Jpn. J. Appl. Phys. Vol. 42 (2003) pp. L 464–L 467
Part 2, No. 5A, 1 May 2003

Wide-Viewing-Angle Transflective Display Associated with a Fringe-Field Driven Homogeneously Aligned Nematic Liquid Crystal Display

Tae Bong JUNG, Jae Chang KIM[1] and Seung Hee LEE*

School of Advanced Materials Engineering, Chonbuk National University, Chonju-si, Chonbuk 561-756, Korea
[1]*Research Institute of Computer, Information and Communication, Pusan National University, Pusan, Kyungnam 609-735, Korea*

(Received February 3, 2003; accepted for publication March 19, 2003)

We have designed a novel transflective nematic liquid crystal (LC) cell driven by a fringe field. A homogeneously aligned LC director rotates almost in plane by applying voltage and, thus, the LC cell becomes an excellent dynamic phase retarder. The transflective display associated with this LC cell exhibits a wide-viewing-angle in both reflective and transmissive displays. [DOI: 10.1143/JJAP.42.L464]

KEYWORDS: reflective nematic liquid-crystal cell, fringe-field switching, in-plane rotation

Transflective liquid-crystal displays (LCDs) are widely used because they show good visibility under both strong and weak lighting conditions while keeping characteristics such as portability, good legibility and low power consumption.[1)] Recently, many results have been reported on twisted nematic (TN) and homogenous cells with compensation film,[2)] and vertical field driven-homogeneous cells (named ECB) with dual color filter structure.[3–5)] However, in both TN and ECB modes, the LC director tilts up along the vertical field direction and the upward tilt of the LC director implies that the viewing angle is limited in that direction. Therefore, the devices driven by a vertical electric field show a very narrow viewing angle in the transmissive area, although they show a proper viewing angle in the reflective area since the light passes through the LC cell twice. Recently, the transflective display is being applied to a display size over 10'' which means that a wide viewing angle is also necessary.[5)]

The transmissive-type display fringe-field switching (FFS), has a wide viewing angle and high transmittance owing to the in-plane rotation of the LC director.[6–11)] Taking advantage of the in-plane rotation of the LC director that allows realization of a wide viewing angle intrinsically, we previously reported the reflective FFS mode with a cell retardation value of $\lambda/2$ and a single polarizer.[12,13)] However, the device has a compensation film below bottom glass substrate and thus the reflector should exist below the film. Therefore, with that configuration, the realization of both the reflective and the transmissive displays at the same time is very difficult.

In this paper, a novel transflective display associated with the FFS mode has been examined. A computer simulation has been used to design the device and then the electro-optic characteristics of it have been studied. The results show that the device with an optimized cell structure exhibits a wide-viewing angle in both reflective and transmissive displays.

In brief, the FFS mode device only has electrodes on the bottom substrate. A common electrode exists as a plane and a pixel electrode in a slit form with a distance between them exists. The passivation layer is positioned between the common and the pixel electrodes. The detailed cell structure is the same as in the previous report.[10)] With this electrode structure, a fringe electric field is generated when a voltage is applied. The LCs are homogeneously aligned at the initial state and do rotate almost in plane above the whole electrode surface with bias voltage, giving rise to high transmittance.

To obtain optical design and calculate electrooptic characteristics, a computer simulation using 2×2 extended Jones matrix has been used.[14)] For the simulation, a LC ($\Delta n = 0.068$ at $\lambda = 550$ nm, $\Delta\varepsilon = -4.5$, $K_{11} = 13.5$ pN, $K_{22} = 6.0$ pN, $K_{33} = 15.1$ pN) is used, the rubbing direction which is the optic axis of the LC is 12° against the horizontal component of field, and the surface tilt angle is 2°. The pretilt angle generated by rubbing was 2°. For calculation, the transmittances for the single and parallel polarizers, and compensation film of $\lambda/2$ are assumed to be 41%, 35%, and 90%, respectively.

