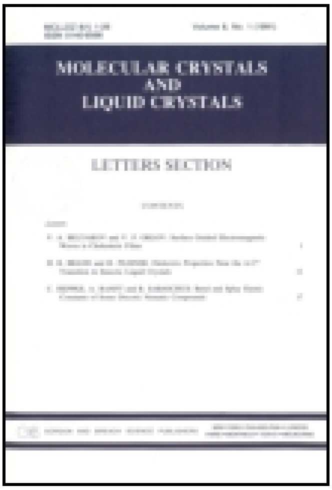

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The Optical Technology to Improve the Gamma-Curve in Liquid Crystal Display Modes

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The Optical Technology to Improve the Gamma-Curve in Liquid Crystal Display Modes

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We introduce an optical approach, which can improve the γ-curve distortion using a pair of positive and negative A*-type retardation films only for various liquid crystal display (LCD) modes. Optimization of a pair of* A*-plates was performed by calculating the polarization difference (*Δp*) between the normal and oblique incidence under a voltage applied state as functions of the retardation and the optical axis of the used* A*-plates. From the calculated results, LCD modes show an improvement of the γ-curve distortion over the 60% without any loss of optical performance in the dark state.*

Keywords Gamma-curve; distortion; liquid crystal display; polarization difference

1. Introduction

During the past 20 years, liquid crystal displays (LCDs) have been so much successful in display market, and widely used for entire displays from mobiles to TV application display larger than 40 inches. The most reason why LCDs are successful is due to high image quality in all viewing directions by developing of the many new liquid crystal (LC) modes such as wide view-twisted nematic (WV-TN) [1], 4-domain twisted nematic (4D-TN) [2], multi-domain type of vertical alignment (MVA) [3], in-plane switching (IPS) [4] and fringe-field switching (FFS) [5]. Up to now, most of studies for improving the electro-optical characteristics of the LC modes was focused on the color shift and viewing angle property in on and off state. However, current display devices require better image quality in off-axis in all gray scales, so γ-curve of LC modes becomes more important. Most of LC modes can casue the image distortion at middle gray levels in off-axis. Therefore, method to improve the γ-curve distortion have been proposed by applying a novel electrode structure [6, 7]. However, these methods require complex cell structures, such as two times the number of the transistor compared to a conventional thin film transistor (TFT) LCD [6], or a different electrode structure domain in the sub-pixel [7].

In this paper, we introduced an optical technology, which can reduce the γ-curve distortion using retardation films only in various LCD modes, including the WV-TN, 4D-TN, and MVA LCD mode. The proposed optical configuration of LCD modes added a pair of a *A*-plates, which consist of a positive *A*-plate and a negative *A*-plate, to the bottom and top substates without any change in conventional cell structure. In order to optimize

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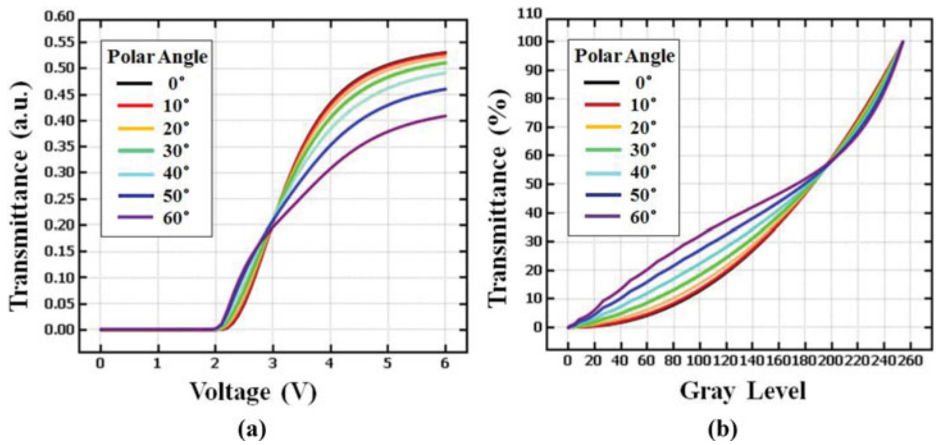

Figure 1. The calculated (a) V-T curve and (b) γ-curve distortion for a sample LC mode with MVA type with the middle gray levels in the normal and oblique viewing angle.

the optical parameter of used films, we calculated the polarization difference between the on-axis and off-axis as functions of the optical axes and the retardation (Δnd) under the voltage applied state. This optical approach regarding the improvement of γ-curve for many LCD modes can make excellent image quality in all gray levels without any deterioration in the contrast ratio in dark state.

