Jpn. J. Appl. Phys. Vol. 41 (2002) pp. 2944–2948
Part 1, No. 5A, May 2002

Dual Domain Effects on a Homogeneously Aligned Nematic Liquid Crystal Cell Driven by a Fringe-Field

Hyang Yul KIM[1,4], Gye Rok JEON[2], Dae-Shik SEO[3], Myong-Hoon LEE[4] and Seung Hee LEE[4*]

[1] *Cell Process Development Group, Hyundai Display Technology, San 136-1, Ami-ri, Bubal-eup, Ichon-si, Kyungki-do 467-701, Korea*
[2] *Department of Biomedical Engineering, College of Medicine, Pusan National University, Pusan 602-739, Korea*
[3] *Department of Electrical and Computer Engineering, Yonsei University, Seoul 12-749, Korea*
[4] *School of Advanced Materials Engineering, Chonbuk National University, Chonju-si, Chonbuk 561-756, Korea*

(Received January 28, 2002; accepted for publication March 1, 2002)

The fringe-field switching (FFS) mode is known to exhibit both a wide viewing angle and high transmittance, owing to the approximated in-plane rotation of the liquid crystal (LC) director. However, 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. The degree of color shift becomes even stronger when the retardation value of the cell is high. This problem was greatly improved using a wedge shape of only pixel electrodes. These wedged shaped pixel electrodes allow two different field directions to exist in a pixel, enabling the LC director to rotate in two opposite directions. Consequently, owing to the dual domain effect with unidirectional rubbing, the color shift dependence on the viewing angle is greatly reduced.
[DOI: 10.1143/JJAP.41.2944]

KEYWORDS: fringe-field switching, liquid crystal, wide viewing angle, color shift

1. Introduction

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. In the off state, the LC molecules are homogeneously aligned with the optical axis coincident with one of the crossed polarizer axes for both modes; thus, the cell appears to be black. 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 order to overcome such a problem in the IPS mode, the wedge shaped pixel and counter electrodes were suggested, that is, two different field directions are constructed inside a pixel so that with bias voltage the LC molecules rotate in two directions, clockwise and counterclockwise, imitating a virtual two-domain.[8,9]

In the FFS mode, the cell retardation value that shows maximum light transmission is much higher than that of the IPS mode, especially when using the LC with positive dielectric anisotropy, due to a high twist and tilt effect.[10] This indicates that the viewing angle dependency of the transmittance in the bright state for a single domain (1-D) of the FFS mode becomes stronger compared with the cell having low a retardation value. In order to overcome this problem, we designed a new cell structure that has a wedge shaped pixel electrode, which was named dual domain (2-D) FFS mode. Experimentally, we proved that the newly designed 2-D FFS cell reduces the degree of color shift as the viewing direction changes and improves viewing angle.

2. Experimental Results and Discussions for 1-D and 2-D FFS Modes

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

$$T/T_{\mathrm{o}} = \sin^2(2\psi)\sin^2(\pi d\Delta n(\theta,\phi)/\lambda)$$

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,[8] and a similar effect was also observed in the FFS mode.

Figure 1 shows the cross-sectional view of the IPS and the FFS cell structures with a configuration of the LC director in the on (white) states. As indicated, in the IPS device the horizontal field exists only between electrodes, and, thus, the LC rotates in that area deviating from the axes of the crossed polarizers, giving rise to limited transmittance. In the FFS device, the pixel and the common electrodes, which are made of transparent conductor [such as indium-tin-oxide (ITO)], exist only on one substrate with horizontal distance only between pixel electrodes. Therefore, when a voltage is applied, a fringe field that has both horizontal and vertical components is generated, and the fringe field drives the LC molecules to rotate almost in plane above whole surface area, giving rise to high transmission. It should be noted that the twist angle of the mid-director in the FFS device is

