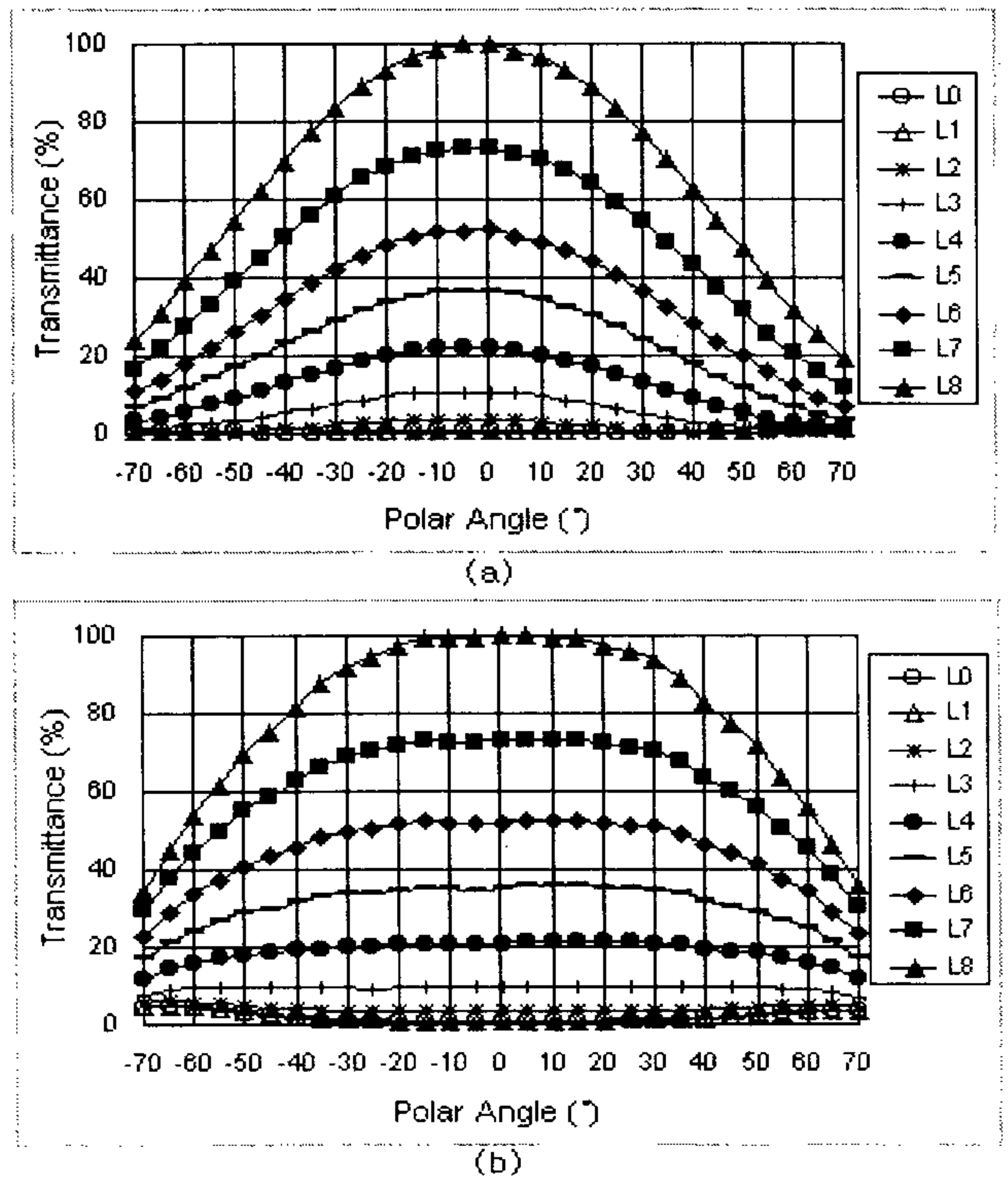

Figure 5. The transmittance in 9 grays of the FFS mode with (a) 1-D and (b) 2-D structures in the sectional plane from 24° to 204° of the azimuthal direction.

