Mol. Cryst. Liq. Cryst., Vol. 495, pp. 186/[538]–193/[545], 2008

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400802432626

Viewing Angle Switching in Fringe-Field Switching Liquid Crystal Display

Young Jin Lim[1], Eun Jeong[1], Youn Sik Kim[1], Youn Hak Jeong[1], Won-Gun Jang[2], and Seung Hee Lee[1]
[1]Polymer BIN Fusion Research Center, School of Advanced Materials Engineering, Chonbuk National University, Chonju, Chonbuk, Korea
[2]Korea Photonics Technology Institute (KOPTI), Wolchul-dong, Buk-gu, Gwangju, Korea

We propose a pixel structure of viewing angle switchable liquid crystal display (LCD) associated with fringe-field switching (FFS) mode using one panel. In the device, one pixel is composed of main- and sub-pixel, in which the former has a role of image expression using the FFS mode and the latter has a role of viewing angle switching using the electrically controllable birefringence (ECB) mode. Consequently, before applying voltage to the sub-pixel, the device shows wide viewing angle, however, when the proper voltage is applied to the sub pixel, the displayed image is blocked in an oblique viewing angle.

Keywords: fringe-field switching; liquid crystal display; viewing angle switching

INTRODUCTION

Last several years, a wide viewing angle was a main issue for large size thin-film-transistor (TFT)-LCDs to compete with emissive displays which exhibit wide viewing angle. Since the LCDs use an anisotropic structure of liquid crystal, viewing angle dependency is an intrinsic issue. Nevertheless, development of several liquid crystal modes such as film compensated twisted nematic [1], vertical alignment [2–4], in-plane switching (IPS) [5], fringe-field switching (FFS) [6,7].

This research was supported by the Ministry of Education and Human Resources Development (MOE), the Ministry of Commerce, Industry and Energy (MOCIE), and the Ministry of Labor (MOLAB) through the fostering project of the Lab of Excellency.
Address correspondence to Seung Hee Lee, School of Advanced Materials Engineering, BK-21 Polymer BIN Fusion Research Team, Chonbuk National University, Chonju, Chonbuk 561-756, Korea. E-mail: lsh1@chonbuk.ac.kr

BACK TO CONTENTS

Nowadays, as increasing the range of use for portable displays such as notebook computers, mobile phones, personal digital assistants, and tablet personal computers, display contents have been exposed to many people around, especially when working outdoors. So information on display has to be under the protection according to important degree of information or user's willing. Therefore, LCDs with function of controlling viewing angle are in demand. Recently, several viewing angle switching displays which can control viewing angle have been studied and developed [8–14]. Most of conventional viewing angle switching displays are composed of two cells or three polarizers. However, these displays have increase in thickness, cost and power consumption which is not proper to portable display. In this paper, we propose a structure of viewing angle controllable LCD using one panel of FFS mode which is widely commercialized for transmissive displays.

CELL STRUCTURE AND SWITCHING PRINCIPLE

In the proposed device, viewing angle switchable FFS cell is composed of main- and sub-pixel in which the former has general FFS electrode structure and the latter has its common electrode that is additionally patterned partly on the upper substrate as shown in Figure 1. As expected, the liquid crystal director rotates almost in plane in the main-pixel, while it tilts upward perpendicular to the substrate in the sub-pixel.

