Film Compensation based on Discotic Film in Fringe Field Switching Mode

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Abstract

Film compensation to suppress a light leakage in the dark state of fringe-field switching (FFS) at off normal direction was performed by optimizing retardation value of discotic (negative A) and TAC films including in-plane switching (IPS). The normal FFS mode shows wide viewing angle characteristics that region of CR 10:1 is over 70° of polar angle in all directions. The optimized FFS cell exhibits much better performances than other methods do in terms of CR and color uniformity.

1. Introduction

Nowadays, the liquid crystal displays (LCDs) are in charge of an important role in human to machine interfaces. The application fields of the LCDs are greatly extended ranging from small size mobile phones to large size LC-television (TV). Especially, the LCD-TVs should meet customer's high requirements such as wide viewing angle, fast response, high resolution, low power consumption and high color reproducibility. For applications of LC-TV and large-size monitor with wide viewing angle, film compensation technology has been developed continuously by improving film characteristics according to the new LC modes such as in-plane switching (IPS) mode [1], fringe field switching (FFS) mode [2-4], vertical aligned (VA) mode [5] and optically compensated bend (OCB) mode [6].

To improve the viewing angle characteristics of horizontal switching mode in oblique directions, various optical configurations of compensation films have been applied [7-11] and very wide viewing characteristics are achieved even in oblique directions. Recently, IPS-pro using the concept of the FFS mode has improved black representation by applying optimized biaxial film [12]. However, a biaxial film has difficulty in production process to yield in good uniformity in retardation when applying large size LC-TV and use of multiple films increase production cost.

In this paper, we investigated film compensation using only single film, a discotic film [13,14] to compensate light leakage in oblique viewing directions in a dark state of FFS and IPS cell. In addition, the out of plane retardation value R_{th}' of TAC (triacetyl cellulose) film and R_{th}'' of discotic film have been optimized.

2. Simulation

In the FFS and IPS mode, effective birefringence (Δn_{eff}) is not zero at off-normal axis except for the directions coincident with transmittance axis of polarizer, resulting in a light leakage as well as color shift change as the viewing direction changes in a dark state. So, the light passing through the LC layer depends on $d\Delta n_{eff}/\lambda$ with viewing angle in a dark state. Consequently, the FFS and IPS show relatively low CR and color shift characteristics due to light leakage and $d\Delta n_{eff}/\lambda$ in oblique directions.

To remove this light leakage of FFS and IPS cells, we proposed optical configurations of discotic film compensation as shown in Fig. 1. The optic axes of LC and discotic film is parallel each other and discotic film was stood perpendicular against the substrate. LC is optically positive birefringence ($n_x=n_y<n_z$) and discotic LC with disk-like shape is optically negative birefringence ($n_x=n_y>n_z$). Therefore, this optical compensation configuration compresses light leakage in the dark state in all viewing directions more effectively than other methods do because optical isotropy can be achieved easily.

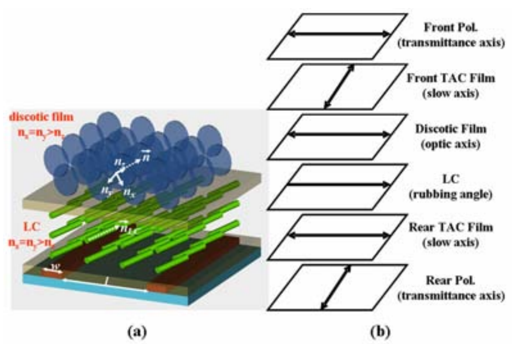

Fig. 1. Proposed (a) optical concept and (b) cell structure of discotic film compensation in the FFS LC cell.

To compensate perfectly light leakage in all viewing direction in the proposed cell, it should be satisfied with the condition: $d\Delta n_{Rear\ TAC\ film+LC}(\Theta,\Phi,\lambda) + d\Delta n_{Discotic\ film+Front\ TAC\ film}(\Theta,\Phi,\lambda) = 0$. Case 1 was optimized by R_{th}' of both front and rear TAC films having same value and R_{th}'' of discotic film. And case 2 was optimized by R_{th}' of only front TAC and R_{th}'' of discotic films as shown in Fig. 1(b). For optical characteristics, commercially available software, LCD Master (Shintech, Japan), and the 2 x 2 Jones matrix method [15] were used. The LC for IPS cell with physical properties such as $\Delta\varepsilon = +7.2$, $\Delta n = 0.08$ (at 550 nm) is used. Cell gap is 4 ㎛ and *w, l* are 5 and 10 ㎛, respectively. The LC for FFS cell with physical properties such as $\Delta\varepsilon = +7.2$, $\Delta n = 0.10$ (@550 nm) is used. Cell gap is 4 ㎛ and t *w, l* are 3 and 4.5 ㎛, respectively. The transmittances for the single and parallel polarizers were assumed to be 41% and 35%, respectively.