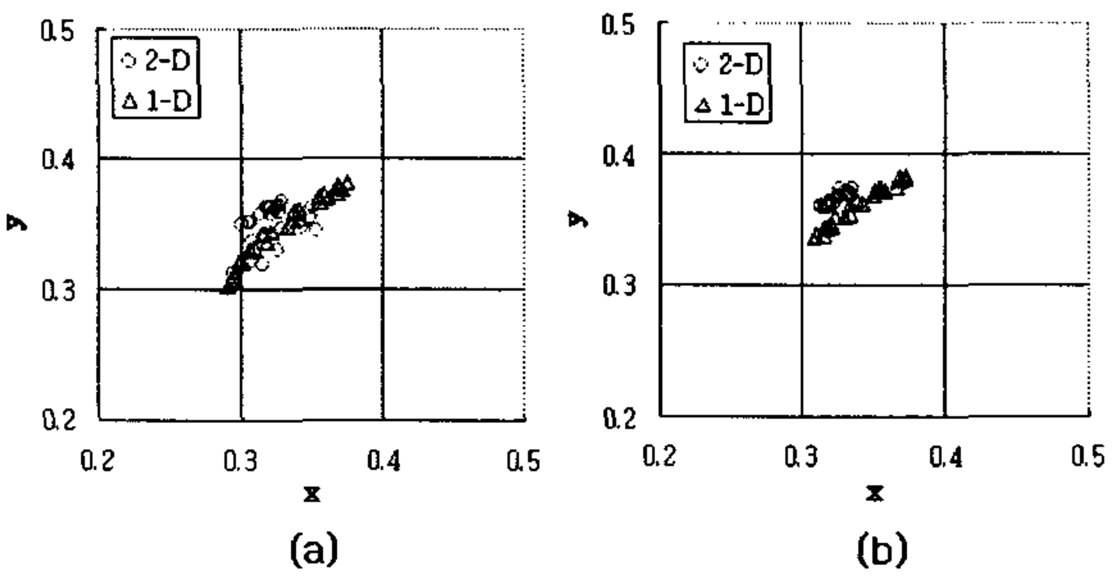

Figure 6. Viewing angle dependency of color coordinates at (a) mid-grey level and (b) white state for the FFS mode with 1-D and 2-D.

3. Summary

We proposed a new cell structure for the dual domain FFS device that enables the LC director to rotate in two opposite directions. Experimental results show that the FFS mode with dual domain exhibits a wide viewing angle in terms of the luminance uniformity and the contrast ratio of the cell. Most importantly, the new device shows strong color purity, such that the color coordinates change only slightly when the viewing direction changes. We believe that the new FFS device produces the best image quality among all LC displays.

4. References

[1] R. Kiefer, B. Weber, F. Windscheid and G. Baur: Proc. 12th IDRC, p. 547 (1992).

[2] M. Oh-e, M. Ohta, S. Aratani and K. Kondo: Proc. 15th IDRC, p. 577. (1995)

[3] K. Kondo, S. Matsuyama, N. Konishi and H. Kawakami: Dig. Tech. papers of 1998 SID, p. 389 (1998).

[4] S. H. Lee, S. L. Lee, and H. Y. Kim: Proc. 18th IDRC, p.371 (1998).

[5] S. H. Lee, S. L. Lee and H. Y. Kim: Appl. Phys. Lett., 73 (1998) 2881.

[6] S. H. Lee, S. L. Lee, H. Y. Kim and T. Y. Eom: Dig. Tech. papers of 1999 SID, p. 202 (1999).

[7] S. H. Lee, H. Y. Kim and S. L. Lee: Proc. 6th IDW, p.191 (1999).

[8] S. H. Lee, S. M. Lee, H. Y. Kim, J. M. Kim, S. H. Hong, Y. H. Jeong, C. H. Park, Y. J. Choi, J. Y. Lee, J. W. Koh and H. S. Park: Dig. Tech. papers of 2001 SID, p. 484 (2001).

[9] S. Aratani, H. Klausmann, M. Oh-e, M. Ohta, K. Ashizawa, K. Yanagawa and K. Kondo: Jpn. J. Appl. Phys. 36 (1997) L27.