Japanese Journal of Applied Physics
Vol. 44, No. 9A, 2005, pp. 6695–6697

Brief Communication

Analysis of Reflective Part with Wide-Band Property in Single Gap Transflective Fringe-Field Switching Mode

Jun Baek PARK*, Hyang Yul KIM, Youn Hak JEONG, Dong Hoon LIM, Seo Yun KIM, Young Jin LIM and Seung Hee LEE[1]

SBU Development Center, BOE TFT-LCD SBU, San 136-1, Ami-ri, Bubal-eub, Ichon-si, Kyungki-do 467-701, Korea
[1]*School of Advanced Materials Engineering, Chonbuk National University, Chonju, Chonbuk 561-756, Korea*

(Received March 24, 2005; accepted June 2, 2005; published September 8, 2005)

This study investigates reflective mode with wide-band property using liquid crystal (LC) cell ($\lambda/2$) and inner retarder ($\lambda/4$). In wide-band type, the maximum contrast ratio increases and viewing angle decreases compared with the case that slow axis of LC and the transmission axis of analyzer coincide. However, for perfect dark state, the retardation of LC cell should be kept 0.275 µm. If not, maximum CR decreases from 150 to 100. [DOI: 10.1143/JJAP.44.6695]

KEYWORDS: transflective FFS mode, inner retarder, wide-band property, contrast ratio

Recently, single gap transflective liquid crystal (LC) modes driven by in-plane electric field such as in-plane switching (IPS) and fringe-field switching (FFS) have been investigated by many researchers due to merit of wide viewing angle.[1–4] Especially, for excellent transmittance and reflectance efficiencies, the process to fabricate $\lambda/4$ film using reactive mesogens (RM) material (by Merck) inside LC cell is essential.[5–7] However, owing to relatively large birefringence of RM compared with normal quarter wave film, in addition high reflectance leakage in short wavelength, wide-band property such as the role of wide-band quarter wave film is significantly needed for high contrast ratio of reflective part. However, the drawback of this concept is that retardation of LC cell be kept exactly 0.275 µm (ideal $\lambda/2$ retardation) lower than the value (0.37 µm) of conventional FFS mode. This results in decrease of LC efficiency and degraded dark state owing to cell gap variation. In this study, using wide-band type combination of LC cell ($\lambda/2$) and inner retarder ($\lambda/4$), contrast ratio and characteristics resulting from cell gap variation are investigated.

For simulation (by simulator LCD Master) considering thickness effect and retardation effect of inner retarder between LC cell and second indium–tin oxide (ITO), we inserted wavelength-dependent birefringence data of air curable RMS03-013 (by Merck, $\Delta n = 0.155$) into birefringence data of conventional retardation film and attached outside LC cell. And we inserted layer of thickness 8870 Å with dielectric constant $\epsilon = 3$ beneath LC cell. The simulator LCD Master used in simulation considers wavelength-dependent absorption efficiency of polarizer as well as wavelength-dependent Δn of inner retarder. In simulation, in wavelength 550 nm, the transmittance under cross polarizers is about 0.36 considering polarizer efficiency.

Figure 1(a) shows reflective optical configuration of fringe-field driven transflective mode using inner retarder ($\lambda/4$). The optical configuration of Fig. 1(a) is for general reflective display. For dark state, slow axis or rubbing direction of LC cell ($\lambda/2$) makes θ_H with the transmission axis of analyzer and slow axis of inner retarder ($\lambda/4$) makes $\theta_H + 45°$ with slow axis of LC cell ($\lambda/2$). Regardless of θ_H, the condition: $2\theta_H + 45° = \theta_Q$ should be satisfied. If slow axis of LC cell is rotated by 22.5° from initial θ_H, the

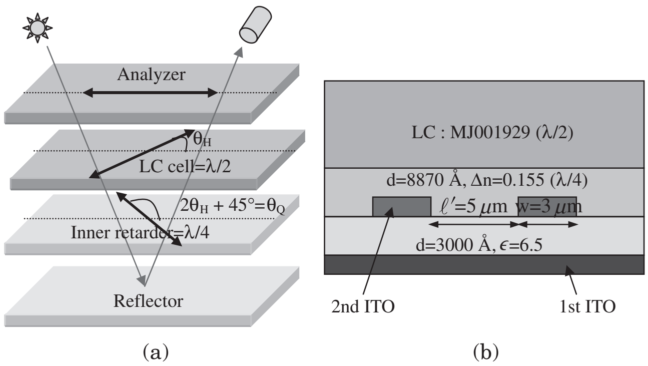

Fig. 1. (a) Reflective optical configuration of fringe-field driven transflective mode using inner retarder. (b) Side view of simulation.