---

[*] To whom correspondence should be addressed; E-mail: lsh1@moak.chonbuk.ac.kr

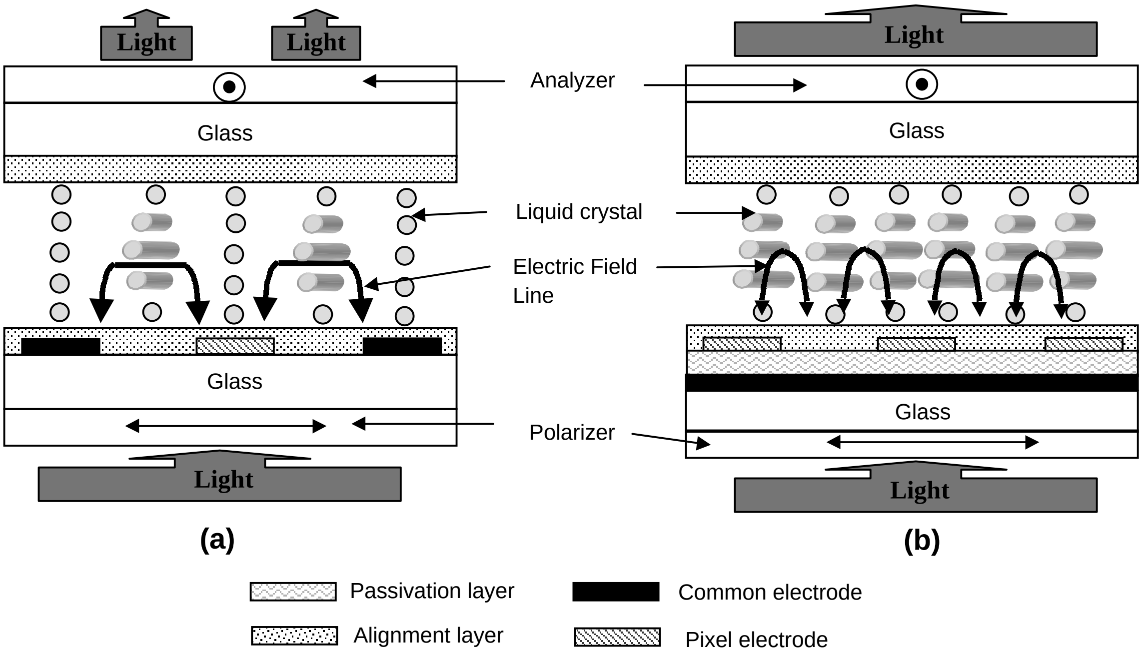


Fig. 1. Cross-sectional view of (a) the IPS and (b) the FFS cell structures with configuration of the LC molecules in on state. Here the boxes with arrow indicate light transmittance.

periodically alternating along a horizontal direction due to alternating field intensity along that axis.[10)]

The electrode design used in cell fabrication was the same as in the previous paper.[11)] The surface pre-tilt angle generated by the 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) from Merck Co. were used.

For electro-optic measurement, a halogen lamp was used as a light source and a square wave, 60 Hz voltage source from a function generator was applied to the sample cell. The photo multiplier tube detected the light that passed through the cell.

Figure 2 shows the top view of one pixel structure of the 1-D and 2-D FFS modes with a thin-film transistor (TFT). 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 78° 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 horizontal, and the LC director has an angle of 78° 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 3 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

