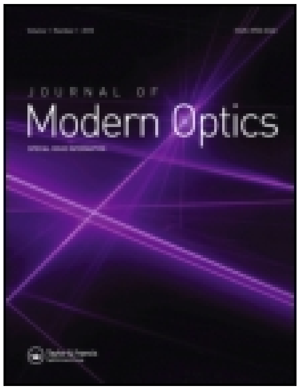

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A wide-view twisted nematic liquid crystal cell with improved image quality obtained by decreasing γ-curve distortion

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A wide-view twisted nematic liquid crystal cell with improved image quality obtained by decreasing γ-curve distortion

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Wide-view (WV) film, which was introduced by Fuji Co., has been commercialized to block light leakage of twisted nematic (TN)-liquid crystal (LC) cells in a dark state when the viewing angles are in the off-axis direction. In this investigation, we designed an optical compensation structure of a TN-LC cell with an improved γ-curve, as well as a viewing angle property in the dark state. Basically, we used a pair of optical films consisting of a positive and a negative *A*-plate in order to avoid affecting the viewing angle property in the dark state. Then, we optimized the positive and negative *A*-plate to improve the viewing angle property in the gray levels by calculating polarization variations as a function of the optical axis and the retardation of the pair of the *A*-plates. From this calculation, we were able to show that the proposed normally white (NW) WV-TN cell exhibits wide viewing angle performance, including good γ-curve stability.

Keywords: liquid crystal display; optical configuration; wide viewing angle; Poincaré sphere

1. Introduction

The remarkable improvements in the performance of liquid crystal displays (LCDs) have led to the widely expanding demand for display application such as TVs, monitors, mobile phones, tablet PCs and so on. Among various LC modes, the wide view (WV)-twisted nematic (TN) mode is dominant for many display areas on account of its low power consumption, high light efficiency and low driving voltage [1]. In particular, the compensation film known as a WV film is very helpful for improving viewing angle performance, as it optically compensates for the asymmetrical transmittance of the on-voltage state and thus gives a very high contrast ratio even in the off-axis direction [2,3]. In spite of the optical merits of the TN cell with WV film, this system still has a serious deficiency in terms of optical viewing angle in a gray level because the optimized optical films are designed for a wide viewing angle in the dark state, which is an on-voltage state. In general, image distortions in the gray level in the oblique direction can be assessed by measuring the γ-curve [4,5].

In this paper, we report the study of an optical approach to improve γ-curve distortion in the WV-TN cell. The design of the optical configuration of the WV-TN cell is focused on the optical improvement of the viewing angles, both in the dark and gray-level state. Basically, we use a pairing of a positive *A*-plate and a negative *A*-plate to the conventional WV-TN cell with the same retardation and optical axis, because this does not affect the dark state of the LC cell. Then, the optimization of the pairing of the positive and negative *A*-plates was performed by calculating the polarization difference on the Poincaré sphere between the goal position and the calculated position as functions of the retardation and the optical axis of the pair of *A*-plates.

2. Review of a conventional WV-TN cell

The conventional WV-TN cell consists of two hybrid aligned discotic layers at both sides of the TN layer [2,3]. As for the conventional WV-TN cell in the normal direction (polar angle $\theta = 0°$, azimuth angle $\phi = 0°$), we can perceive a high image quality whose most fundamental γ index is briefly 2.2 [5].

However, the transmittance in the diagonal direction does not decrease as much as that in the normal direction when decreasing the voltage. Therefore, the γ-curve cannot maintain a γ index of 2.2 in the diagonal direction when the viewing angle and contrast ratio are excellent. We can observe that the γ-curve distortion in the middle gray levels is the most severe, as shown in Figure 1, because of the transmittance difference between the normal and diagonal direction.