Figure 1 shows cell configuration in the reflective FFS mode. The optic axis of the LC with a cell retardation value of $\lambda/4$, compensation film's slow axis of $\lambda/2$, and the polarizer make angles of 12°, 72°, and 87° with the horizontal axis, respectively. Hereafter, the angle indicates the anticlockwise value against the horizontal x-axis. When a voltage is not applied, linearly polarized incident light passing through the polarizer in the normal direction changes polarization direction to 57° after passing through the compensation film since the angle between the polarizer and the film is 15°. Next, the linearly polarized light makes 45° with the LC and thus it becomes circularly polarized after passing through the LC. Finally, the reflected light passes through the LC and the film once again becomes linearly polarized with a polarization direction of 90° and,

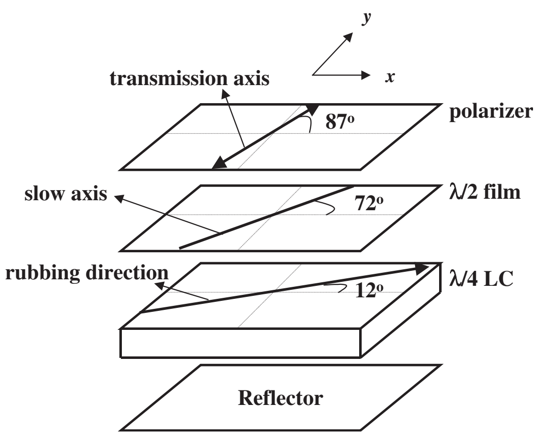

Fig. 1. Cell structure of the reflective FFS mode with a single polarizer.

*To whom correspondence should be addressed. E-mail address: lsh1@moak.chonbuk.ac.kr thus, it is blocked by the polarizer. When a voltage is applied, the LC director rotates almost in plane, giving rise to reflectance. White state can be obtained when the LC director rotates by 45° because the optic axis of the LC and direction of the linearly polarized light are coincident in that position so that the polarization state is not changed when passing through the LC. In fact, the reflective display with only the LC of $\lambda/4$ is also possible. However, the compensation film is absolutely necessary to obtain a good dark state since it cannot be obtained only using the LC due to wavelength dispersion.[15]

Since the reflective area shows a normally black (NB) mode, the transmissive area also should show the NB mode. In the reflective part, the axes of the top polarizer, the film and the LC are fixed as described above. Therefore, we have investigated a parameter space that shows reflectance as a function of the slow axis of the $\lambda/2$ film and the transmission axis of the polarizer below the LC cell, as shown in Fig. 2 From this, several possible conditions exist for a dark state. One such solution is when the slow axis of the film is 72° and the transmission axis of the polarizer is 87° with the optic axis of the LC fixed at 12°, as shown in Fig. 3. A cell configuration in the transmissive area consists of two compensation films of $\lambda/2$, a LC of $\lambda/2$ and two polarizers. Therefore, if the optic axis of the LC is β, the slow axes of the compensation films and the polarizer of the top and bottom side should be $\beta + 60°$ and $\beta + 75°$, respectively.

Figure 4 shows voltage-dependent reflectance (V-R) and transmittance (V-T) curves with above mentioned cell structures. Here, the cell gap in the transmittance area is 4 µm, twice of that in the reflectance area. The threshold voltages in both areas are not the same as each other due to cell gap difference and, in addition, the reason for low reflectance is that in the FFS mode the light efficiency is slightly decreased when the cell gap becomes very low, such as like 2 µm.[16] Figure 5 shows wavelength-dependent luminance in the dark and white states in both areas. Light leakage is well controlled in both areas and is about the same since the light propagation is the same for both parts. The

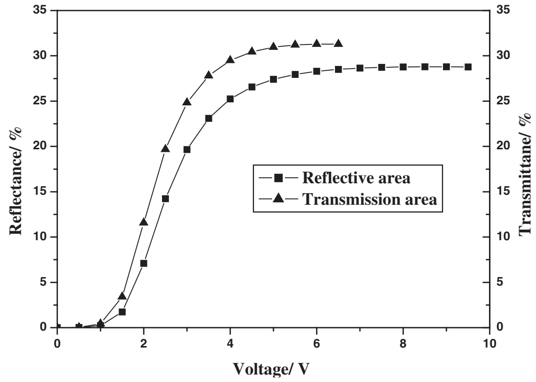

Fig. 4. Calculated voltage-dependent reflective and transmissive curves.

