Dual-Antiferroelectric Liquid Crystal Display with High Transmittance Efficiency and Dispersion-Free

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Abstract

If an antiferroelectric liquid crystal (AFLC) cell is set between crossed polarizers for optical modulators or displays, it has low transmittance efficiency. This happens because AFLC materials have inherent tilt angles of typically 18°~ 38°, not 45°. To improve the low transmittance efficiency, we propose a new optical configuration for antiferroelectric liquid crystal displays, which also improves color dispersion.

1. Introduction

The discovery of antiferroelectric liquid crystals (AFLCs)[1] has attracted researchers' attention from both fundamental and practical viewpoints, and significant research has been carried out to understand their characteristics[1]~[15].

The response time of AFLCs is several hundreds microseconds due to the spontaneous polarization [11]. This high-speed characteristic is suitable for displaying dynamic imagery since it is essential to avoid motion artifacts such as decreased dynamic contrast ratio, stroboscopic motion, and blurred moving edges[16]. The surface-stabilized antiferroelectric liquid crystal display (AFLCD)[1]~[3],[10],[13] is a widely studied and most promising one. But for practical applications it has some problems such as a poor alignment at the AF-state, pretransitional effect, low transmittance efficiency, and a low cell gap requirement. Poor alignments and pretransitional effects have been studied in published papers[10],[14]~[15]. However, there was no attempt to improve the low transmittance efficiency due to their inherent tilt angle of typically 18°~ 38°, not 45°.

To improve the low transmittance efficiency, we propose a dual-AFLC cell structure. This new AFLCD improves the low brightness and also the inferior dispersion characteristics of the conventional surface-stabilized AFLCD. We compare a dual-AFLCD with a conventional AFLCD by simulation and on experiments with the fabricated cells.

2. Configuration

Figure 1 shows the optical configuration of the proposed dual-AFLCD. It is composed of two polarizers, two surface-stabilized AFLC cells and a backlight source. The optic axes of the two AFLC cells located between the crossed polarizers are perpendicular to each other. Each optic axis of the AFLC cells is parallel to the transmission axis of the adjacent polarizer. The tilt angle and Δnd of both AFLC cells are 22.5° and 275nm, respectively.

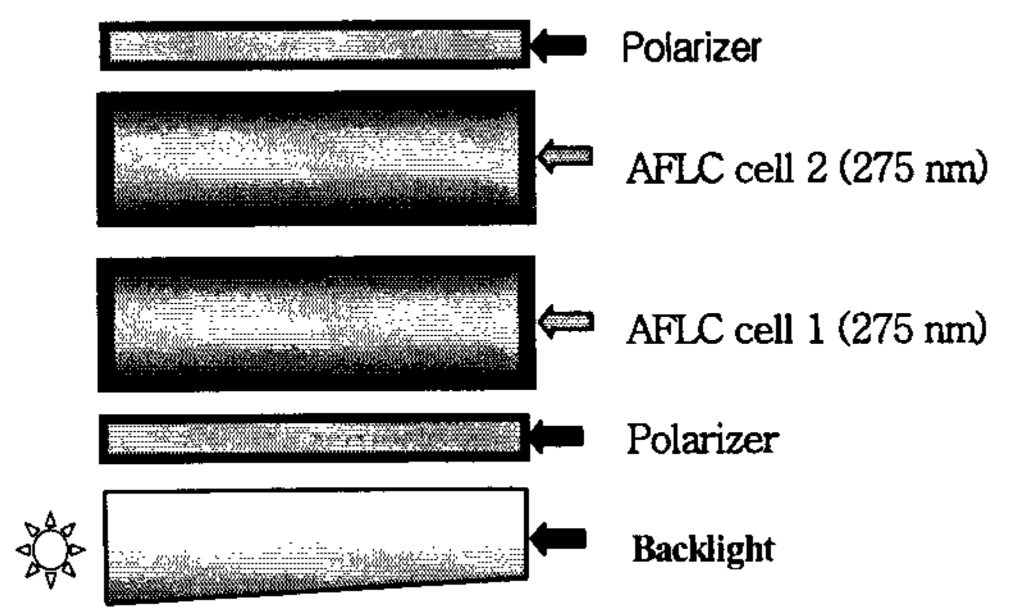


Fig. 1. The configuration of dual-AFLCD

3. Principle of operation

The operation principle of the dual-AFLCD is explained in Fig. 2. Solid arrows indicate the transmission axis of the polarizers and the optic axis of the AFLC cells, and open arrows express the polarization direction of the light passing the cells.