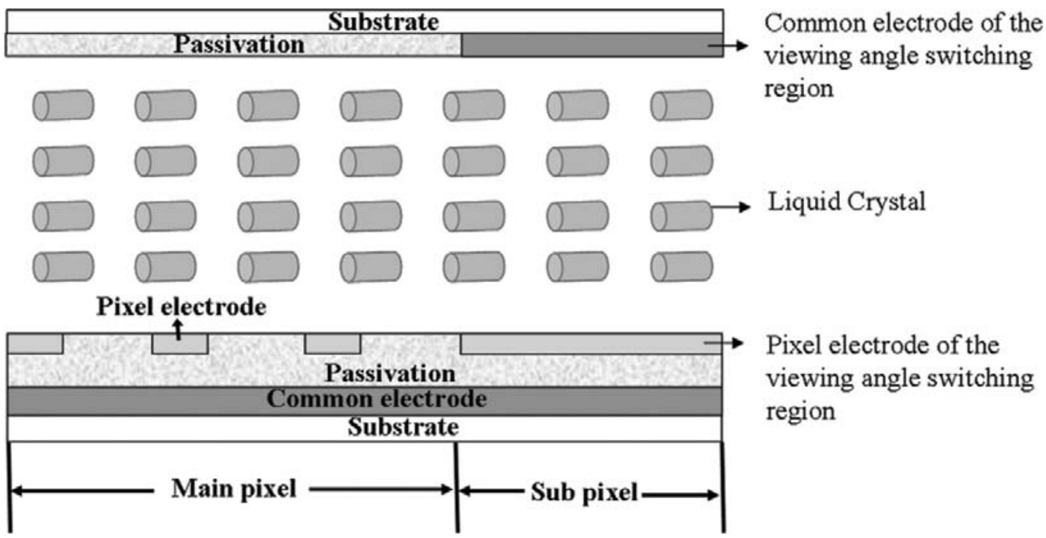


FIGURE 1 Schematic cell structure of the viewing angle controllable FFS-LCD. (See COLOR PLATE V)

BACK TO CONTENTS

In general, the transmittance of the LCD with uniaxial liquid crystal medium between crossed polarizers can be described as follows:

$$T = T_0 \sin^2 2\psi(V) \sin^2(\delta/2)$$

where ψ is an angle between polarizer and LC director, and δ is phase difference between ordinary and extraordinary rays, defined by $\delta = 2\pi d \Delta n_{eff}(V)/\lambda$ where d is thickness and Δn_{eff} is voltage-dependent effective birefringence of liquid crystal layer, and λ is an incident wavelength.

For the LCDs to exhibit wide viewing angle, two requirements should be satisfied at least. One is a good dark state at viewing directions as well as normal directions and the other is good uniformity of grey as well as white states along viewing directions. In the FFS mode, the liquid crystal is homogenously aligned with a condition $\psi = 0$ at normal direction, giving rise to excellent dark state at normal direction. Even in oblique viewing direction, the effective cell retardation is not so large due to homogenous alignment that the pretty good dark state is achieved, which does not require compensation film to compensate liquid crystal layer except for television application fields. To achieve a bright state, the liquid crystal rotates almost in plane by fringe-electric field, giving rise to good uniformity in brightness along viewing directions due to small difference of Δn_{eff} according to viewing directions [15,16]. Consequently, the device shows wide viewing angle.

Now, in order to prevent from peeping the high image quality displayed at normal direction in oblique viewing directions, we control orientation of the liquid crystal director in sub-pixel. In the sub-pixel, the liquid crystal has a homogeneous alignment like in the main-pixel with same optic axis but the orientation of the liquid crystal is controlled by vertical electric field. Therefore, reorientation of the liquid crystal director does not cause any light leakage at normal direction, however, when the director has enough tilt, the effective cell retardation $d\Delta n_{eff}$ becomes not negligible such that quite amount of light leakage is generated in oblique viewing angles. Using this light leakage, the characters or images can be displayed in at off normal axis, if sub-pixel can be controlled independently by extra TFT in addition to the TFT of main-pixel. Consequently, this generates extra image over a main image in oblique viewing directions, that is, the original image is overlapped with made image when the voltage is controlled to the extra pixel for viewing angle control.

