Electrode optimization for single gamma in transflective in-plane switching liquid crystal cells

Gak Seok Lee*, Jae Chang Kim, and Tae-Hoon Yoon
Dept. of Electronics Engineering, Pusan National University
Busan 609-735, Korea

Young Sik Kim, Won Seok Kang, and In Byeong Kang
Panel Design 4 Team, LG. Philips LCD, Gumi-si
Gyungsangbuk-do 730-726, Korea

Phone: +82-51-510-1700 , E-mail: neodol@pusan.ac.kr

Abstract

In this paper we report the influence of rubbing direction and electrode distance to the voltage dependent transmittance in in-plane switching (IPS) mode. Moreover, we applied this to a transflective IPS cell to realize a single gamma characteristics both in the transmissive part and the reflective part..

1. Introduction

Since liquid crystal (LC) was found, it has been applied enormous parts of displays. From electronic watchs to televisions (TV), we can find LCDs in anywhere around us. Though the most of market share of LCDs turns to PC monitors and televisions, that of mobile displays (e.g., mobile phone, personal digital assistance (PDA), game console, etc.) is growing year after year.

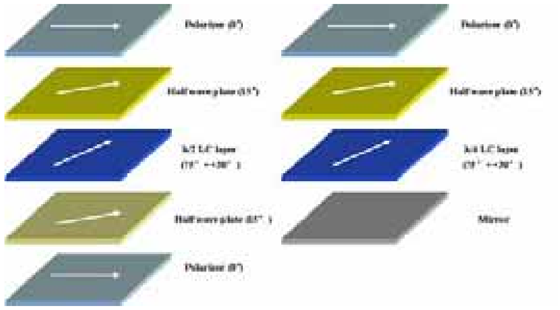
Different from earlier years, demands for mobile display devices with high performances, such as wide-viewing angle, fast response time and so on, are very strong. Most of people possess at least more than one mobile device. They want to watch on-air TV programs and movies, and to play computer games on the street as they do home. One of the most desired properties is wide-viewing angle.

To achieve wide-viewing angle, it can be a good method to use in-plane switching (IPS) mode, which intrinsically has good viewing-angle tolerance. So, it is natural that there have been many attempts to apply IPS mode to transflective LCDs.[1-4] But, when using IPS mode, the electro-optic characteristics of the reflective and the transmissive parts are different so that it cannot help but to use two driving circuits.

In this paper, we analyzed how the electrode structure and the electrode direction, which corresponds to rubbing angle, affect electro-optic characteristics of IPS mode and showed that gamma curves of the two parts can coincide through optimizing those two parameters.

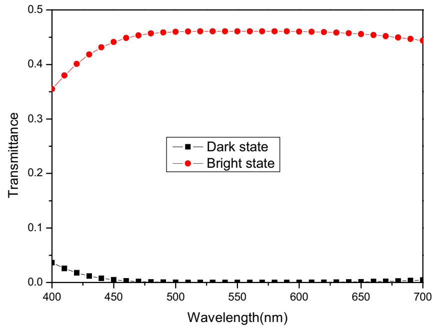
2. Optical Configuration

This method of optimization can be applied to all kinds of transflective IPS LCDs. But, in this paper, we choose one which shows the best spectral characteristics among them. The optical configurations are shown in Fig. 1.[4] The reflective part of a transflective display is designed in the wide-band quarter-wave structure to achieve the dispersion-free dark state over the entire range of visible wavelengths. A polarizer, a half-wave film, and a quarter-wave LC layer are set to 0°, 15°, and 75°, respectively. In this optical condition, an LC cell shows a good dark state with little wavelength dispersion.[5] To achieve the bright state, we used two switching methods: horizontal switching to 30°.
After the optical condition of the reflective part is determined, the transmissive part can be designed with the mirror method. Two polarizers, half-wave films, and a half-wave LC layer are set as shown in Fig 1. To achieve the bright state, LC molecules can be switched by the same method as that of the reflective part.

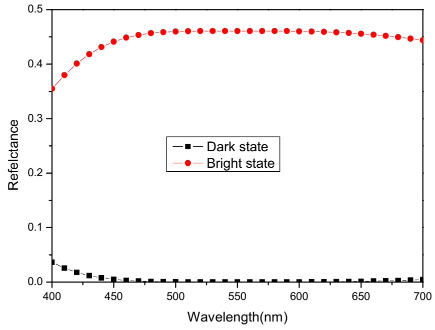


(a) the transmissive part (b) the reflective part

Fig. 1. Optical configuration of a transflective IPS cell.



(a) the transmissive part



(b) the reflective part

Fig. 2. Spectral characteristics of a transflective IPS cell.

3. The effect of electric field on electro-optic characteristics of IPS cell

A static electric field imposed on a nematic LC has many physical effects. Among them, one is related to the anisotrophy of the dielectric constants of LC materials. For a general direction of the electric field E, the relation between electric displacement D and field has the form

$$D = \varepsilon_{\perp} E + (\varepsilon_{\parallel} - \varepsilon_{\perp})(n \cdot E)n \qquad (1)$$

The difference $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$ may be positive or negative, depending on the detailed chemical structure of the constituent molecules. With a positive anisotrophy, LC molecules realign the direction parallel to a field. With a negative, LC molecules realign perpendicular to a field.