Below the threshold voltage, both AFLC cells are in the AF-state, this displays a dark state and it is

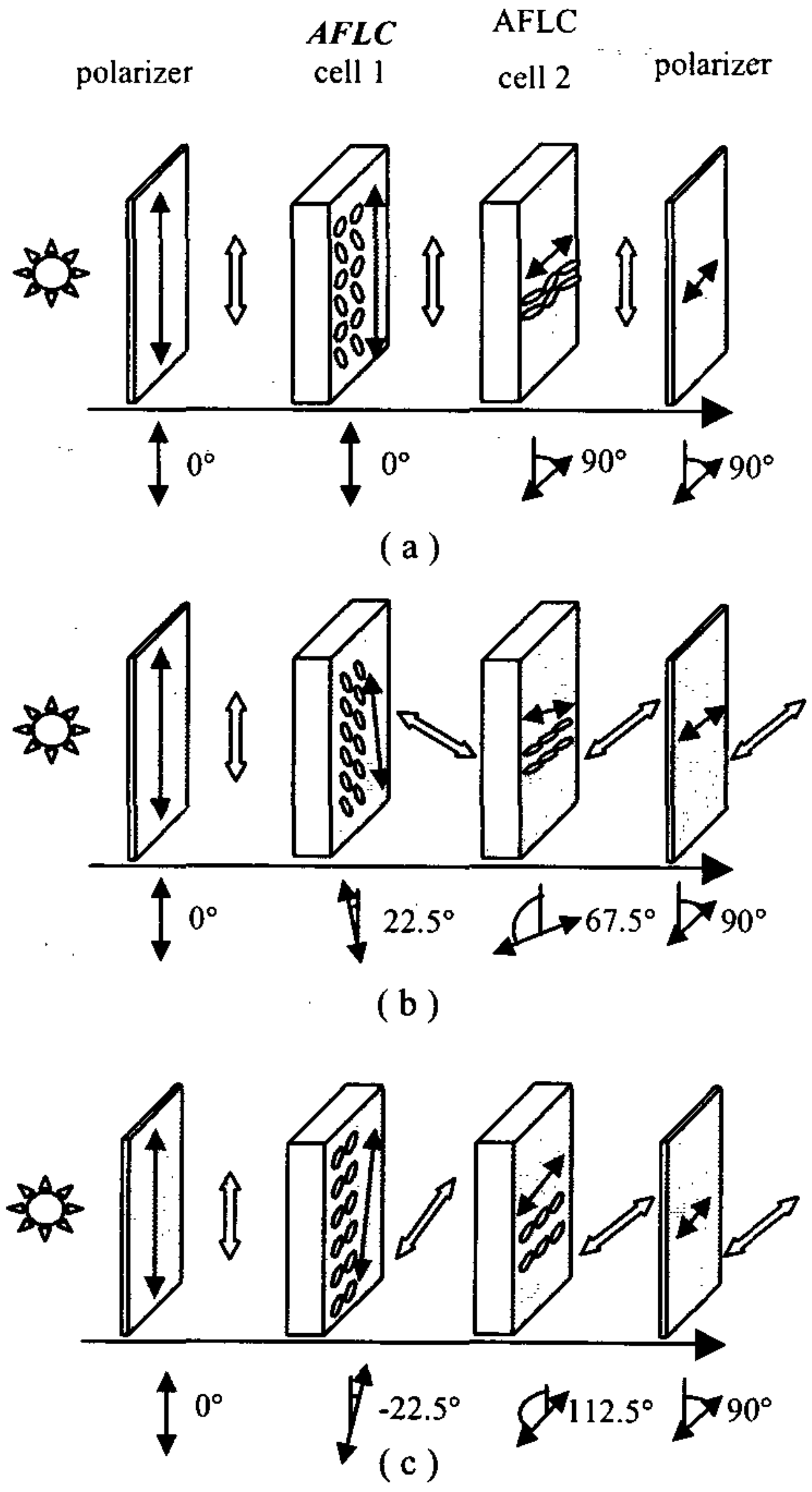


Fig. 2. The operation principle of dual-AFLCD: (a) dark state, (b) bright state 1, and (c) bright state 2