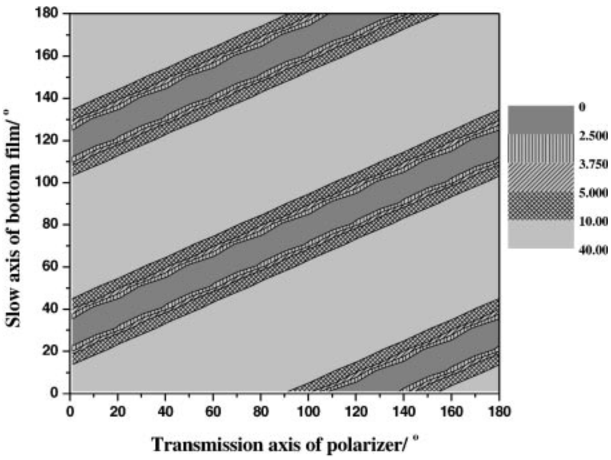

Fig. 2. Parameter space that shows reflectance as a function of slow axis of the $\lambda/2$ film and transmission axis of the bottom polarizer.

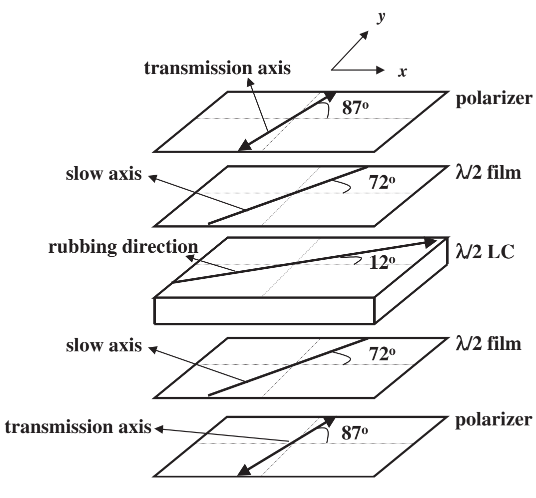

Fig. 3. Cell structure in the transmissive part in the transflective FFS mode.

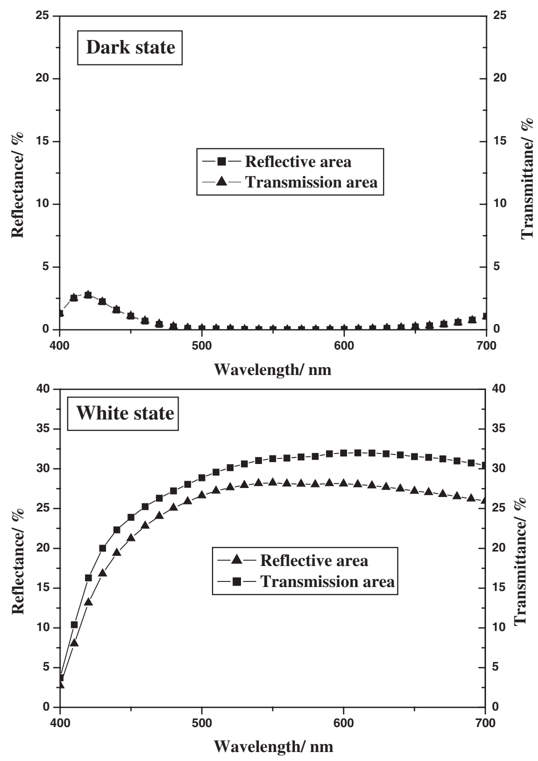

Fig. 5. Wavelength dependence of a dark state and a white state in the reflective and transmissive parts.

