Advanced Optical Configuration for Transmissive and Reflective Mode in the In-Plane Switching LC cell

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Abstract

We propose a novel optical configuration for transmissive and reflective mode in the IPS LC cell to improve the viewing angle characteristics in a diagonal direction. The optical design was performed on a Poincaré sphere. From the calculation, we confirmed that the proposed configuration provides excellent viewing angle characteristics.

1. Introduction

Viewing angle is critically important for liquid crystal display (LCD), especially for high definition displays. And also it is important to reflective mode, which is suitable for mobile display devices because of their low power consumption and lightweight. The horizontal-switching liquid crystal (LC) modes such as the Super-In Plane Switching (S-IPS) mode [1,2] and the Fringe Field Switching (FFS) mode [3] show superior viewing angle characteristics without compensation film. In spite of the excellent viewing angle performance, the contrast ratio in the diagonal direction is relatively lower because of the change of the effective angle of the absorption axes of the polarizers and retarders, the change of the retardation of each optical plate with oblique incident direction and the phase dispersion [4-6]. The problems occur in the tansmissive mode as well as reflective mode. In the large displays, it causes a serious problem. In order to improve the viewing angle property of the transmissive IPS LC mode, we proposed a novel optical configuration of IPS LC mode by using an A-plate and positive C-plate in addition to IPS LC cell. And for the reflective IPS LC mode, we proposed a novel optical configuration which consists of a single biaxial film and positive C plate in addition to quarter wave LC cell. Optical optimization has been performed on Poincaré sphere by applying a spherical trigonometry method [7-8]. In order to verify the calculation of the proposed optical configuration, we use the *'DiMOS'* program, which is supplied by autronic-MELCHERS Gmbh in Germany. As a result, we found that the contrast ratio of the proposed configurations for the transmissive and reflective modes can be increased compared with the conventional IPS cell in the diagonal direction.

2. Design of the optical configurations and results

As we mentioned above, horizontal-switching LC modes show superior viewing angle. However, in the diagonal direction, the optical contrast ratio got worse because of the light leakage in the dark state in the tansmissive mode as well as reflective mode. There are several reasons for the decrease of the contrast ratio in the diagonal direction. The most important reason of them is the movement of the polarizer's absorption axis and optical axes in each optical film by change of the polar angle θ and azimuthal angle ϕ in the observation direction.

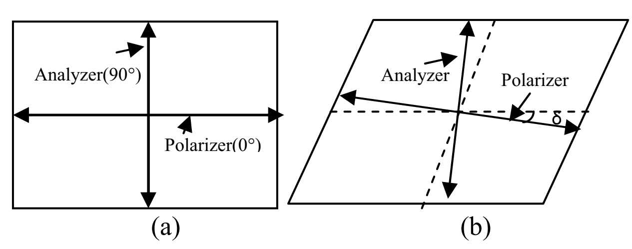


Figure 1. Change in the effective angle of the crossed polarizers: (a) Normal direction (b) Oblique direction

Figure 1 shows the change in the effective angle of the crossed polarizers. Under observation at normal direction, the change of the axes doesn't occur, as shown in Fig. 1(a). On the other hand, in oblique incidence, the axes of the two polarizers are changed by angle δ from normal incidence, as shown in Fig. 1(b). And a numerical approach to obtain the deviation angle δ is as shown below. If we assume that the birefringence is small (i.e., $| n_e - n_o | << n_e, n_o$) and the refractive indices are well matched at the interface, we can assume that both ordinary and extraordinary waves propagate along the same direction. Then, deviation angle δ in terms of ϕ_c and θ_o can be described as below [7-8]

$$\delta = \psi - \arcsin\left\{ \frac{\sin\phi_c \cos\phi_c \cos\theta_o - \cos\theta_c \sin\theta_o}{\left[1 - (\sin\phi_c \cos\phi_c \cos\theta_o + \cos\theta_c \cos\theta_o)^2\right]^{1/2}} \right\}, \qquad (1)$$

where ϕ_c is the azimuth angle of the optical axes of the A-plate and polarizer and θ_o is the polar angle of the incident light for the LC cell layer, respectively. In the oblique incidence, the optical axis of the retardation film will also be changed, which is similar to the polarizer. The effective angle of the optical axis of the A-plate is exactly the same as that of the polarizer. In the case of the biaxial plate, we assume the small birefringence, too. So deviation angle δ of the biaxial plate can be represented as δ of the uniaxial plate. In contrast, the effective slow and fast axes of the negative C and positive C plates move to 90°with respect to the projected angel of the incident k vector, respectively. And the second factor is the change of the retardation of each optical plate with oblique incident direction [7, 9].