2. Electro-Optical Characteristics in Gray Levels of LC Modes

The current LCDs are required to perform the optical improvement for wide-viewing property in all gray-levels on voltage state to obtain better image quality, so the γ-curve of the LC modes becomes more improtant. In general, when viewers are watching the display screen in normal direction, they can perceive high image quality and the vivid colors because the γ- curve has briefly 2.2 which is most fundamental value of the gamma index [8]. However, the γ-curve is deviated from the ideal value with 2.2 in the oblique direction because the V-T curve distortion is caused by the transmittance difference in off-axis direction.

Figure 1 shows the the calculated V-T curve and the γ-curve distortion for a sample LC mode with MVA type with the middle gray levels in the normal and oblique viewing angle. In Fig. 1(a), we observe the gray inversion region between 2 volt and 3 volt, and it makes a serious γ-curve distortion, as shown in Fig. 1(b), especially in the middle gray levels, which are maximized at particular voltage state.

3. An Optical Approach for Improving the γ-curve Distortion and Optimization

In order to improve the γ-curve distortion of LC modes, we used a pair of *A*-plates, which consisted of a positive *A*-plate and a negative *A*-plate, to the bottom and top substrates as shown in Fig 2. In this configuration, the optical condition should be satisfied so that the proposed configuration is performed for the wide-view performance in both the dark state

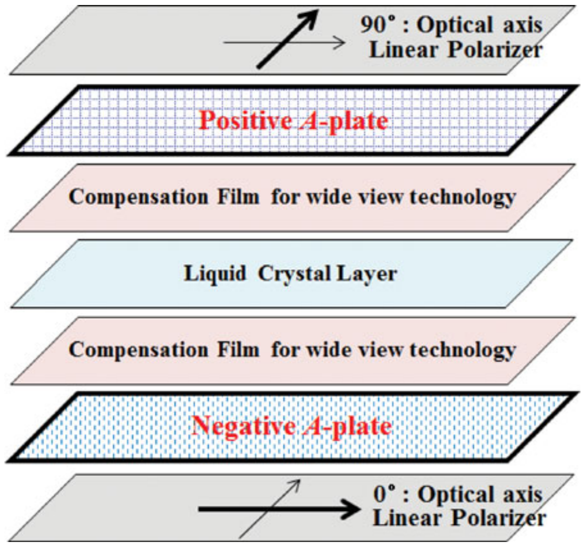

Figure 2. The proposed optical configuration of LC modes.

and all gray levels. We can describe the optical condition as follows:

$$\sum \text{Retardation (Negative } A\text{-plate} + \text{Positive } A\text{-plate}) = 0 \tag{1}$$

Equation (1) represents the optical condition of the pair of A-plates for improving viewing angle properties in the gray scale. It can be assumed that, if this equation is satisfied, the optical performance in the dark state will not be affected by the pair of A-plates, so that the pair of A-plates can be optimized without any deterioration of the optical performance in conventional LC modes.

Parameter optimization of two A-plates can be made by calculating the polarization difference (Δp). The Δp is defined by the difference between the polarization position (S_1) of the output polarizer absorption axis and the final polarization position of the light in front of the output polarizer as shown in Eq. (2) [9]:

$$\Delta p = \{(S_{1(a)} - S_{1(p)}) + (S_{2(a)} - S_{2(p)}) + (S_{3(a)} - S_{3(p)})\}^{1/2} \tag{2}$$

$$I = I_0 \cos^2(\Delta p/2) \tag{3}$$

where $S_{1(a)}$, $S_{2(a)}$, and $S_{3(a)}$ are the Stokes vector of the absorption axis of the output polarizer. $S_{1(p)}$, $S_{2(p)}$, and $S_{3(p)}$ are the Stokes vector of the polarization position of the light in each domain in front of the output polarizer at 2.2 V. And I_0 represents the light intensity at the absorption axis.