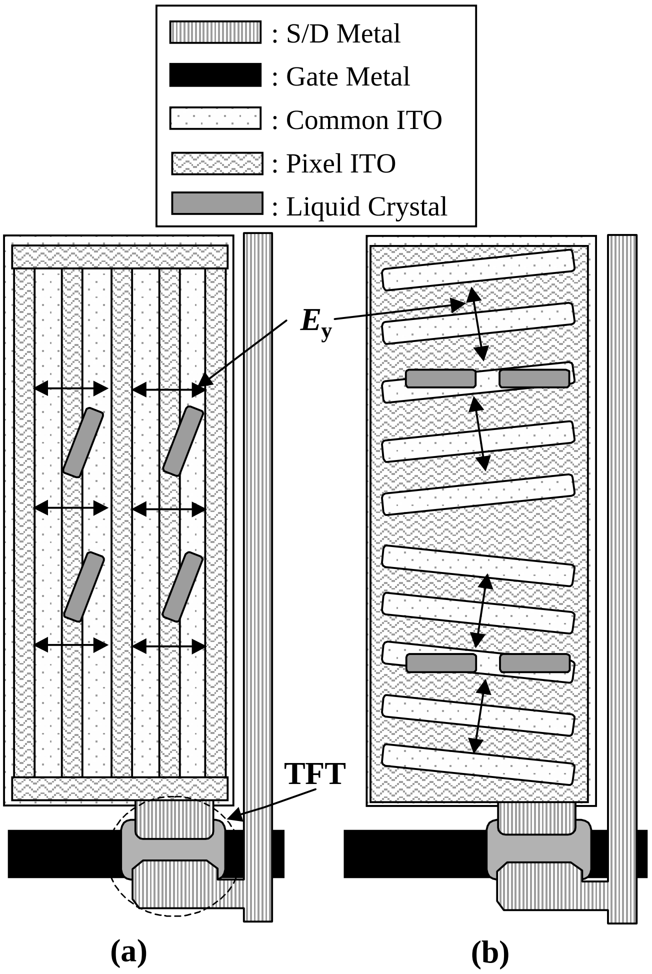


Fig. 2. One pixel structure of the FFS device with TFT for (a) 1-D and (b) 2-D.

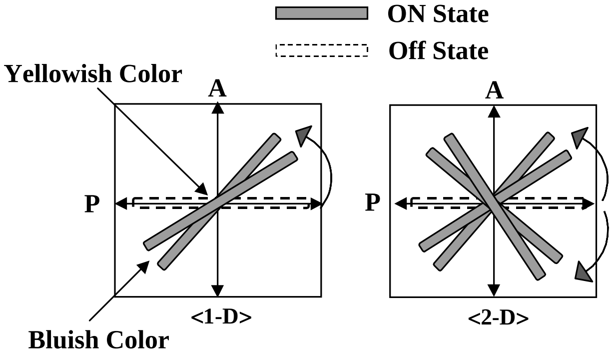


Fig. 3. Configuration of the LC director in the off and the on states in the FFS mode with 1-D and 2-D.

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.

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°. Figure 4 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. Figure 5 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