polarized light going through LC cell ($\lambda/2$) coincides with the slow axis of $\lambda/4$ plate. This results in white state. If the slow axis of LC cell (θ_H) equals 15° and θ_Q equals 75°, wide-band property (excellent dark state in overall wavelength ranges) will be obtained without wide-band quarter-wave film.[8] The simulation results shows excellent dark state under low polar angle compared with any other optical configurations except short wavelength region. Figure 1(b) shows side view of simulation. Unlike conventional FFS mode,[9,10] the thickness of inner retarder ($\Delta n = 0.155$) on second ITO should be ideally 8870 Å, so the operating voltage of reflectance curve increases over 1 V due to increase of capacitance. And, because retardation of LC cell ($\Delta n = 0.0987$) should be 0.275 ($\lambda/2$) for the dark state, the cell gap of LC cell should be 2.78 µm precisely. However, if θ_H equals 0°, in other words, the transmission axis of analyzer coincides with slow axis of LC cell, the dark state remains same regardless of cell gap variation.

Figure 2 shows schematics of optical configurations used in simulation at each split (reflector is not displayed). The angle is defined with respect to horizontal axis and horizontal direction is the same as the direction of horizontal component of fringe-field. I selected basic reference structure and split #2 considering wide-band concept when the transmission axis of analyzer makes 15° with rubbing direction and the slow axis of inner retarder coincides with horizontal axis. And, I selected ±10° cases with respect to wide-band case to investigate the characteristics and trend of wide-band structure. After voltage is applied, LC molecules

*E-mail address: confucian@boehydis.com

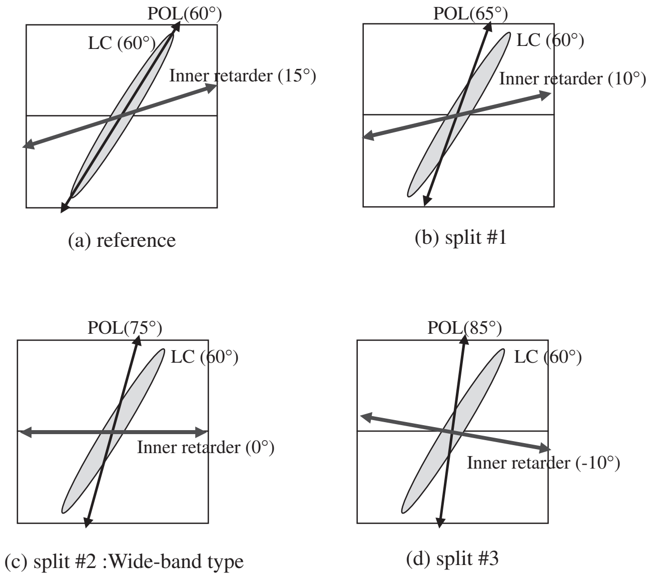

Fig. 2. Schematics of optical configurations used in simulation at each split (reflector is not displayed).

rotates in clockwise direction due to positive dielectric anisotropy. The rubbing direction with respect to horizontal component of fringe-field is 60° for increasing operating voltage of reflective curve.

Figure 3 shows wavelength-reflectance curve regarding polar angle (10–80°) under azimuth angle = 60° in dark state at each split. As expected, reflectance leakage of wide-band type (split #2) is lowest compared with any other cases in low polar angle (< 30°) like using wide-band quarter wave film. However, the reflectance characteristic of short wavelength range is not still improved. And, as polar angle increases, reflectance characteristic of split #2 becomes poor compared with reference. It is expected to show wide-viewing characteristic in reference case compared with split #2, however relatively low contrast ratio in low polar angle. In split #3, reflectance characteristic remains relatively good in low polar angle like split #2, but the poorest reflectance characteristic is shown in high polar angle.

