Optimization of Circular polarized Transflective Vertical Alignment Liquid Crystal cell

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ABSTRACT

We propose an optical configuration for transflective vertical alignment (VA) liquid crystal (LC) cell with circular polarizer to enhance the viewing angle in the dark state. The proposed optical design was performed on a Poincaré sphere. From calculations, we confirm that the proposed configuration can show high viewing angle property compared with conventional configuration.

1. Introduction

Recently, lots of studies have been performed to improve the optical properties in Liquid Crystal Display (LCD) industry [1-4]. Especially, the rapid growth of market regarding mobile devices has made the research for wide viewing angle and high brightness very active [5]. In particular, transflective LC mode can be an important display mode to be able to satisfy both the indoor and outdoor display applications because the transflective mode can realize merits of transmissive mode and reflective mode at once. In various LCD modes, multi-domain vertical alignment (MVA) mode is greatly employed in pure transmissive LCDs like LCD TVs owing to its wide viewing angle under two crossed linear polarizers [6]. However, for mobile applications using both transmissive and trasflective LCDs, MVA cell is usually sandwiched between two circular polarizers (CPs) for high efficiency and a functional reflective mode. Optical configuration for a circular polarizer in normal direction normally requires the two optical films that consist of a uniaxial $\lambda/2$ retarder and a uniaxial $\lambda/4$ retarder in addition to a linear polarizer for excellent dark state. However, in terms of oblique incidence, undesired light leakage may happen because the oblique light incidence make polarization of the light passing through the cell deviated from the desired polarization positions.

In this paper, we proposed an optical configuration of the circular polarizer that consists of the $\lambda/2$ biaxial film, a negative C-plate in addition to the positive $\lambda/4$ *A*-plate and the linear polarizer in order to compensate the deviated polarization of the light passing through the LC cell. We applied the proposed optical configuration of the circular polarizer to the transflective VA LC cell. In order to verify the optical characteristics of the proposed CPs, we compared the calculated optical properties of the proposed CPs to those of the conventional CPs.

2. Design of wide-view circular polarizers

2.1 Conventional configuration

Fig. 1(a) depicts the detailed configuration of the top and bottom conventional broadband circular polarizers; each comprises a linear polarizer and two uniaxial positive *A*-plates. The LC director in the VA LC cell is vertically aligned to the substrate in the electrically off state. We assume that the optical axis of the VA LC cell in the absence of an electric field is the same to the optical axis of the positive *C*-plate.

In terms of green wavelength (550 nm) light, Fig. 1(b) shows the corresponding polarization trace for the reflective mode on the Poincaré sphere when the ambient light is reflected back to the viewer by the metal reflector just below the top circular polarizer in Fig. 1(a). The polarization state of the ambient light after passing through the top linear polarizer is the point *T*, and the final absorption direction will be at point *A*. The light from point *T* will be converted by the top circular polarizer to a circular polarization at point *C*. The light having circular polarization is further converted to linear polarization at point *A* after passing through the reflector surface. It means conventional broadband circular polarizers show a perfect dark property in the normal incidence.

However, the reflective mode even in the conventional circular polarizers has a large off-axis light leakage. Fig. 1(c) shows the polarization state of the light when the light obliquely passes through the VA-cell in the diagonal direction. In the dark state, the oblique incident light experiences the deviated angle δ compared to the normal incidence when it passes the polarizer. Therefore, the position of the transmission axis of the top linear polarizer will deviate by 2δ from S_1 on the Poincaré sphere. Therefore, the start polarization position in the oblique incidence becomes the position *T*.

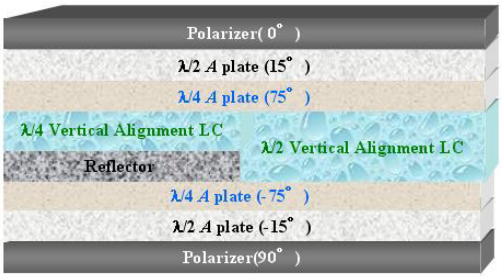

Fig. 1(a)

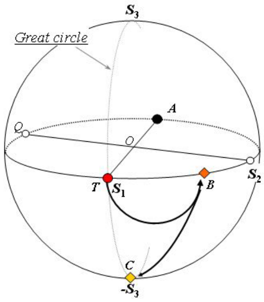

Fig. 1(b)

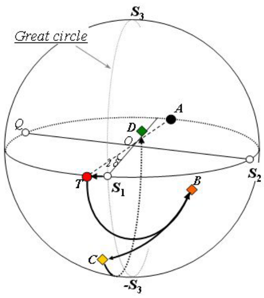

Fig. 1(c)

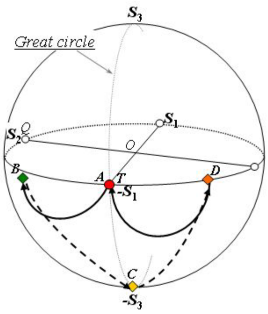

Fig. 1(d)