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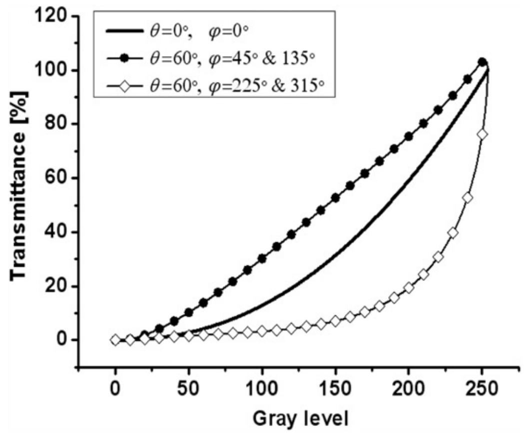

Figure 1. The calculated γ-curve of the conventional WV-TN cell. The solid line shows the γ-curve with index of 2.2.

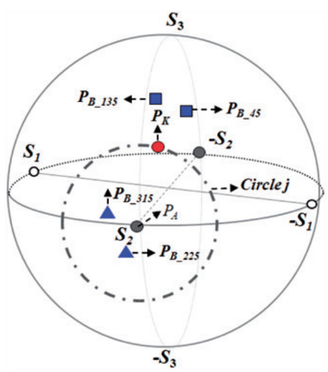

Figure 2. The polarization states of light in front of the output polarizer on the Poincaré sphere with 1.8 V applied, representing the 70th gray-level, in the conventional WV-TN cell. (The color version of this figure is included in the online version of the journal.)

To analyze the problem of the transmittance difference between the normal direction and the oblique direction, we have investigated the polarization state in the middle gray levels, which is approximately the 70th gray level when 1.8 V is applied to the LC cell on the Poincaré sphere, as shown in Figure 2. Figure 2 illustrates the calculated polarization states of the light passing through the conventional WV-TN cell. P_A is the transmission axis of the input polarizer and absorption axis of the output polarizer. P_K gives the polarization state of the light in front of the output polarizer in the normal direction.

P_{B_45}, P_{B_135}, P_{B_225} and P_{B_315} represent the polarization positions of the light in front of the output polarizer with azimuth angles ϕ of 45°, 135°, 225° and 315°, respectively ($\theta = 60°$, which induces maximum light leakage normally [6]).

Circle j in Figure 2 implies an equi-polarization line that can provide the same transmittance because the distances between the polarization positions on *Circle j* and the absorption axis of the output polarizer P_A are the same. The polarization position in the normal direction at 1.8 V, P_K, is shown on *Circle j*, and the polarization difference [7–9] between P_K and P_A can be described as follows:

$$\Delta P_{(A-K)} = \sqrt{\left(S_{1(A)} - S_{1(K)}\right) + \left(S_{2(A)} - S_{2(K)}\right) + \left(S_{3(A)} - S_{3(K)}\right)}, \quad (1)$$

where $S_{1(A)}$, $S_{2(A)}$, $S_{3(A)}$, $S_{1(K)}$, $S_{2(K)}$ and $S_{3(K)}$ are the Stokes parameters of positions P_A and P_K, and $S_1 + S_2 + S_3 = 1$. Based on the calculated Stokes parameters of the position P_A and P_K, $\Delta P_{(A-K)}$ can be calculated as 0.454 ($\lambda = 550$ nm) using Equation (1). In Figure 2, the calculated values of the polarization differences $\Delta P_{(A\text{-}B\_45°)}$, $\Delta P_{(A\text{-}B\_135°)}$, $\Delta P_{(A\text{-}B\_225°)}$ and $\Delta P_{(A\text{-}B\_315°)}$ in the oblique direction at 1.8 V are calculated as 0.742, 0.742, 0.238 and 0.238, respectively, so we can simply understand that P_{B_45} and P_{B_135} will provide higher transmittance than that of the normal direction, while P_{B_225} and P_{B_315} will provide lower transmittance than that of the normal direction. We can simply recognize the coincidence with the γ-curve in Figure 1.