Figure 3 represents the polarization distribution of the three primary lights in front of output polarizer in normal direction at applied voltage state, which means gray level. R, G and B dotted circle line show the same Δp line from the position S_1. To get improved gamma curve in oblique viewing angle, we should move to Δp line in Fig. 3 in oblique direction because similar Δp implies similar transmittance compared to the normal direction as shown in Eq. (3). Therefore, optimization of two A-plates was made by inspecting the Δp.

Figure 4 shows the optimization process for the proposed optical configuration. This is kind of parameter space that calculate the Δp as functions of the optical parameter,

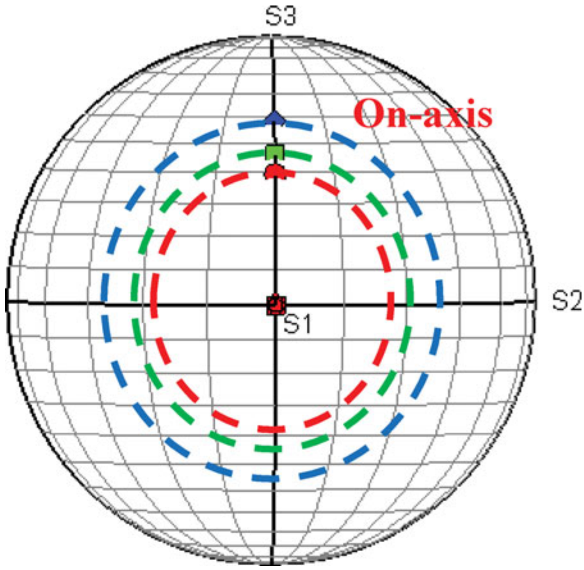

Figure 3. The polarization distribution of the three primary lights in front of output polarizer in normal direction at applied voltage state.

which are optical axis and the retardation value of used two *A*-plates. We investigate the Δp contour map in each viewing angle in all LC modes. Figs. 4(a) and 4(b) represent examples of optimized Δp in MVA LC mode [10] and WV TN mode [11] in oblique viewing direction, respectively. From these optimized optical axis and retardation value of the two *A*-plate, enhanced optical performances in all gray scale can be achieved.

From the above optical approach, we calculated the γ-curve of optimized sample LC modes in oblique viewing direction in all gray scales. Figures 5(a) and 5(b) show the improved the γ-curve of a MVA LC mode [10] and WV-TN mode [11] in the middle gray levels at the normal and oblique viewing angle. We confirm that the gray inversion in the

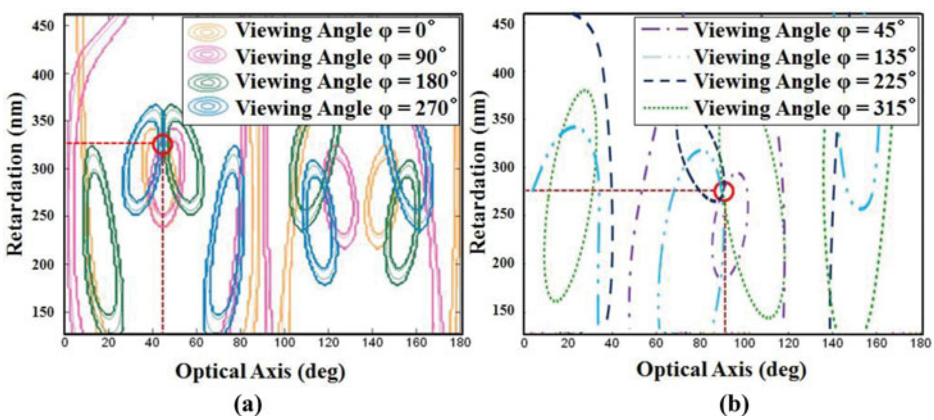

Figure 4. The Δp contour map for optimization of *A*-plate parameters: (a) in MVA LC mode and (b) WV-TN LC mode.