BACK TO CONTENTS

SIMULATION RESULTS AND DISCUSSION

In order to achieve switchable FFS-LCD as described in the above section, we propose a pixel structure of array substrate, as shown in Figure 2. Viewing angle controllable LCD is divided by main pixel for image expression and the extra pixel for viewing angle control. Here, two pixels are controlled by two data lines (left- and right ones are connected to the sub- and main-pixel, respectively) and one gate line. In the main pixel, the LC rotates by fringe-field to generate gray levels and thus all electro-optic characteristics are exactly the same as that of the normal FFS mode. Here, the rubbing angle is assumed to be in vertical direction, making an angle of 10° with respect to slanted pixel electrode direction. In the extra pixel, the LC director tilts up in vertical directions in response to vertical electric field due to additionally patterned part of upper substrate such that $\psi = 0$. Therefore, in the extra pixel, although the LC director tilts up, the transmittance is not generated in the normal direction; however, quite amount of light leakage is generated in the oblique directions due to increase of $d\Delta n_{eff}$.

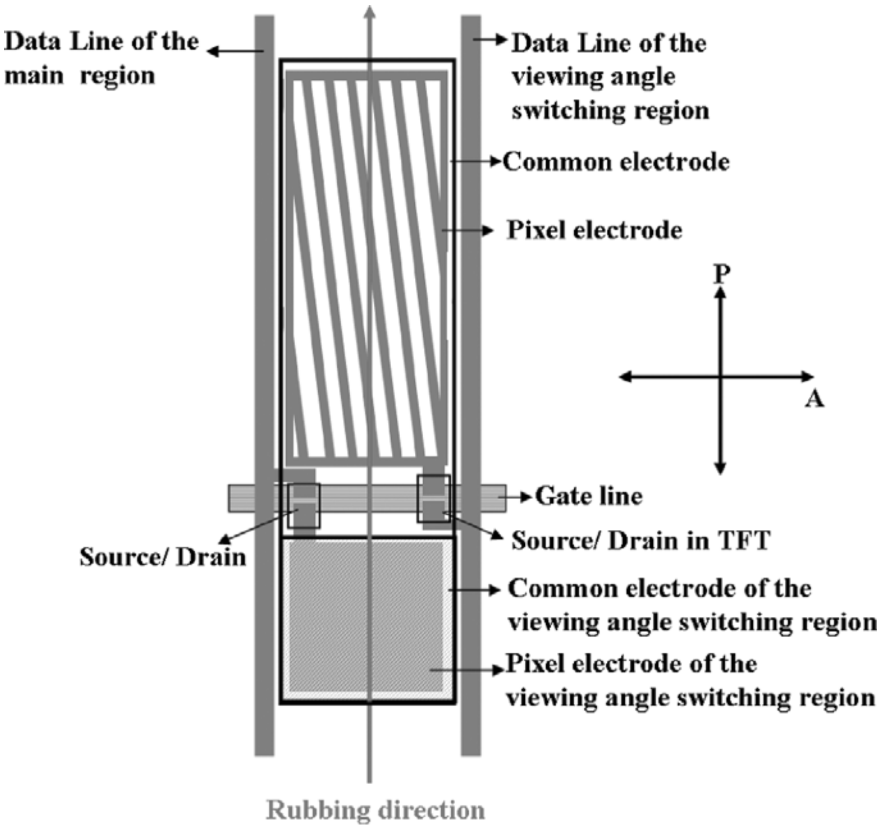


FIGURE 2 Top view of electrode structure of the viewing angle controllable FFS-LCD. (See COLOR PLATE VI)

BACK TO CONTENTS

Figure 3 shows one of examples of an arrangement of color filter matching electrode structure shown in Figure 2. The main pixel is composed of red, green, and blue color filter to generate full colors and the extra pixel has only a transparent resin on top substrate to maximize light leakage in oblique viewing directions.

Electro-optic characteristics of switchable FFS-LCD mode was performed based on simulation works using three-dimensional finite element method (FEM) module of TechWiz LCD (Sanayi System, Korea). For calculation of optical transmittance, 2×2 extended Jones matrix [17] was used. Simulation conditions followed in the present study uses liquid crystal ($\Delta\varepsilon + 7.4$, $K1 = 11.7\,pN$, $K2 = 5.1\,pN$, $K3 = 16.1\,pN$, $\Delta n = 0.1$ at 550 nm). The angle of slit electrode in the main-pixel was 10° with respect to the rubbing direction and cell gap was $4.0\,\mu m$.