3. The proposed novel optical design of WV-TN cell

We can understand that minimization of the γ-curve distortion in the WV-TN cell can start with the minimization of the transmittance differences between normal and oblique direction in the gray level by moving the polarization position of the light passing through the output polarizer in the oblique direction to *Circle j*. In order to satisfy the optical compensation for both the dark state and the gray level, we apply a pair of compensation films that consist of a negative *A*-plate and a positive *A*-plate to the WV-TN LC cell, as shown in Figure 3. We used a commercial liquid crystal supplied by JNC Co. Ltd. for the calculation and the material characteristics of the liquid crystal are as follows: elastic constants K_{11}, K_{22} and K_{33} are 10.1, 7.8 and 16.2, respectively; dielectric constants $\varepsilon_{//}$ and $\varepsilon_{\perp}$ are 15.5 and 3.5; and optical anisotropy Δn is 0.116. The applied Δnd values of the TN cell and hybrid discotic film are 0.395 µm and 0.192 µm, respectively.

In this optical configuration, optimization of the LCD can be achieved under the following conditions:

$$\sum \text{Retardation (TN cell + Two WV films)} = 0, \quad (2)$$

$$\sum \text{Retardation (Negative A + Positive A)} = 0. \quad (3)$$

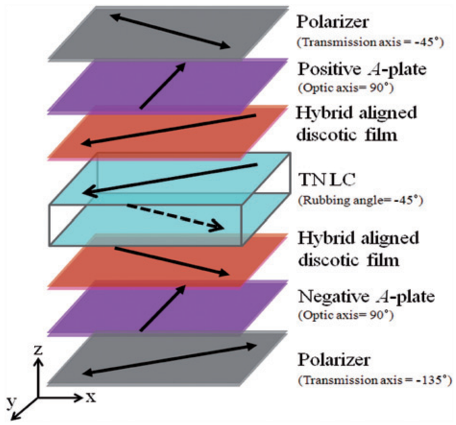

Figure 3. The optical configuration of the proposed WV-TN cell with a pair consisting of a negative *A*-plate and a positive *A*-plate. (The color version of this figure is included in the online version of the journal.)

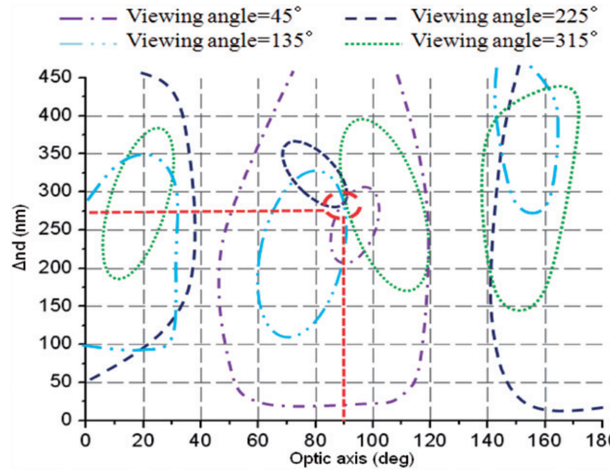

Figure 4. A parameter space of the polarization difference consisting of the optical axis and the retardation of the pair of *A*-plate parameters for optimization. (The color version of this figure is included in the online version of the journal.)

Equation (2) represents the basic optical principle of the conventional WV-TN cell for achieving a good dark state along the viewing direction [10,11]. In addition, we applied the pairing of the negative and positive *A*-plates, which satisfied the condition of Equation (3). Equation (3) implies that we can control the retardation of the pair of negative and positive *A*-plates for gray level without any scarification of the dark state in the normal and oblique direction. Instead, we can observe that there is an optimum value of the retardation and the optical axis of the pair of negative and positive *A*-plates which can improve the γ-curve. The optimal values of the pairing of the negative and positive *A*-plates can be calculated by observing the polarization difference $\Delta P_{(A-B)}$ as a function of the optical axis and retardation. The optimization of the pair of optical films can be set at the condition satisfied by the relation $\Delta P_{(A-B)} \approx \Delta P_{(A-K)}$. This implies that the positions P_{B_45}, P_{B_135}, P_{B_225} and P_{B_315} move to the *Circle j* due to the pair of the optical films and this will induce almost the same transmittance at the gray level compared with that in the normal direction. To investigate the optimal parameters of the pair of *A*-plates, we perform the calculation of the polarization difference as a function of the optical axis and the retardation value (Δnd) of the two *A*-plates. The variation range of the optical axis and the retardation for optimization are from 0° to 180° and from 50 nm to 450 nm, respectively.