shown in Fig. 2(a). There are two cases that achieve a bright state as shown in Figs. 2(b) and 2(c). One is obtained with a ferro (+) state of the AFLC cell 1 and a ferro (-) state of the AFLC cell 2, and the other is obtained with a ferro (-) state of the AFLC cell 1 and a ferro (+) state of the AFLC cell 2. Figure 2(b) shows the bright state of the first case. Linearly polarized incident light from the source is changed into 45° linearly polarized light while passing through the AFLC cell 1 whose optic axis is tilted to the ferro (+) state by an angle of 22.5°. Then this light travels through the AFLC cell 2 which is in the ferro (-) state and whose optic axis is tilted by an angle of 67.5°. Finally the light comes out as 90° linearly polarized light. The polarization direction of the transmitted light is coincident with the transmission axis of the rear polarizer. Therefore, a bright state is realized. The other bright state can be achieved when the AFLC cell 1 is in the ferro (-) state and AFLC cell 2 is in the ferro (+) state as shown in Fig. 2(c).

4. Dispersion Characteristics

Our dual-AFLCD has the characteristics of the wideband λ/2 film like the λ/2 achromatic retarder[17]. The superior dispersion characteristics of the dual AFLCD can be described clearly using the Poincáre sphere[18]-[20]. Figures 3 (a)~(c) show the change of the polarization state of the light spectrum on the Poincáre sphere for the light paths shown in Figs. 2 (a)~(c), respectively. As shown in Fig. 3(a), there is no dispersion in the dark state. In Fig. 3(b), path 1 represents the change of the polarization state by the AFLC cell 1 on the Poincáre sphere. Since the retardation of green light of 550 nm is exactly λ/2 after passing the AFLC cell 1, the polarization state changes to the point P which is a 45° linearly polarized state. However, the other wavelengths except 550nm do not experience the retardation of λ/2, hence they move to a point somewhere between points P_1 and P_2. The light of shorter wavelengths than 550nm moves to P_1, while light of longer wavelengths moves to P_2. These dispersion characteristics are the characteristics of the conventional surface-stabilized AFLCD, so we cannot avoid color dispersion. However, in the dual-AFLCD, this dispersion is compensated after passing path 2 by the same principle. All the light of different wavelengths meet on the point P_{out}. They are all 90° linearly polarized light. So the output will have excellent dispersion characteristics and maximum transmittance. The other bright state with the configuration of Fig.2 (c) can be also explained by the same procedure.

5. Simulation and Experiments

Spectroscopic characteristics for dark and bright states of the conventional AFLCD and the dual–AFLCD are simulated using the commercial program, DIMOS. The results are shown in Figs. 4(a) and 4(b). The dual-AFLCD has double the transmittance and more excellent dispersion characteristics than a conventional AFLCD.

We also fabricated a conventional surface-stabilized AFLCD and a dual-AFLCD. The tilt angle and Δnd of all displays are 24° and 550nm, respectively. The spectroscopic characteristics for the dark and bright states of both the displays are shown in Figs. 5(a) and 5(b). To realize a bright state, a square wave of ±15V and 0.25 KHz was simultaneously applied to each display. In the dark state, light leakage occurs because the alignments of all AFLCDs are not perfectly homogeneous.[9] In the dual AFLCD, the dark state is much better than the conventional AFLCD. The crossed AFLC cells also compensate for the optical effect of poor alignment. Transmittance of the dual AFLCD is doubled compared to the transmittance of the conventional AFLCD. The dispersion characteristics of the dual AFLCD are also improved as our dual AFLCD has the characteristics of the wideband λ/2 film[17]. In the bright state of the dual AFLCD, the ripples due to the interference between the glasses of the two AFLC cells can be reduced by using thinner glass.