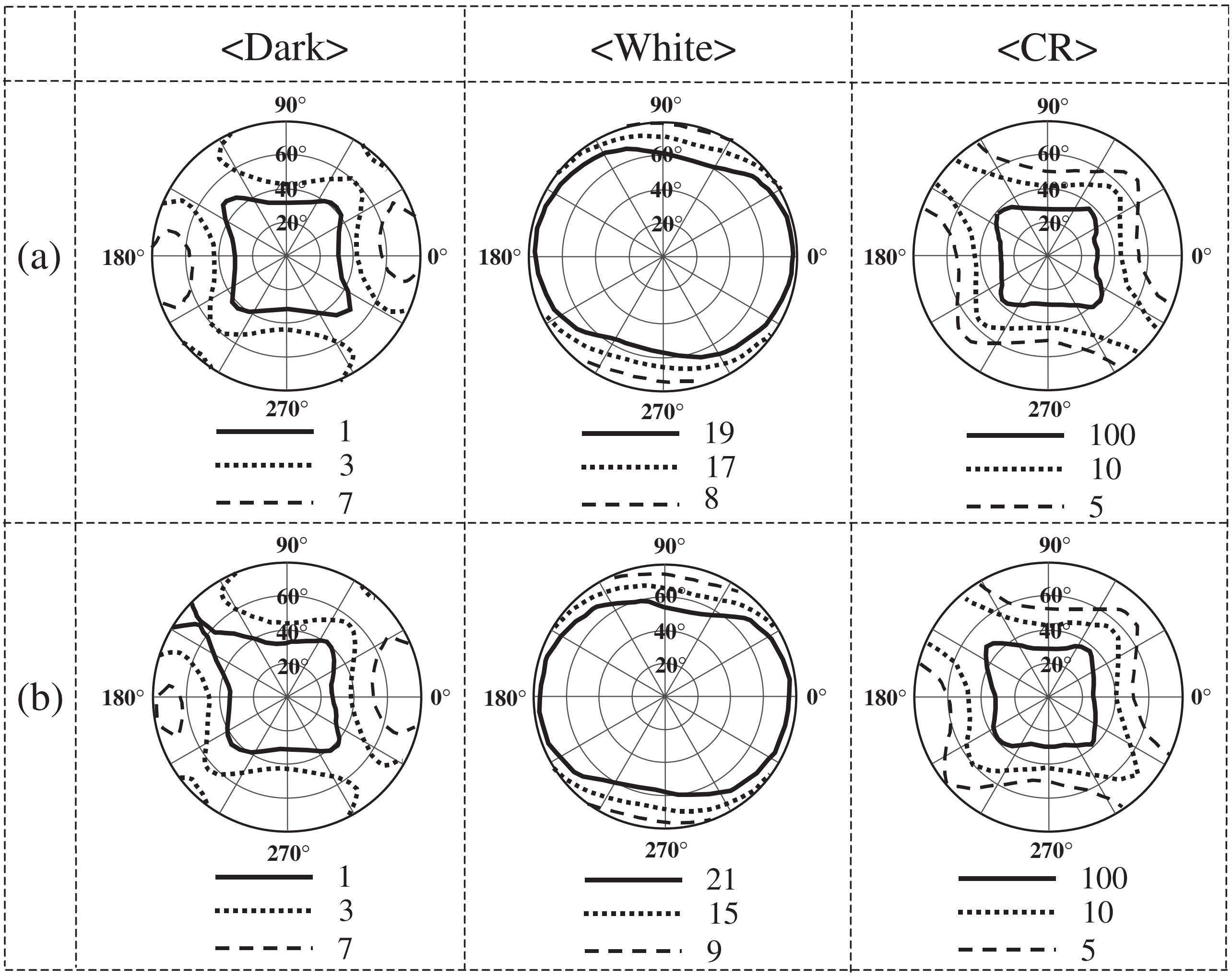

Fig. 6. Iso-reflectance and the transmittance contour at dark and white states, and the iso-contrast contour dependent on the viewing angle at an incident wavelength of 550 nm in (a) the reflective and (b) the transmissive parts.

wavelength dependence of the white state is good compared with that of the ECB mode.[17] Figure 6 shows the iso-luminance contour in the dark, the white states and the iso-contrast contour at 550 nm in the reflective and the transmissive areas. In the dark state, light leakage of less than 1% exists at more than 30° of the polar angle in all directions for both parts. For luminance uniformity in the white states, 50% luminance of the maximum luminance at normal directions exists at over 60° of the polar angle in all directions. Consequently, contrast ratio (CR) greater than 5 exists at over 60° of the polar angle in diagonal directions and about 55° in horizontal and vertical directions in the reflective area. In the transmissive area, it shows similar characteristics. Now, in order to compare the viewing angle characteristics between the ECB mode and the FFS mode, the viewing angle dependence of 6 grey levels has been checked by changing the polar angle up to 80° at the rubbing axis, as indicated in Fig. 7. In the ECB mode with a unidirectional upward tilting director, the luminance uniformity in most greys is destroyed, causing a grey scale inversion at an off-normal direction. However, it shows symmetry along the rubbing direction, and also the grey scale inversion does not exist up to 50° of the polar angle in the FFS mode.