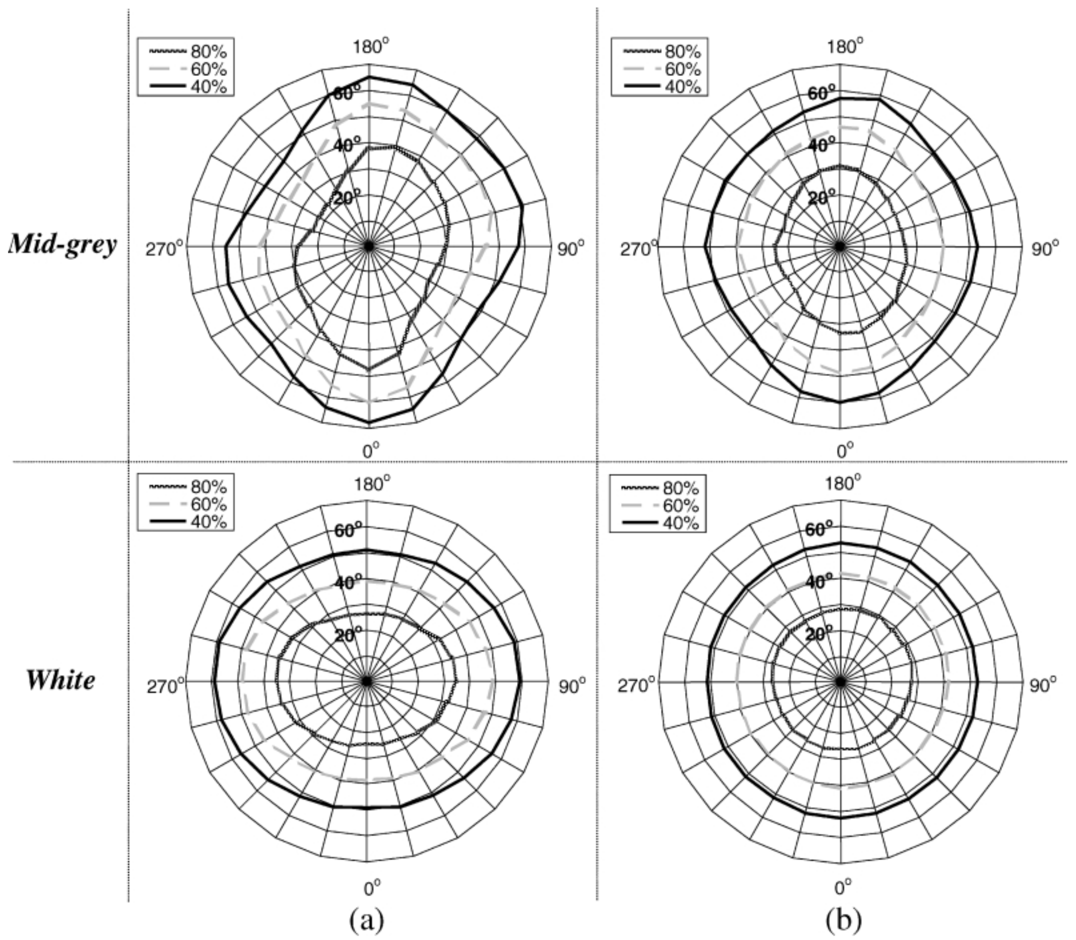
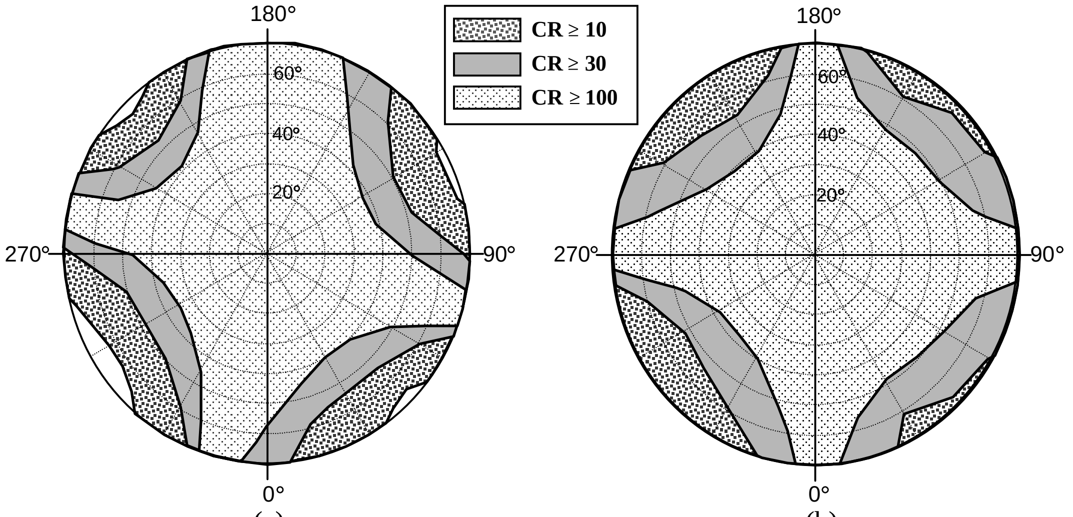
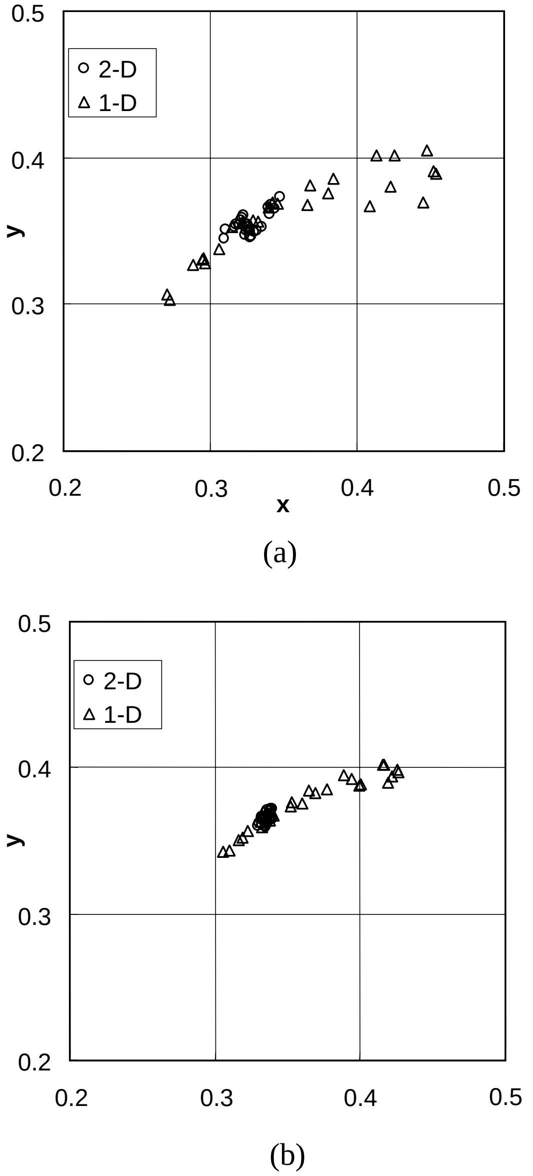