2-1. The optical design for transmissive mode

The conventional IPS LC cell for the transmissive mode consists of an IPS LC cell and two tri-acetyl-cellulose (TAC) films on the crossed polarizers. In principle, the optical axis of the LC cell is aligned parallel to the absorption axis of the input polarizer for the dark state. In these days, the TAC film has no retardation. Figure 1 shows the polarization state of the light passing through the conventional IPS LC cell for the transmissive mode on the Poincaré sphere in the oblique direction. The polarization state passing through the polarizer moves to the position A, which is deviated with 2δ form S_1, because the axis of the polarizer moves to δ from the normal incidence. Therefore, the position A is start position. The polarization of the light passing through the LC cell is never changes because the optical axis of the LC cell is coincident with input polarizer. The position A, which is the polarization state in front of the output polarizer, is quite different from position G of the output polarizer. There we can assume that the difference between A and G will cause serious light leakage in the dark state.

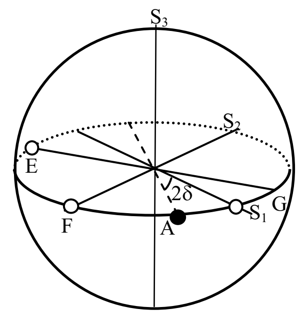


Figure 1. The polarization state of light passing through the conventional transmissive mode in oblique direction on the Poincaré sphere

Figure 2(a) shows the proposed optical configuration of the LC cell, which can obviously reduce the light leakage in the off-axis direction. Optimization of the optical configuration has been performed at the diagonal direction, ϕ = 45° because the light leakage in the dark state is maximized at ϕ = 45°.

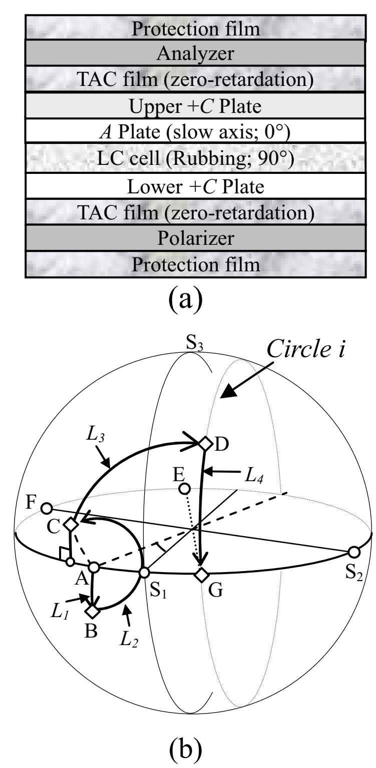


Figure 2. (a) Optical configuration of the proposed horizontal-switching LC cell for transmissive mode, (b) polarization path on the Poincaré sphere

The optical configuration of the proposed LC cell consists of a horizontal switching LC cell with half-wave retardation, two +*C*-plates, an *A*-plate and protection films with zero retardation, as shown in Fig. 2(a) [9]. The optical axis of LC cell and upper *A*-plate is aligned parallel and perpendicular with the absorption axis of the incident polarizer, respectively. An optical polarization path of the proposed LC cell can be described on the Poincaré sphere as shown in fig. 2 (b). At the oblique incidence, the polarization position of the polarizer will move to *A* with 2δ from S_1. Position *E* represents the position of output polarizer in the oblique incident. The polarization of the light passing through the lower +*C*-plate move to position *B* along the circle path L_1. The polarization of the light arrives at the position *C* along the circle path L_2 by the LC cell, which is centered at position *A*. And the polarization state of the light will rotate to *D* on the circle *i* along the path L_3 by passing through the upper *A*-plate, which is centered at position *E*. Finally, the polarization state will rotate to position *G* along the path L_4 on the circle *i* by passing through the upper *C*-plate. Position *G* is exactly adjusted to the opposite position of the polarization state of the output polarizer *E*. Therefore, it clearly provides blocking of light leakage in the dark state.

2-2. The optical design for reflective mode

In the reflect mode, the light leakage like generating in the transmissive mode occurs. The conventional reflective LC cell is sequentially stacked by a polarizer, a half-wave retarder and a quarter-wave LC cell in addition to a reflector. Figure 3 shows the polarization state of the light passing through the conventional reflective LC cell on the Poincaré sphere in the oblique direction.

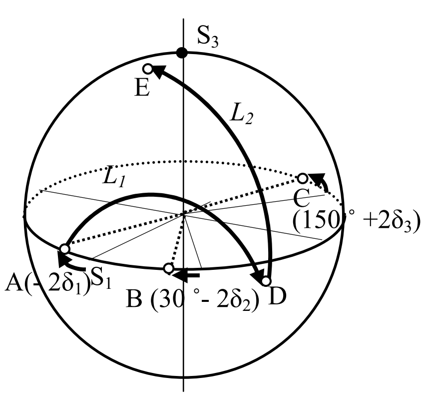


Figure 3. The polarization state of light passing through the conventional LC cell for reflective mode in oblique direction on the Poincaré sphere

In the oblique direction, the polarization of the light passing through the polarization proceeds to *A* with deviation angle δ_1. By passing through the half-wave retarder, the polarization state of the light proceeds to position *D* with circle path L_1, which has centering the axis of the half wave film (point *B*). The polarization of the light passing through the quarter-wave LC layer proceeds to *E* with circle path L_2, which is centered at the axis of the quarter wave LC cell (point *C*). As a result, the polarization of the light in front of the mirror obviously deviates to *E* from the desired destination S_3, which can get a perfect dark state in the reflective mode. Therefore, we can assume that the deviation between S_3 and *E* will cause serious light leakage in the dark state. In order to compensate the light leakage of the dark state in the oblique incident, we apply the biaxial half-wave retarder instead of uniaxial half-wave retarder and the positive *C*-plate in front of mirror, as shown in Fig. 4(a) [10].