3. Results and discussions

Figure 2 shows maximum light leakage in a dark state of IPS cell according to R_{th}' of TAC films and R_{th}'' of discotic film in (a) case 1 and (b) case 2. R_{th}' of front and rear TAC films and R_{th}'' of discotic film should be optimized coincidently considering R_{th}' of TAC films to maximize effects of discotic compensation. In case of IPS cell, case 1 shows that the least maximum light leakage in a dark state was 0.007310 at R_{th}' of 65.2nm in the front and rear TAC film and R_{th}'' of 88nm in the discotic film. And case 2 shows that the least maximum light leakage in a dark state was 0.001637 at R_{th}' of 89.65 nm in the front TAC film and R_{th}'' of 152nm in the discotic film.

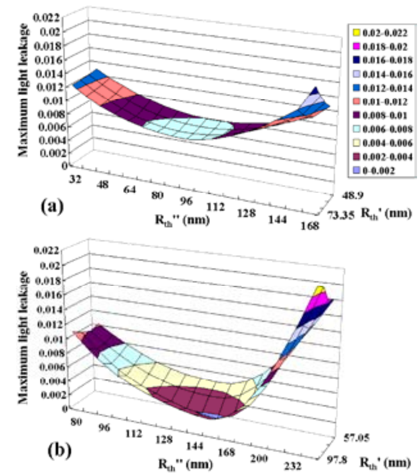

Fig. 2. Maximum light leakage in a dark state of IPS cell: (a) case 1 and (b) case 2.

Figure 3 indicates maximum light leakage in a dark state of FFS cell according to R_{th}' of only front TAC film and R_{th}'' of discotic film in (a) case 1 and (b) case 2. In case of FFS cell, case 1 shows that the least maximum light leakage in a dark state was 0.003925 at R_{th}' of 48.9nm in the front and rear TAC films and R_{th}'' of 128nm in the discotic film. And case 2 shows that the least maximum light leakage in a dark state was 0.001497 at R_{th}' of 89.65 nm in front TAC film and R_{th}'' of 144nm in the discotic film.

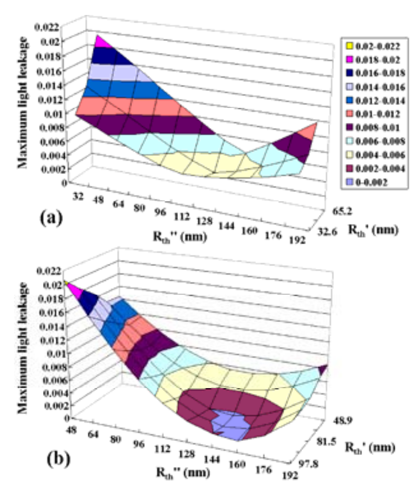

Fig. 3. Maximum light leakage in a dark state of FFS cell: (a) case 1 and (b) case 2.

Table 1 shows optimized condition of R_{th}' and R_{th}'' for minimizing light leakage in each case. Optimization condition of R_{th}' and R_{th}'' is different in each case. Maximum light leakage in case 2 was much more decreased than in case 1. And then drop ratio of light leakage was 77.0 % in IPS cell and 61.1 % in FFS cell in case 2 compared to case 1. In case 1, maximum light leakage of FFS cell was much low as 46.3% compared to IPS cell in case 1. In case 2, maximum light leakage FFS cell was low as 8.6% compared to IPS cell in case 2. Consequently, maximum light leakage of FFS cell was much lesser than that of IPS cell and maximum light leakage of case 2 was much lesser than that of case 1. As a result, FFS cell optimized by only front TAC and discotic films presents better performance to compensate light leakage in a dark state.

TABLE 1. Optimized conditions of R_{th}' and R_{th}'' for minimizing light leakage in each case.

		Front R_{th}' (nm)	Rear R_{th}' (nm)	R_{th}'' (nm)	Maximum light leakage
IPS	Case 1	65.2	65.2	88	0.007310
	Case 2	89.65	none	152	0.001637
FFS	Case 1	48.9	48.9	128	0.003925
	Case 2	89.65	none	144	0.001497

Figure 4 shows Iso-luminance in T_0 and iso-CR contours (a) IPS and (b) FFS in an optimized case 1. Here, iso-luminance contour lines that represent relative transmittance of 70%, 50% and 30% with respect to the maximum transmittance at normal direction are compared to each other. The region of CR 100:1 is over 50° of polar angle in all directions and CR 50:1 existed around 60° of polar angle in all directions in IPS cell as shown in Fig. 4(a). However, in FFS cell, region of CR 100:1 is over 60° of polar angle in all directions and CR 50:1 doesn't exist in all directions in FFS cell as shown in Fig. 4(b).