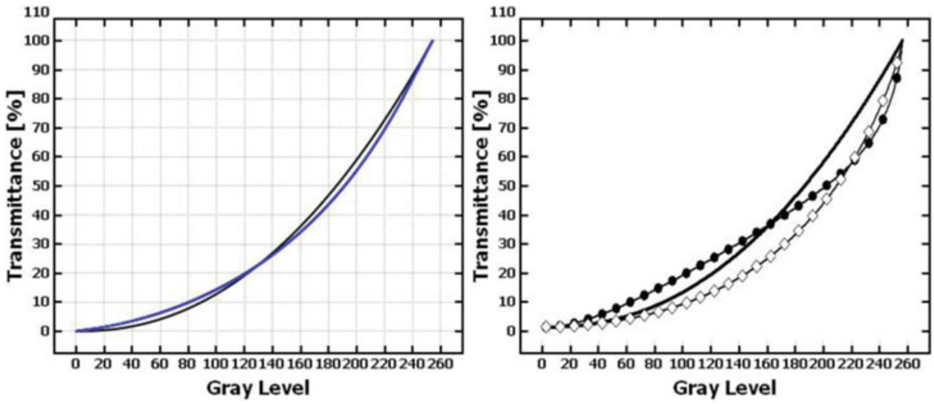

Figure 5. The optimized γ-curve in the middle gray levels at the normal and oblique viewing angle: in (a) a MVA LC mode and (b) in a WV-TN LC mode.

oblique direction can be effectively removed by applying a pair of optimized *A*-plates, so excellent γ-curve can be provided at all gray-scale.

Figures 6(a) and 6(b) shows the calculated iso-contrast contour of the MVA LC mode and WV-TN mode. Two optimized LC modes can perform the excellent iso-contrast without any loss of optical performance for wide-view property because the optical condition is satisfied with Eq. (1).

The γ-curve distortion can be quantitatively assessed by calculating the parameter GDI which means the gamma distortion index. The equation for parameter GDI is as follows [10, 11]:

$$GDI = \text{Average} \left| L_{i(\text{on-axis})} - L_{i(\text{off-axis})} \right|_{i=0\ \sim 255} \tag{4}$$

where *Li*(on-axis) and *Li*(off-axis) represent the brightness between the *i*th gray level in the on- and off-axis direction, and < > denotes the average for all cases of arbitrary gray levels. The GDI of sample LC modes, which apply the proposed optical technology, can improve by more than 60% in oblique viewing angles compared to conventional LC modes.

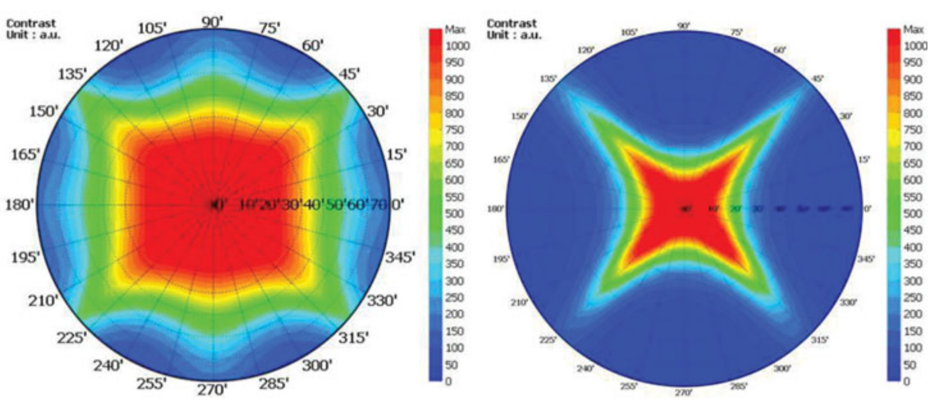

Figure 6. The calculated iso-contrast contour of (a) the MVA LC mode and (b) WV-TN mode.

4. Conclusion

In summary, we introduced an optical approach for reducing the the γ-curve distortion in the off-axis without any loss of optical performance in the dark state in LCD modes. The proposed optical technology applied a pair of *A*-plates, which consist of a positive *A*-plate and a negative *A*-plate, to the bottom and top substates in conventional structures of LCD modes any change in cell structure. Optimization of the pair of *A*-plates parameters was performed by calculating the polarization difference between the normal and oblique incidence under a voltage applied state as functions of the retardation and the optical axis of the used *A*-plates. We verified the enhanced optical performance by applying the proposed technology in two samples including MVA LC mode and WV-TN mode. As a result, the calculated GDI of two samples can be improved can be improved by more than 60% in oblique viewing angles compared to a conventional LC modes.

Acknowledgments

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