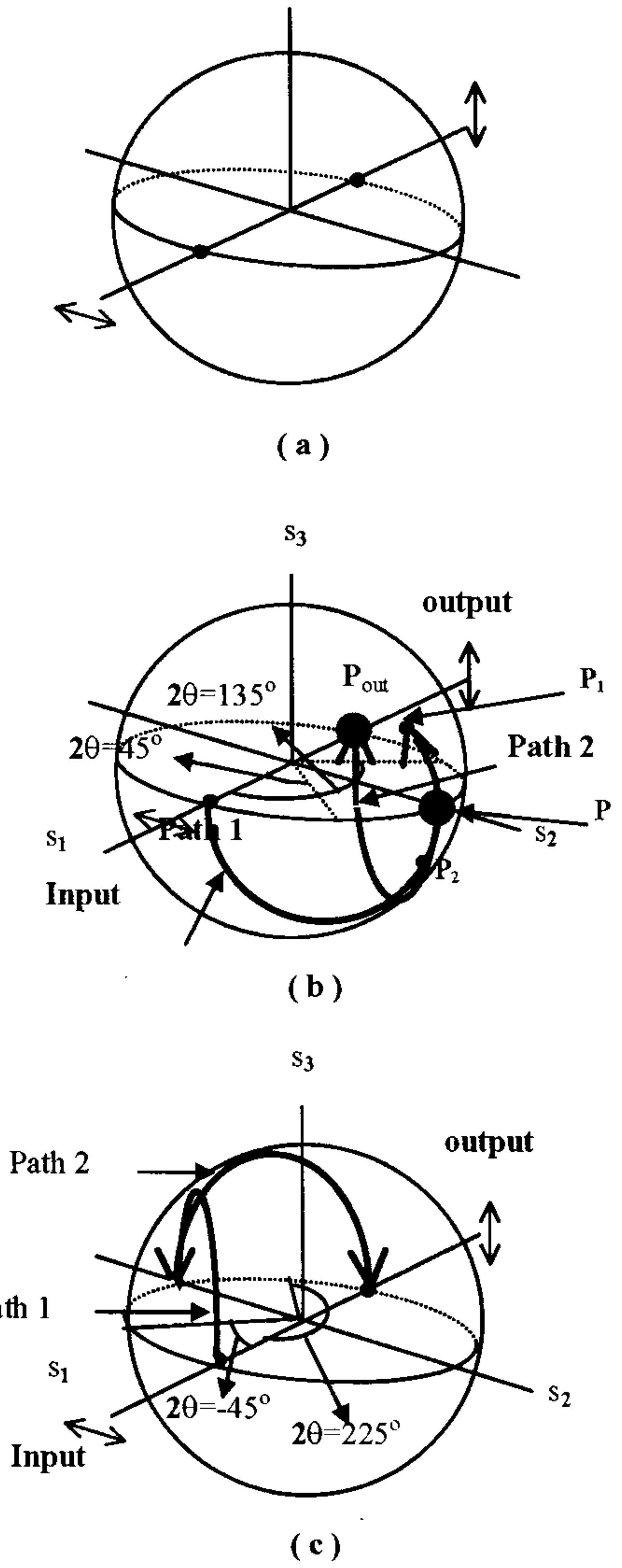


Fig. 3. The change of polarization state on the Poincáre sphere; (a) dark state, (b) bright state 1, and (c) bright state 2 for the configuration of Figs. 2(a)~(c), respectively