Figure 4 shows a two-dimensional contour map of the polarization difference as a function of the optical axis and the retardation value of the pair of *A*-plates; this is satisfied with a polarization difference range of 0.3–0.65. From the optimization process shown in Figure 4, we can observe the optimized condition of the pair of *A*-plates is at around an optical axis of 90°

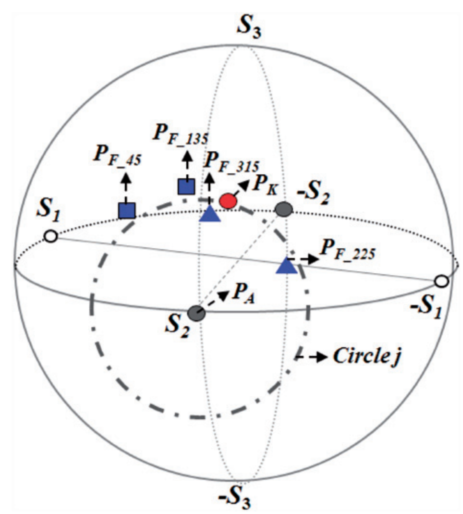

Figure 5. The polarization stats of light in front of the output polarizer on the Poincaré sphere with 1.8 V applied, which represents the 70th gray-level, in the proposed WV-TN cell. (The color version of this figure is included in the online version of the journal.)

as well as a retardation of $\Delta nd = \pm 268.8$ nm ($\lambda = 550$ nm). In this condition, the polarization difference values ($\Delta P_{(A\text{-}B\_45°)}$, $\Delta P_{(A\text{-}B\_135°)}$, $\Delta P_{(A\text{-}B\_225°)}$ and $\Delta P_{(A\text{-}B\_315°)}$) change from 0.742,0.742, 0.238 and 0.238, respectively, to 0.630, 0.630, 0.396 and 0.396.

Figure 5 shows the polarization positions of the light in front of the output polarizer of the proposed WV-TN LC cell with optimized conditions. Compared to the polarization positions of the conventional WV-TN LC cell shown in Figure 2, the polarization positions of the proposed WV-TN LC cell are located closer to the *Circle j,* which implies a similar polarization difference with that of the normal direction. These calculated results imply that polarization differences of the light between in the normal and diagonal direction are diminished, so we can expect that the transmittance difference of the light between the normal direction and the oblique diagonal direction will be reduced. This induces the improvement of the *V–T* curve and γ-curve of the WV-TN LC cell, as shown in Figure 6.

In order to verify the improvement of the γ-curve of the proposed WV-TN LC cell, we calculated the γ distortion between the conventional WV-TN cell and the proposed WV-TN cell by determining the γ distortion index (*GDI*) as follows [12]:

$$GDI = AVG\langle \left| L_{i(on-axis)} - L_{i(off-axis)} \right| \rangle_{i=0\sim 255}, \qquad (4)$$

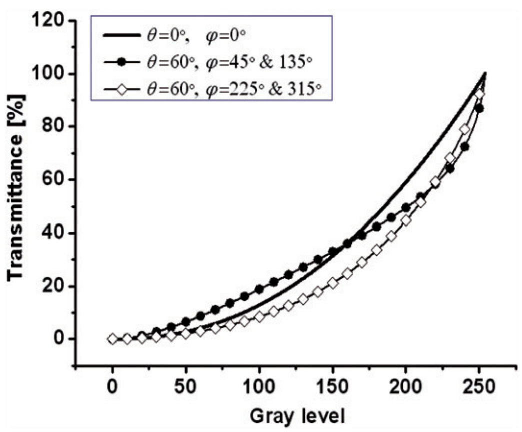

Figure 6. The calculated γ-curve of the proposed WV-TN cell. (The color version of this figure is included in the online version of the journal.)