Electric fields have very different effects, depending on LC modes. As for the Freedericksz cell (splay cell), the threshold voltage can be obtained as

$$V_{th} = \pi \sqrt{\frac{K_{11}}{\Delta\varepsilon}} \qquad (2)$$

The static voltage dependence of output intensity of the Freederickz cell is not affected by cell gap.[5]

On the other hand, in the case of IPS mode, the optical voltage can be expressed as

$$V_{op} = E_{op} \cdot l = \frac{\pi l}{d} \sqrt{\frac{K_2}{\varepsilon_0 |\Delta\varepsilon| \left[\cos(2\Phi) \frac{\sin(2\bar{x})}{2\bar{x}} + \sin(2\Phi) \frac{\cos(2\bar{x})}{2\bar{x}} \right]}} \qquad (3)$$

where Φ is the LC alignment (or rubbing) angle with respect to the electrodes and $\bar{x}$ represents the average twisted angle of the bulk region of LC layer under the exerted electric field.[6]

Unlike the Freedericz cell, cell gap is one of main factors to affect the static voltage dependence of output intensity in IPS mode. In short, different cell gap means different electro-optic characteristics, provided that the other conditions are the same.

Before optimizing the structure and the direction of electrode for single electro-optic characteristics, we analyze how these conditions affect the electro-optic characteristics of IPS mode.

The performance of IPS mode is affected by several factors such as cell gap, birefringence of LC, the structure of electrodes, and electrode direction. Among them, our attention was directed to the ratio between the electrode width and the distance between electrodes and electrode direction which corresponds to the angles between electrodes and the initial alignment direction.

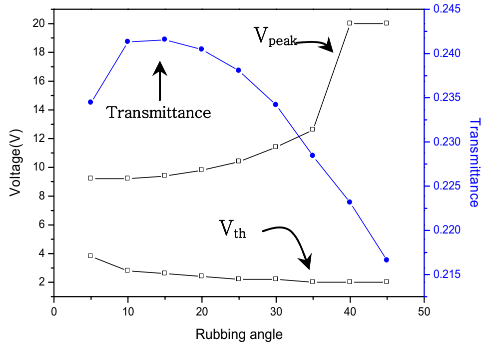
As liquid crystal material, a positive dielectro-anisotropic liquid crystal was used, whose birefringence Δn and dielectric anisotropy Δε are 0.0778 and +13.1, respectively. All the results are calculated by a commercial simulator, *LCD MASTER* (Shintech). To investigate the effects of those factors, we have used a typical IPS configuration. The optical axis direction of homogeneously aligned liquid crystals was in good agreement with the polarization axis of the polarizer. The polarizer and analyzer were crossed. At this configuration, in the voltage-off state, a pure black state can be obtained.

The effects of electrode structure on the electro-optic characteristics of an IPS cell are shown in Fig. 3 (a). As the distance between electrodes is increased, the threshold voltage and the voltage for peak transmittance are increased, which means higher operating voltage. In addition, the transmittance is increased. With the increase of the rubbing angle, the threshold voltage is decreased but the voltage for peak transmittance is increased, which corresponds to the decrease in steepness of the voltage-transmittance(reflectance) (*V*-*T*(*R*)) curve as shown in Fig. 3 (b). In short, the threshold voltage and the steepness in the *V*-*T*(*R*) curve of an IPS cell can be controlled separately by the distance between electrodes and the rubbing angle, respectively.

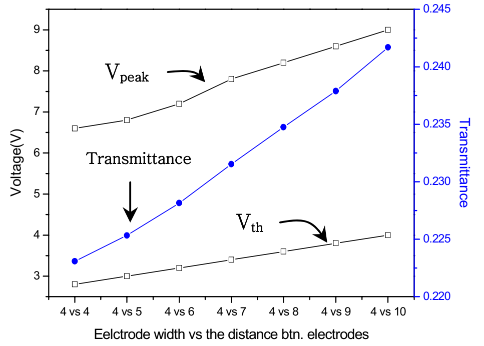
4. Electrode optimization

With a conventional electrode structure, in which the width of the electrodes is about 4 μm and the distance between the electrodes is about 10 μm, *V*-*T* and *V*-*R* curves of this configurations are not matched as shown in Fig. 4. The threshold voltage and the saturation voltage of the reflective part are lower than those of the transmissive part. In other words, the intensity of the applied electric field should be made different from each other to match the *V*-*R* curve with the *V*-*T* curve.

As shown in Fig. 3, the rubbing angle influences the threshold voltage and the distance between electrodes has an effect on the intensity of the electric field. To find conditions for the matched electro-optic characteristics of the two parts, the distance between the electrodes was varied from 4 um to 12 um. The rubbing angle was varied from 0° to 20°. To reduce the number of variables, the width of the electrode was fixed to 4 μm, which is the conventional electrode width of an IPS LCD.