Figure 4 shows iso-contrast contours at applied voltage 6.6 V at each split in the condition of entire visible wavelength region. As expected from the results of dark level shown in Fig. 3, viewing angle (contrast ratio > 5) of reference is over 80° in all observational direction and maximum CR is about 20 due to poor reflectance characteristic in low polar angle. In case of split #2 (wide-band type), the maximum CR is about 200 due to excellent reflectance characteristic in low polar angle, however, viewing angle (CR > 5) is limited to 50° in all observational direction. In case of split #1, the maximum CR is about 50 which corresponds to mid-level of reference (20) and split #2 (200), however, viewing angle (CR > 5) is narrowed to 70° in left/right observational direction and remains over 80° in vertical/bottom direction. Split #3 has the narrowest viewing angle (45° in left/right observational direction and 40° in vertical/bottom direction) due to the poorest characteristic in high polar angle.

Figure 5 shows iso-contrast contours at applied voltage 6.6 V regarding cell gap variation from ideal cell gap = 2.78 μm under split #2 condition. As mentioned above, reference structure which the transmission axis of analyzer coincides with slow axis of LC cell keeps dark state regardless of cell gap variation. In other words, there is no the degradation of contrast ratio if neglecting small variation of white state reflectance. However, if slow axis of LC cell

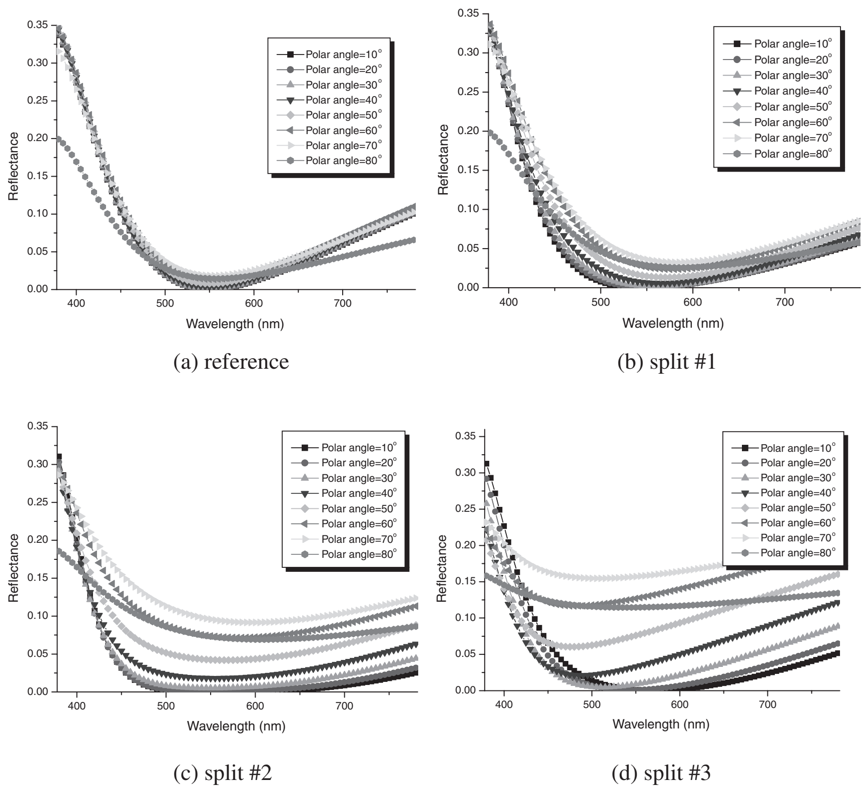

Fig. 3. Wavelength-reflectance curve regarding polar angle (10–80°) under azimuth angle = 60° in dark state at each split.

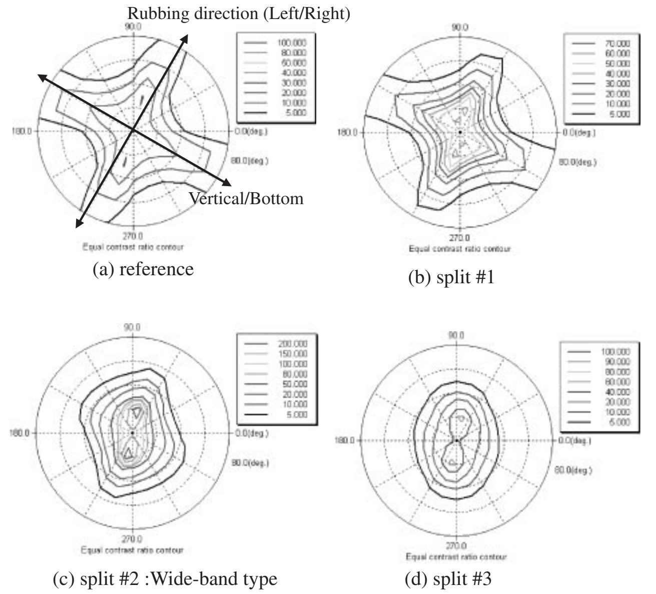

Fig. 4. Iso-contrast contours at applied voltage 6.6 V at each split.