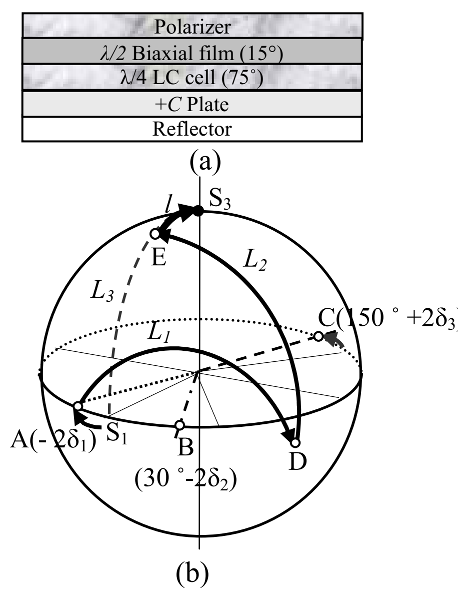
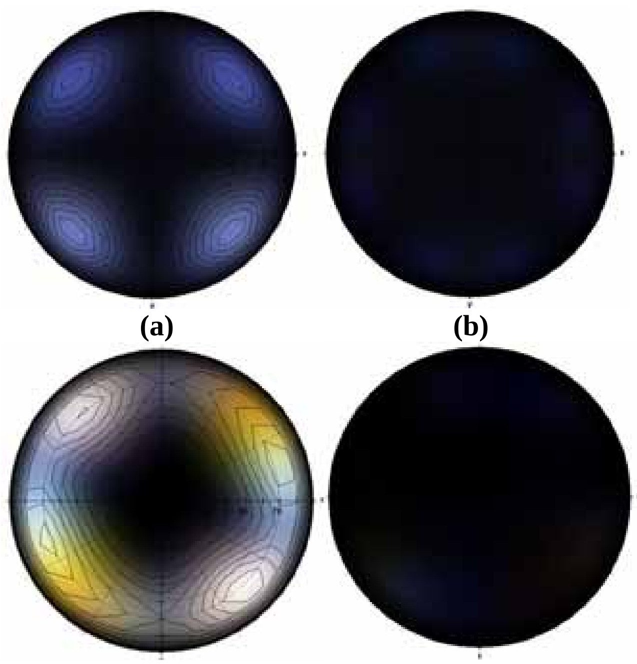


Figure 4. (a) Optical configuration of the proposed LC cell for reflective mode, (b) polarization path on the Poincaré sphere

Figure 4 (b) shows polarization path of the light passing through the proposed LC cell for reflective mode at oblique direction on the Poincaré sphere. The biaxial film helps the polarization path passing through the quarter-wave LC cell to arrive within the line L_3. And we use the positive *C*-plate in order to reduce the deviation length *l* in all direction. The polarization path of the light passing through all plates arrives at position S_3. Thus we can reduce the light leakage in the oblique incidence.

2-3. Results

From the calculation, we can get an improved dark property. Figure 5(a) ~ (d) show a comparison of the calculated iso-dark contour of the conventional and the proposed configuration for transmissive mode and reflective mode, respectively. The Iso-dark contours are calculated by the *DiMOS* software, which is supplied by autronic-MELCHERS Gmbh in Germany. From the fig. 5(b) and (d), we confirm that the maximum light leakage in the diagonal direction is effectively eliminated in the transmissive mode as well as the reflective mode compared with the conventional LC cell in oblique incidence.



(a) **(b)** **(c)** **(d)**

Figure 5. Iso-dark contour (a) The conventional LC cell and (b) proposed LC cell for transmissive mode (c) The conventional LC cell and (d) proposed LC cell for reflective mode

3. Conclusion

In conclusion, we proposed a novel optical configuration for the transmissive mode and reflective mode, which can improve the viewing angle property. For the transmissive mode, we apply an *A*-plate and two +*C*-plates and for the reflective mode, we use the biaxial plate instead of the uniaxial $\lambda/2$ plate and a +*C*-plate. The proposed configuration's optical design was performed on the Poincaré sphere with the trigonometric method. From the calculation, we confirm the proposed optical configurations for transmissive mode and reflective mode provide excellent dark state in diagonal direction as well as in normal direction.

4. Acknoledgement

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