Besides, In optimized case 2, light leakage in a dark state became much more lesser than that of case 1. Therefore, the region of CR 100:1 is over 75° of polar angle in all viewing directions in IPS cell as shown in Fig. 5(a). However, in FFS cell, region of CR 100:1 exists over 80° of polar angle in all directions as shown in Fig. 5(b). Furthermore, region of CR 500:1 is also more increased in FFS cell than IPS cell. Consequently, compensation effects for horizontal switching LC cell based on discotic film show that the FFS cell is more effective than IPS cell in terms of CR. In addition, applying only front TAC and discotic films is the most effective in FFS and IPS cells.

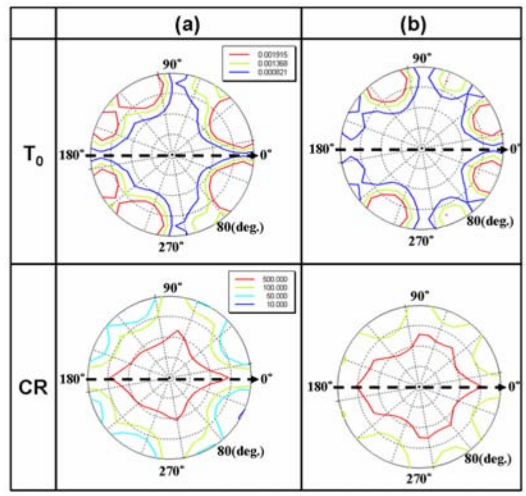

Fig. 4. Iso-luminance in T_0 and iso-CR contours (a) IPS and (b) FFS in an optimized case 1.

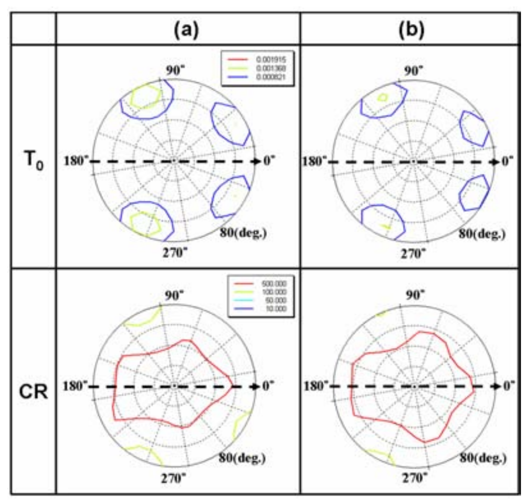

Fig. 5. Iso-luminance in T_0 and iso-CR contours (a) IPS and (b) FFS in an optimized case 2.

We are also evaluating off-axis color uniformity from normal direction at T_{100} and T_{50} IPS and FFS cell in the case 2. Here, Δu'v' means distance of color shift from normal to viewing directions on a 1976 CIE coordinates system. In case of T_{100}, color uniformity of FFS cell shows better performances compared to that of IPS cell. And also In case of T_{50}, color uniformity of FFS cell is better than that of IPS cell except for horizontal direction showing that Δu'v' of FFS cell is larger than that of IPS cell. Overall, color uniformity of FFS cell is better than IPS cell.

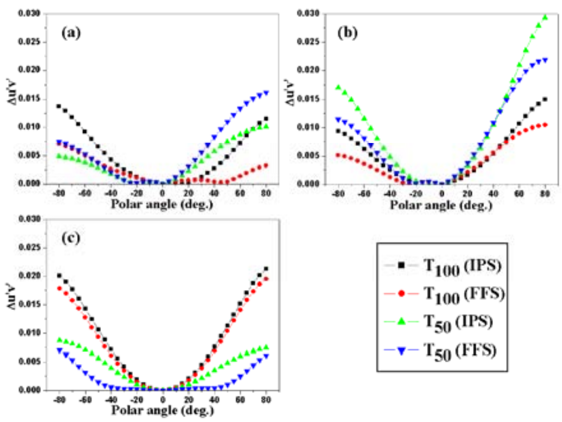

Fig. 6. Comparison of off-axis color uniformity from normal direction along the (a) horizontal, (b) diagonal and (c) vertical directions of IPS and FFS cells in optimized case 2.

4. Summary

We have studied film compensations according to optimizing R_{th}' of TAC and R_{th}'' of discotic films to improve viewing angle dependent light leakage in a dark state of FFS and IPS cells. And the optimized cell for FFS cell exhibits larger CR than IPS cell in all viewing directions. In addition, case 2 optimized by R_{th}' of only front TAC and R_{th}'' of discotic films is better performances than case 1 optimized by R_{th}' of front and rear TAC films and R_{th}'' of discotic film in terms of CR and color uniformity. Besides, rear TAC film should be zero retardation value to maximize removing light leakage in dark state in all viewing directions of FFS cell because applying only front TAC and discotic films is the most effective in FFS and IPS cells. In results, the optimized FFS cell exhibits much better performances than other methods do in terms of CR and color uniformity.

4. Acknowledgements

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5. References

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