Fig. 4. Iso-luminance contour of the FFS mode with (a) 1-D and (b) 2-D at (a) mid-grey level and (b) white state. Here, the numbers in the boxes indicate light transmission in % with respect to maximum transmission at normal direction.



(a) (b)

Fig. 5. Iso-contrast contour of the FFS mode with (a) 1-D and (b) 2-D.



(a)

(b)

Fig. 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.

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. Finally, we investigated the color characteristics when the surface luminance is 50% and 100% of maximum transmission at a normal direction. As already 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.

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.

Acknowledgement

This study was supported in part by a grant (HMP-98-G-1-027) of the HAN (Highly Advanced National) Project, Ministry of Health and Welfare, R.O.K.

1) R. Kiefer, B. Weber, F. Windscheid and G. Baur: Proc. 12th Int. Display Research Conf. (Society for Information Display and the Institute of Television Engineers of Japan, Hiroshima, 1992) p. 547.
2) M. Oh-e, M. Ohta, S. Aratani and K. Kondo: Proc. 15th Int. Display Research Conf. (Society for Information Display and the Institute of Television Engineers of Japan, Hamamatsu, 1995) p. 577.
3) K. Kondo, S. Matsuyama, N. Konishi and H. Kawakami: Dig. Tech. Pap. 1998 Society for Information Display Int. Symp. (Society for Information Display, Anaheim, 1998) p. 389.
4) S. H. Lee, S. L. Lee and H. Y. Kim: Proc. 18th Int. Display Research Conf. (Society for Information Display and the Korean Physical Society, Seoul, 1998) p. 371.
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. Pap. 1999 Society for Information Display Int. Symp. (Society for Information Display, San Jose, 1999) p. 202.
7) S. H. Lee, H. Y. Kim and S. L. Lee: Proc. 6th Int. Display Workshops (Society for Information Display and The Institute of Image Information and Television Engineers, Sendai, 1999) p. 191.
8) S. Aratani, H. Klausmann, M. Oh-e, M. Ohta, K. Ashizawa, K. Yanagawa and K. Kondo: Jpn. J. Appl. Phys. **36** (1997) L27.
9) S. H. Hong, H. Y. Kim, M.-H. Lee and S. H. Lee: Liq. Cryst. **29** (2002) 315.
10) 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. Pap. 2001 Society for Information Display Int. Symp. (Society for Information Display, San Jose, 2001) p. 484.
11) S. H. Hong, I. C. Park, H. Y. Kim and S. H. Lee: Jpn. J. Appl. Phys. **39** (2000) L527.