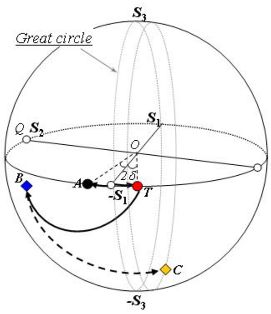

Fig. 1(e)

Fig. 1. (a) Configuration of conventional CPs: polarization states of the light on the Poincaré sphere for (b) the R-mode of the normal incidence (c) and the oblique incidence; (d) the T-mode of the normal incidence (e) and the oblique incidence

The polarization positions of the light after passing through the top $\lambda/2$ and $\lambda/4$ positive *A*-plates is rotated to the polarization position *C*, due to the off-axis phase retardation accumulation from the two positive *A*-plates. Here, the polarization position *D* after passing through the $\lambda/4$ VA-cell with a position of the fast axis *Q* is quite different from the circular polarization position -S_3. Therefore, we can assume that the large deviation between position *D* and position -S_3 will induce a serious off-axis light leakage in the dark state. For the optimal dark state, it is necessary to make the polarization state of the light move to position -S_3 in front of the reflector.

Fig. 1(d) represents the polarization state trace on the Poincaré sphere when a light passes through the transmissive structure from the bottom side at a normal direction. On the Poincaré sphere, the transmission axis of the bottom linear polarizer is represented by the point *T,* while point *A* represents the absorption axis of the top linear polarizer. Points *A* and *T* coincide with each other when the top and bottom polarizers are crossed. The polarization state of the light after passing through the bottom $\lambda/2$ positive *A*-plate is the point *B*, then it is converted by the bottom $\lambda/4$ positive *A*-plate to a circular polarization on the south pole at point *C*. In the same way, the point *C* will be converted back to the point *A* after passing through the top $\lambda/4$ and $\lambda/2$ positive *A*-plates, thus a perpect dark state also can be obtained in the normal incidence.

However, the transmissive mode in the conventional circular polarizers also has a large off-axis light leakage. Fig. 1(e) shows the corresponding polarization state trace when the light obliquely passes through the VA-cell in the diagonal direction. The polarization position *C* after passing through the bottom $\lambda/4$ positive *A*-plate is deviated from circle S_1-S_3 due to the off-axis phase retardation accumulation from bottom positive *A*-plates. Thus, the final polarization position is quite different from the polarization position *A*, which is the position of the absorption axis of the top linear polarizer in the oblique incidence.

2.2 Proposed configuration

To minimize light leakage at oblique incidence, we propose here to use the $\lambda/2$ biaxial film, a $\lambda/4$ positive *A*-plate and a negative *C*-plate, as shown in Fig. 2(a).

In this paper, we apply the top $\lambda/2$ biaxial film with $N_z \approx 0.36$ and the bottom $\lambda/2$ biaxial film with $N_z \approx 0.7$ to the proposed VA-cell. The parameter N_z represents $(n_x - n_z)/(n_x - n_y)$ of the biaxial film. An improved optical polarization path of the proposed LC cell is described on the Poincaré sphere, as shown in Fig. 2(b), (c).

Fig. 2(b) is the change of the polarization state for an oblique incident light inside the proposed configuration for the reflective mode. The start position on the Poincaré sphere is on the position *T* when the light passes through the top linear polarizer and the point *A* represents the absorption axis of the top linear polarizer. In terms of green wavelength light, the polarization position of the light after passing through the top $\lambda/2$ biaxial film ($N_z \approx$

0.36) changes from *T* to *B*, after passing through the top $\lambda/4$ positive *A*-plate, the polarization state changes from *B* to *C*, after passing through the top negative *C*-plate and the $\lambda/4$ VA-cell, the polarization state of the light moves to position *E* in front of the reflector. Then, the position *E* will be converted to the position *A* after passing through the $\lambda/4$ VA-cell, the top negative *C*-plate, the top $\lambda/4$ positive *A*-plate and the top $\lambda/2$ biaxial film ($N_z \approx 0.36$), thus a perfect dark state can be obtained in the oblique incidence.

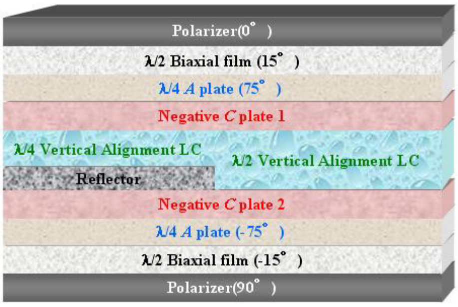

Fig. 2(a)

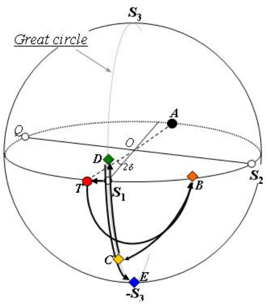

Fig. 2(b)

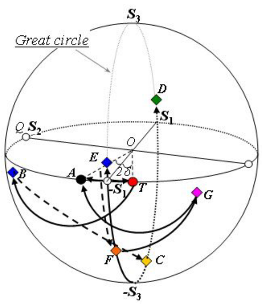

Fig. 2(c)