(a) dependence on the rubbing angle



(b) dependence on the electrode distance

Fig. 3. The influence of rubbing angle and electrode distance in an IPS cell.

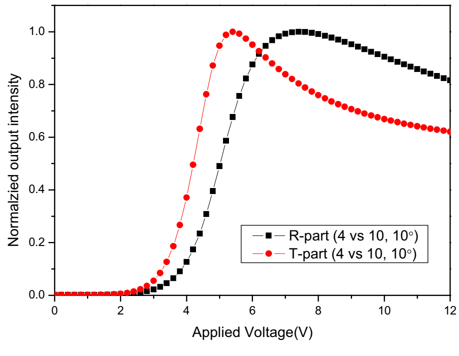


Fig. 4. Normalized electro-optic characteristics of a transflective IPS cell without optimization.

As shown in Fig. 4, the threshold voltage and the voltage for peak transmittance of the reflective part are higher than those of the transmissive part. To make the *V*-*R* curve match the *V*-*T* curve, the intensity

of electric field applied to the reflective part should be bigger than that applied to the transmissive part. Figure 6 shows the normalized electro-optic curves after the optimization, which shows a good match of the *V-R* curve with the *V-T* curve. In other words, they now have a single gamma curve. The optimized condition of the reflective part was 5 μm and 10° and that of the transmissive part was 6 μm and 15°.
Discuss the significance of your work, and compare your findings with previously published work.

5. Electrode structure

Special shape of electrodes can make the multi-directional LC switching of a transflective IPS LCD[3]. Multi-directional switching structure can be optimized to achieve a single gamma curve. Each pixel is separated into two parts, and each part has its own electrodes. Figure 6 shows the configuration for optimization of electrodes. The upper and lower sides represent the transmissive and the reflective parts, respectively. θ_T and θ_R are the angles between LC director and electrodes in the transmissive and the reflective parts, respectively. d_T and d_R are the distances between electrodes in transmissive and reflective parts, respectively. In each part, LC directors can be rotated for the optimal optical characteristics. In this structure, electrode optimization for a single gamma curve can be achieved easily.

6. Conclusion

We studied how the electrode structure and the rubbing angle can affect the electro-optic characteristics of an IPS cell. We found that the operating voltage and the steepness of the *V-T*(*R*) curve in an IPS cell can be controlled separately by the electrode structure and the rubbing angle, respectively. By applying those results to a specific configuration of a transflective IPS LC cell, we confirmed that a single gamma can be achieved through the optimization of the distance between electrodes and the rubbing angle. Those results can be applied to any other configurations of transflective IPS LCD as well to get a single gamma.

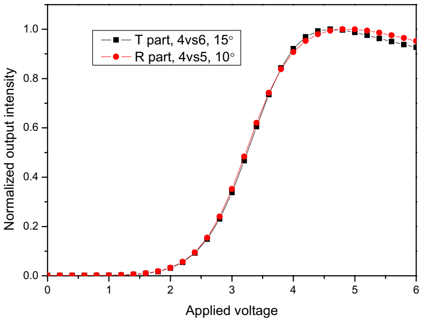


Fig. 5. Normalized electro-optic characteristics of a transflective IPS cell after the optimization.

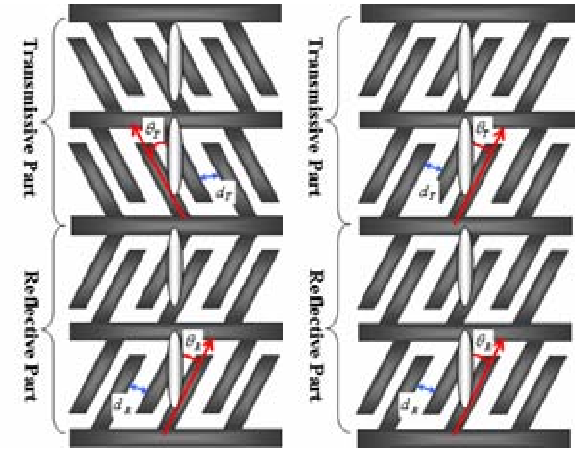


Fig. 6. Electrode structures for a single gamma

7. References

[1] C.-J. Yu, D.-W. Kim and S.-D. Lee , Appl. Phys. Lett. **85**, 5146 (2004)

[2] J. H. Song, Y. J. Lim, M.-H. Lee and S. H. Lee, Appl. Phys. Lett. **87**, 01108 (2005)

[3] K.-H. Park, J. C. Kim and T.-H. Yoon, Jap. J. Appl. Phys. **43**, 7536 (2004)

[4] G. S. Lee, J. C. Kim and T.-H. Yoon, *International Display Workshop '05*, 111 (2005)

[5] T.-H. Yoon, G. D. Lee and J. C. Kim, Opt. Lett. **25**, L1547 (2000)

[6] Y. Sun, Z. Zhang, H. Ma, X. Zhu and S.-T. Wu, Appl. Phys. Lett. **81**, 4907 (2002)