Figure 4(a) shows a dark state of the pixel when a voltage 3 V is applied to the sub-pixel including left data line for a narrow viewing angle mode. Here, the potentials of right data line and pixel electrode in the main-pixel remain to be 0 V. With this voltage condition, the liquid crystal director in sub-pixel tilts upward without generating the light leakage at normal direction, however, the light leakage is

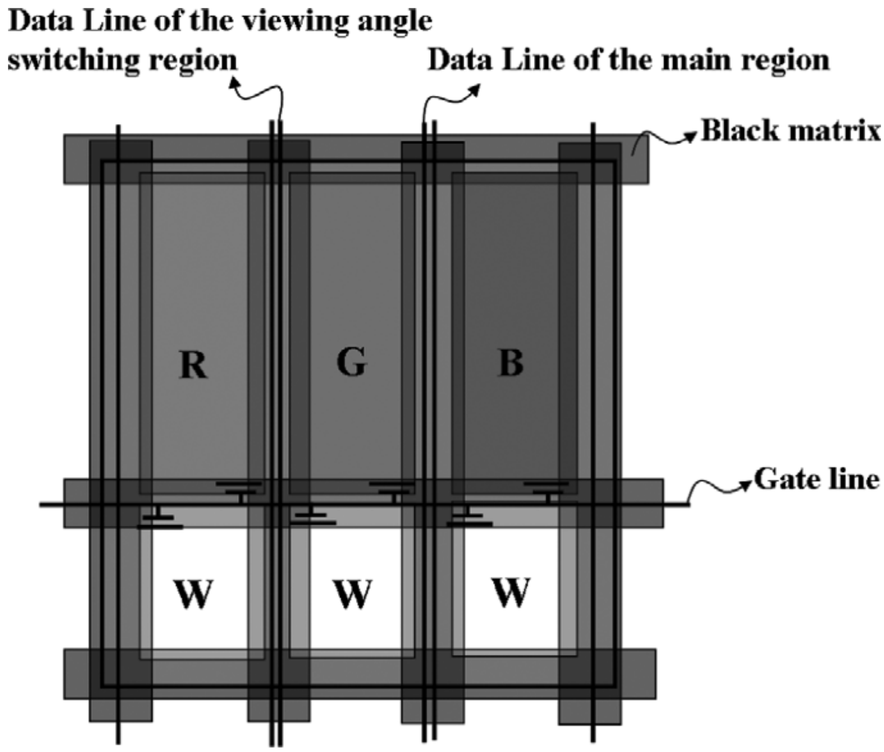
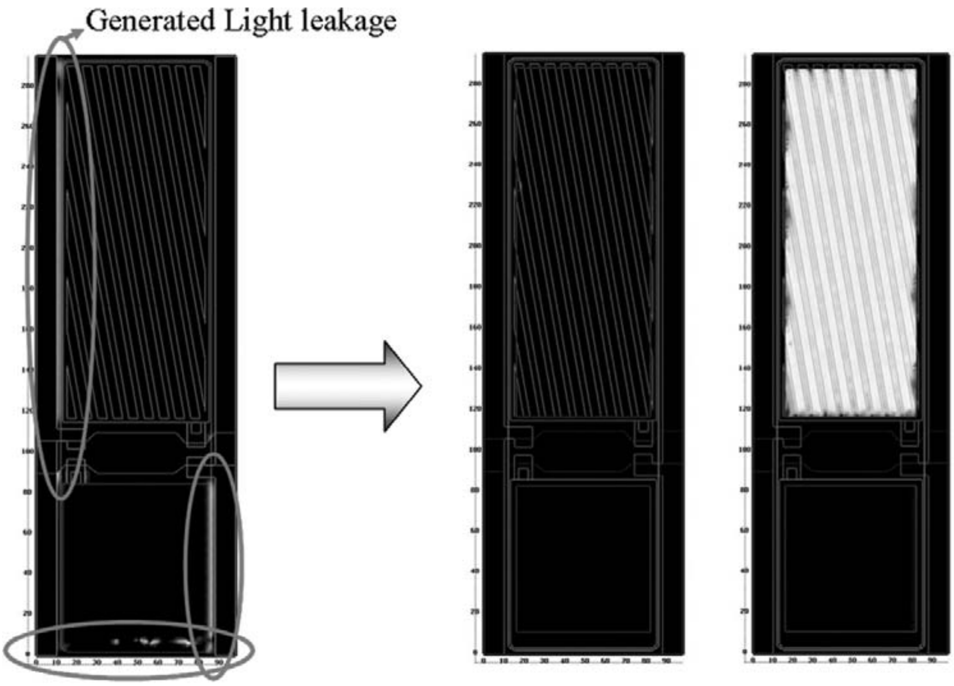