Fig. 2. (a) Configuration of proposed CPs: polarization states of the light on the Poincaré sphere for (b) the R-mode (c) and the T-mode of the oblique incidence

Fig. 2(c) is the polarization state of an oblique incident light inside the proposed configuration for the transmissive mode. The start position is on the position *T* when the light passes through the bottom linear polarizer and the point *A* represents the absorption axis of the top linear polarizer. The polarization position of the light after passing through the bottom $\lambda/2$ biaxial film ($N_z \approx 0.7$) changes from *T* to *B*, after passing through the bottom $\lambda/4$ positive *A*-plate, the polarization state changes from *B* to *C*, after passing through the bottom negative *C*-plate, the $\lambda/2$ VA-cell and the top negative *C*-plate, the polarization state of the light moves to position *F*. Then, the top $\lambda/4$ positive *A*-plate converts the light from point *F* to point *G*, and the light is further moved to point *A* by the top $\lambda/2$ biaxial film ($N_z \approx 0.36$). The off-axis light leakage is also eliminated in the oblique incidence because *A* overlaps the absorption axis orientation of the top linear polarizer.

As for the blue (450 nm) and red (630 nm) wavelength light (not shown here), the polarization positions of the light passing through the optical components follow the same way with the green wavelength light.

In this paper, we could achieve the excellent optical wide viewing angle by handling the $\lambda/2$ biaxial film's in-plane phase retardation value ($d \cdot \Delta n/\lambda$, $\Delta n = n_x - n_y$) and its N_z factor. As we can see from Fig. 2(b), (c) in the oblique incidence, the phase compensation could be almost perfectly conducted.

3. Results and discussion

We compared the optical transmittance of the proposed wide-view CPs with the conventional CPs for the dark state in the diagonal direction, as shown in Fig. 3. We observed that the proposed configuration effectively eliminates the off-axis light leakage in the dark state compared to the conventional CPs. We verified the improved viewing angle of the proposed wide-view CPs by using commercial LC software *TechWiz LCD* by SANAYI System Co. in Korea instead of performing experiments because each optimized film requires very long time to be supported. Figure 4 shows the comparison of the luminance of the proposed wide-view CPs to that of the conventional CPs in the dark state. From the calculated results in Fig. 3 and 4, we confirmed that the proposed wide-view CPs effectively eliminates light leakage in the dark state so that the off-axis contrast ratio of the proposed wide-view CPs can increase far beyond that of the conventional CPs in calculations.

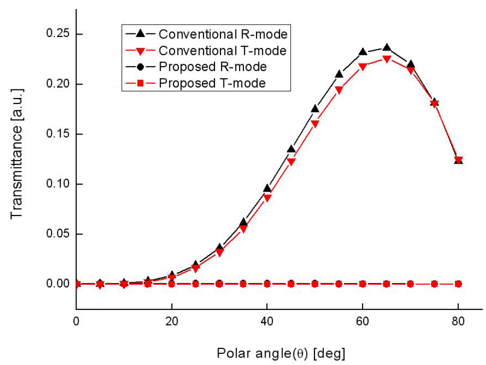

Fig. 3. Comparison of the transmittance between the conventional and the proposed CPs as a function of the polar angle at ϕ = 45° in the dark state

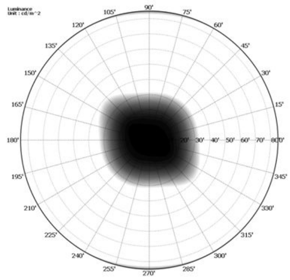

Fig. 4(a)

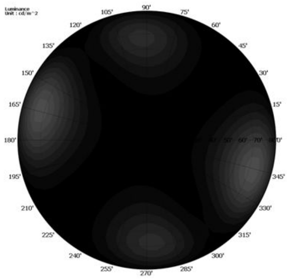

Fig. 4(b)

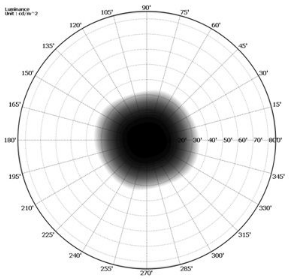

Fig. 4(c)

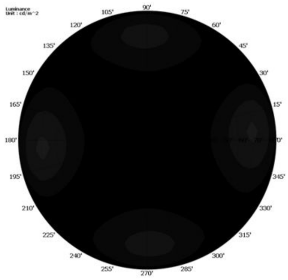

Fig. 4(d)

Fig. 4. Calculated luminance in the dark state: (a) the conventional CPs (b) and the proposed CPs for R-mode; (c) the conventional CPs (d) and the proposed CPs for T-mode

4. Conclusion

In conclusion, we proposed a compensation method for a wide-view CPs. The dake state off-axis light leakage is almost suppressed by using two $\lambda/2$ biaxial films and negative *C*-plates on the Poincaré sphere. At the same time, we also obtained a broadband reflective mode from the same configuration. We confirmed that the proposed configuration provides very low light leakage in the dark state and a good viewing angle property.

5. Acknowledgement

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6. References

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