where $L_{i(on\text{-}axis)}$ and $L_{i(off\text{-}axis)}$ represent the brightness between the *i*th gray level at the on-axis and off-axis direction, and $\langle\ \rangle$ denotes the average for all cases of arbitrary gray levels. From Equation (4), we can calculate a γ-curve improvement of 56.47% ($\theta = 60^\circ$, $\phi = 45^\circ$, 135°) and 61.71% ($\theta = 60^\circ$, $\phi = 225^\circ$, 315°). We calculated about 10% to 60% of γ-curve improvement in the range of 20° to 60° of polar angle θ.

Figure 7 shows the comparison of an iso-contrast of the proposed WV-TN LC cell and the conventional WV-TN LC cell. From the results, we can confirm that the optical performance of the proposed WV-TN LC is also almost equivalent to that of the conventional WV-TN LC cell, so that the proposed WV-TN cell can show excellent optical performance in both the dark state and gray levels. The calculation in this paper has been performed by using the TECHWIZ LCD made by SANAYI system.

4. Conclusion

The idea of the proposed WV-TN LC cell was focused on improvement of the γ-curve in addition to a wide viewing angle in the dark state. The proposed optical configuration of the WV-TN LC cell is achieved by applying a pair of negative and positive *A*-plates in addition to WV films to a TN LCD. We optimized the pair of *A*-plates on a Poincaré sphere by investigating the polarization difference of the light between that in normal direction and in an oblique diagonal direction in gray level. For verification, we compared the calculated results of the optical performances in dark state, *V–T* curve and γ-curve viewing angle of the proposed WV-TN LC cell with that of the conventional WV-TN LC cell. As a result, we confirmed that

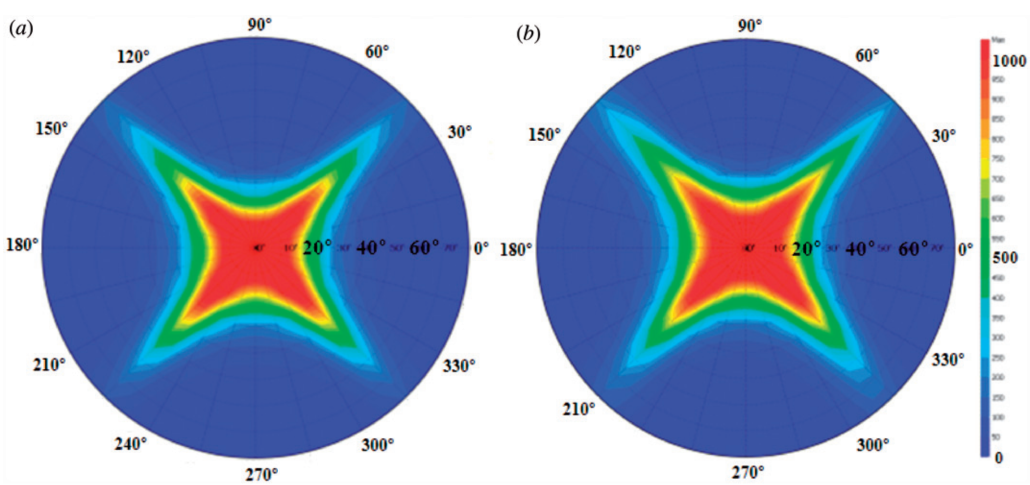

Figure 7. Comparison of the iso-contrast of (*a*) the conventional WV-TN cell (*b*) the proposed WV-TN cell. (The color version of this figure is included in the online version of the journal.)

the proposed optical configuration can provide the improved γ-curve without any deterioration of optical performance in dark state.

Therefore, we believe that the proposed WV-TN cell of excellent optical properties with small gamma distortion will contribute to development of mobile display applications and TV with TN cell technologies.

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