FIGURE 3 Arrangement of color filter corresponding to Figure 2. Here, R, G, and B indicate red, blue, and green color filters, respectively and W indicates white transparent resin. (See COLOR PLATE VII)

BACK TO CONTENTS



(a) (b) (c)

FIGURE 4 (a) Dark state without black matrix in the narrow viewing and (b) Dark state and (c) white state of the controllable viewing angle FFS-LCD with black matrix for both narrow viewing angle mode and wide viewing angle mode. (See COLOR PLATE VIII)

observed between pixels and data lines due to interfering lateral field which rotates the liquid crystal, generating ψ. Therefore, in order not to lose any contrast ratio at normal direction by such light leakage, proper size of black matrix blocking such light is positioned on top substrate. In this way, a perfect dark state is observed, as shown in Figure 4(b). The white state in the main-pixel is achieved by applying 6 V to the main-pixel electrode, as shown in Figure 4(c) and no light leakage is observed except for the main-pixel region.

Finally, the iso-contrast ratio in wide and narrow viewing angle mode is calculated, as shown in Figure 5. In wide viewing angle mode, only main-pixel is operated, exactly like in the conventional FFS mode so that the contrast ratio larger than 100 exists over 80° of polar angle in vertical and horizontal directions. However, in narrow viewing angle mode in which the liquid crystal tilts upward perpendicular to the substrate along vertical direction, a strong light leakage does occur except for a vertical direction and thus the region in which the contrast ratio is larger than 20 becomes only about 30° along horizontal direction. The contrast ratio greatly decreases when the sub-pixel functions, however, it is still too high not to protect the images.

BACK TO CONTENTS

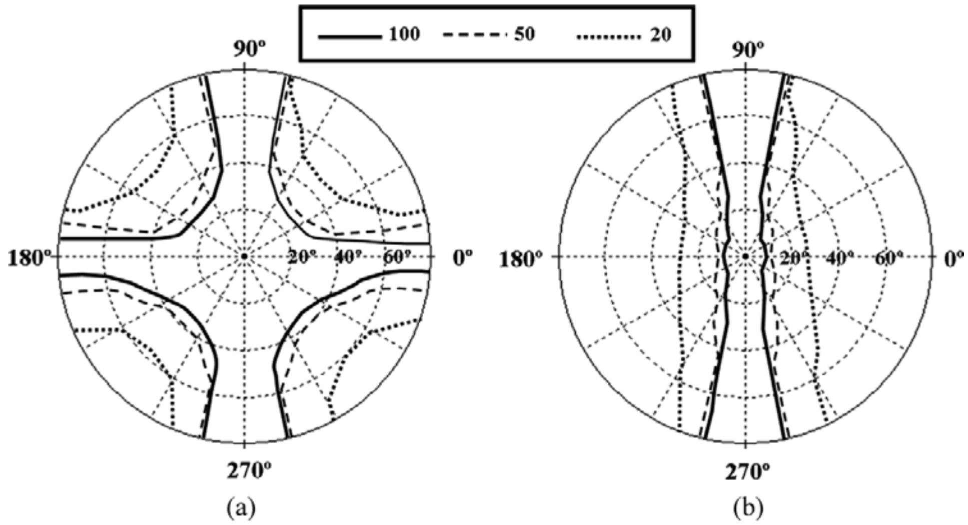


FIGURE 5 Iso-contrast curves: (a) wide viewing angle mode and (b) narrow viewing angle mode. The values in box indicate contrast ratio.