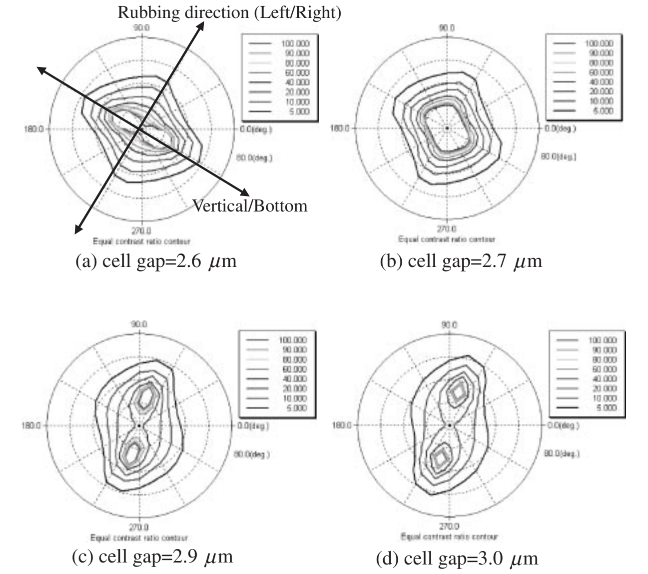

Fig. 5. Iso-contrast contours at applied voltage 6.6 V regarding cell gap variation from ideal cell gap = 2.78 μm under split #2.

does not coincide the transmission axis of analyzer, the retardation of LC cell remains 0.275 unconditionally. As shown in Fig. 5, maximum CR decreases from 150 to 100 due to poor dark state. As the cell gap increases, viewing angle in left/right observational direction broadens and viewing angle in vertical/bottom direction is narrowed.

In summary, we studied wide-band property using LC cell ($\lambda/2$) and inner retarder ($\lambda/4$) in reflective mode. In low polar angle, reflectance leakage is very low, however, in high polar angle, reflectance leakage is significantly high compared with conventional case. In the middle and long wavelength, excellent dark state is achieved as expected, however, the light leakage in short wavelength region is not improved. Contrast ratio and viewing angle characteristic depend on the level of reflectance leakage in dark state. In other words, maximum CR increases, but viewing angle decreases compared with conventional case.

1) R. Watanabe and O. Tomita: Proc. 9th Int. Display Workshops, Hiroshima, 2002, p. 397.
2) T. H. Yoon, K. H. Park, Y. J. Ko, J. C. Kim and G. D. Lee: SID Dig., 2004, p. 26.
3) J. H. Song and S. H. Lee: Jpn. J. Appl. Phys. **43** (2004) L1130.
4) S. G. Kang, S. H. Kim, S. C. Song, W. S. Park, C. Yi, C. W. Kim and K. H. Chung: SID Dig., 2004, p. 31.
5) S. J. Roosendaal, B. M. I. van der Zande, A. C. Nieuwkerk, C. A. Renders, J. T. M. Osenga, C. Doornkamp, E. Peeters, J. Bruinink and J. A. M. M. van Haaren: SID Dig., 2003, p. 78.
6) B. M. I. van der Zande, A. C. Nieuwkerk, M. van Deurzen, C. A. Renders, E. Peeters and S. J. Roosendaal: SID Dig., 2003, p. 194.
7) H. K. Lee, S. E. Lee, S. A. Cumming, M. Verrall, O. Parri, R. Harding and S. Marden: IMID Dig., 2003, p. 1.
8) T. H. Yoon, G. D. Lee and J. C. Kim: SID Dig., 2001, p. 898.
9) S. H. Lee, S. L. Lee, H. Y. Kim and T. Y. Eom: J. Korean Phys. Soc. **35** (1999) S1111.
10) S. H. Lee, S. H. Hong, H. Y. Kim, J. H. Park, W. G. Lee, G. D. Lee and T. H. Yoon: SID Dig., 2000, p. 763.