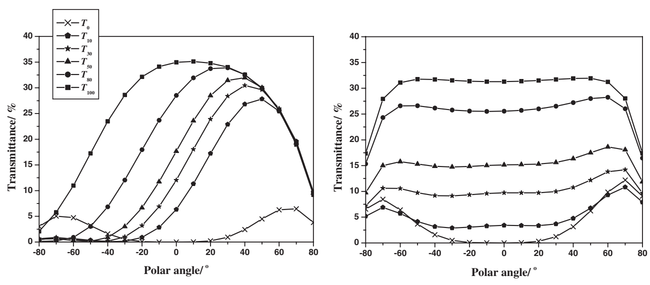

Fig. 7. Viewing angle dependence of the 6 grey levels for (a) the ECB mode and (b) the FFS mode.

In summary, we have proposed a novel transflective display associated with a homogenous alignment to in-plane switching of the LC director, which is driven by a fringe-electric field. Due to in-plane orientation of the LC director, the device exhibits a wide viewing angle without the occurrence of grey scale inversion over a wide range of viewing angles, in the reflective and the transmissive areas. Therefore, it is much superior to the conventional ECB mode in image quality.

This work was performed by the Advanced Backbone IT technology development project supported by the Ministry of Information & Communication in Republic of Korea.

1) R. Watanabe and O. Tomita: *Proc. 9th IDW 2002* (International Display Workshops, Hiroshima, 2002) p. 397.
2) T. Uesaka, E. Yoda, T. Ogasawara and T. Toyooka: *Proc. 9th IDW 2002* (International Display Workshops, Hiroshima, 2002) p. 417.
3) K. Fujimori, Y. Narutaki, Y. Itoh, N. Kimura, S. Mizushima, Y. Ishii and M. Hijikigawa: SID Dig. (2002) p. 1382.
4) Y. Narutaki, K. Fujimori, Y. Itoh, T. Shinomiya, N. Kimura, S. Mizushima and M. Hijikigawa: *Proc. 9th IDW 2002* (International Display Workshops, Hiroshima, 2002) p. 299.
5) K.-J. Kim, J. S. Lim, T. Y. Jung, C. Nam and B. C. Ahn: *Proc. 9th IDW 2002* (International Display Workshops, Hiroshima, 2002) p. 433.
6) S. H. Lee, S. L. Lee and H. Y. Kim: Appl. Phys. Lett. **73** (1998) 2881.
7) S. H. Lee, S. L. Lee and H. Y. Kim: IDRC Dig. (1988) p. 371.
8) S. H. Lee, S. L. Lee, H. Y. Kim and T. Y. Eom: SID Dig. (1999) p. 202.
9) S. H. Lee, H. Y. Kim and S. L. Lee: IDW Dig. (1999) p. 191.
10) S. H. Hong, I. C. Park, H. Y. Kim and S. H. Lee: Jpn. J. Appl. Phys. **39** (2000) L527.
11) 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: SID Dig. (2001) p. 484.
12) G.-D. Lee, G.-H. Kim, S.-H. Moon, J.-D. Noh, S.-C. Kim, W. S. Park, T.-H. Yoon, J. C. Kim, S. H. Hong and S. H. Lee: Jpn. J. Appl. Phys. **39** (2000) L221.
13) S. H. Lee, S. H. Hong, H. Y. Kim, G.-D. Lee and T.-H. Yoon: Jpn. J. Appl. Phys. **40** (2001) 5334.
14) A. Lien: Appl. Phys. Lett. **57** (1990) 2767.
15) T. B. Jung, C. H. Park, J. M. Rhee, Y. B. Kim and S. H. Lee: J. KIEEME **16** (2003) 131 [in Korean].
16) S. H. Lee: unpublished.
17) H.-I. Baek, M.-S. Nam, K.-S. Ha, D.-G. Kim, H.-H. Shin: *Proc. 2nd IMID 2002* (International Meet. on Information Display, Daegu, 2002) p. 556.