Therefore, this light leakage should be in forms of either characters or images when the voltage is controlled to the extra pixel for narrow viewing angle mode. In this way, the image displayed at normal direction can be protected in oblique viewing directions.

CONCLUSION

We proposed a structure of the viewing angle switchable FFS-LCD composed of main- and sub-pixel, in which the former has a role of image expression using the FFS mode and the latter has a role of viewing angle switching using electrically controllable birefringence mode. The optimized structure shows controllable viewing angle from wide to narrow, realizing transmissive FFS-CD with viewing angle control function using only panel. Consequently, this device has advantage selecting the alternative of wide viewing angle mode or narrow viewing angle mode according to the person's environment of private business and purpose.

REFERENCES

[1] Park, C. H., Lee, S. H., Jeong, J. K., Kim, K. J., & Choi, H. C. (2006). *Appl. Phys. Lett.*, *89*, 101119.
[2] Takeda, A., Kataoka, S., Sasaki, T., Chida, H., Tsuda, H., Ohmuro, K., Koike, Y., Sasabayashi, T., & Okamoto, K., (1998). *Soc. Info. Display Symp. Digest*, *29*, 1077.
[3] Kim, S. G., Kim, S. M., Kim, Y. S., Lee, H. K., Lee, S. H., Lee, G.-D., Lyu, J.-J., & Kim, K. H. (2007). *Appl. Phys. Lett.*, *90*, 261910.

BACK TO CONTENTS

[4] Lee, S. H., Park, S. H., Oh, S. T., Lee, M.-H., & Lee, G.-D. (2005). *Appl. Phys. Lett.*, *86*, 031108.
[5] Oh-E, M. & Kondo, K. (1997). *Jpn. J. Appl. Phys.*, *36*, 6798.
[6] Lee, S. H., Lee, S. L., & Kim, H. Y. (1998). *Appl. Phys. Lett.*, *73*, 2881.
[7] Kim, M. S., Seen, S. M., & Lee, S. H. (2007). *Appl. Phys. Lett.*, *90*, 133513.
[8] Hisatake, Y., Kawata, Y., & Murayama, A. (2005). *Soc. Info. Display Symp. Digest*, *36*, 1218.
[9] Adachi, M. & Shimura, M. (2006). *Soc. Info. Display Symp. Digest*, *37*, 705.
[10] Jin, H. S., Chang, H. S., Park, J. K., Yu, S. K., Lee, D. S., & Chung, I. J. (2006). *Soc. Info. Display Symp. Digest*, *37*, 729.
[11] Hiyama, K., Ogawa, R., Ishinabe, T., & Uchida, T., (2006). *Proceeding of the 13th International Display Workshop (Society for Information Display, Otsu, Japan)*, 217.
[12] Jeong, E., Lim, Y. J., Rhee, J. M., Lee, S. H., Lee, G.-D., Park, K. H., & Choi, H. C. (2007). *Appl. Phys. Lett.*, *90*, 05116.
[13] Lim, Y. J., Jeong, E., Kim, Y. S., Rhee, J. M., Lee, G.-D., & Lee, S. H. (2007). *Soc. Info. Display Symp. Digest*, *38*, 756.
[14] Lim, Y. J., Jeong, E., Chin, M. H., & Lee, S. H. (2007). *Proc. 9th European Conference on Liquid Crystals*, Lisbon, Portugal, 220.
[15] Kim, H. Y., Jeon, G. R., Lee, M.-H., & Lee, S. H. (2002). *Jpn. J. Appl. Phys.*, *41*, 2944.
[16] Yu, I. H. O., Song, I. S., Lee, J. Y., & Lee, S. H. (2006). *J. Phys. D: Appl. Phys.*, *39*, 2367.
[17] Lien, A. (1990). *Appl. Phys. Lett.*, *57*, 2767.

BACK TO CONTENTS