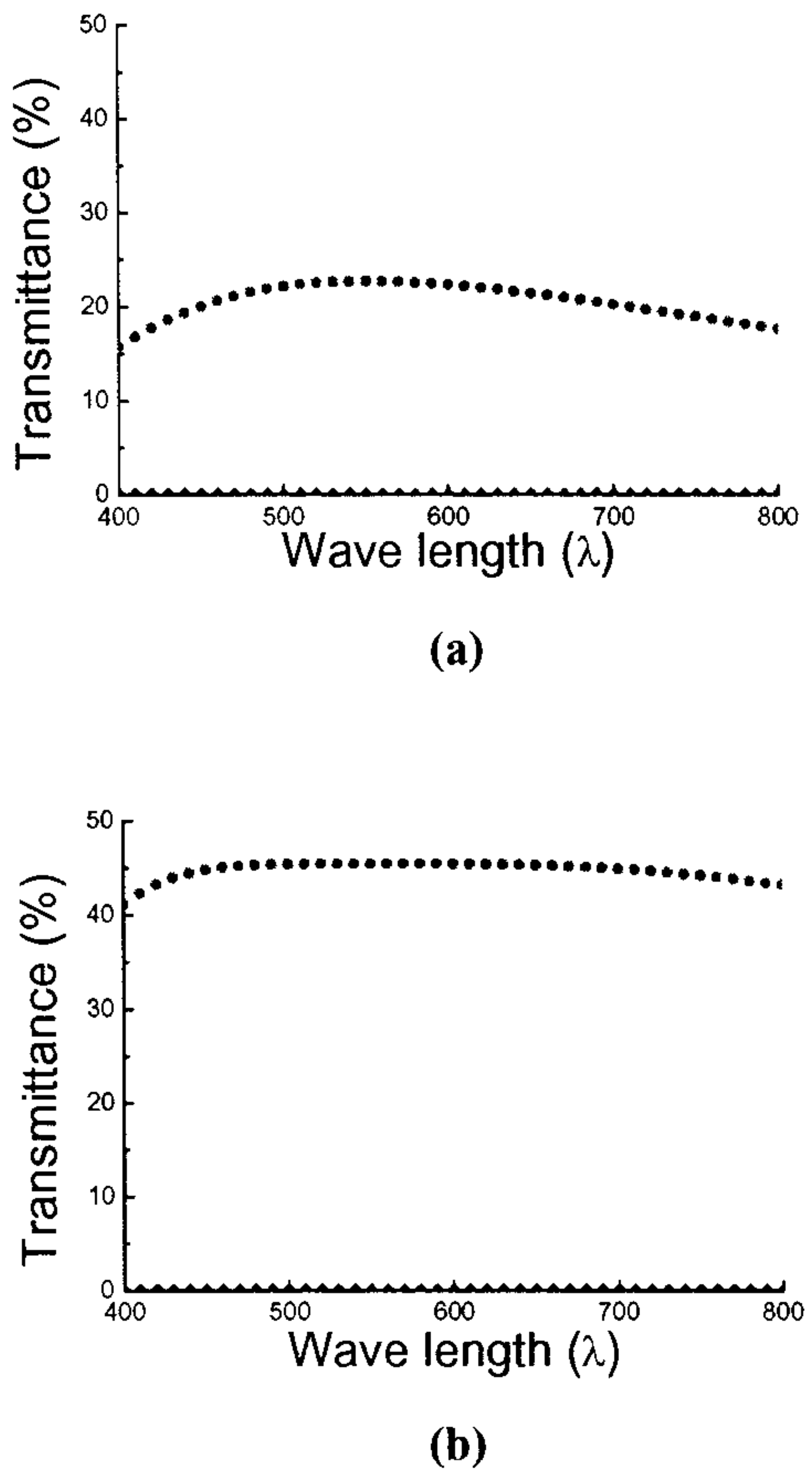
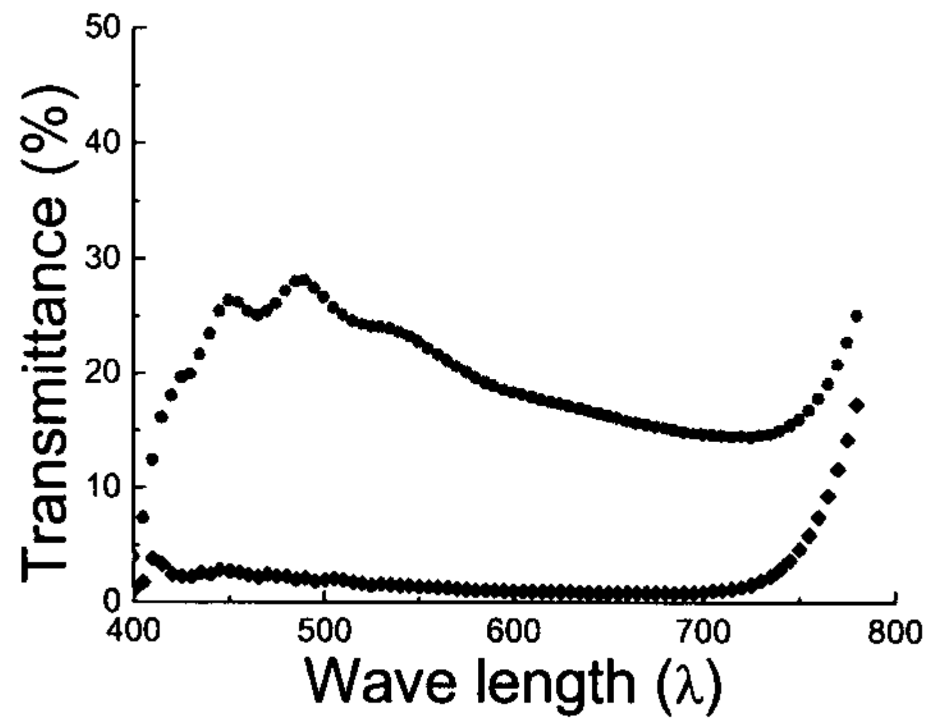
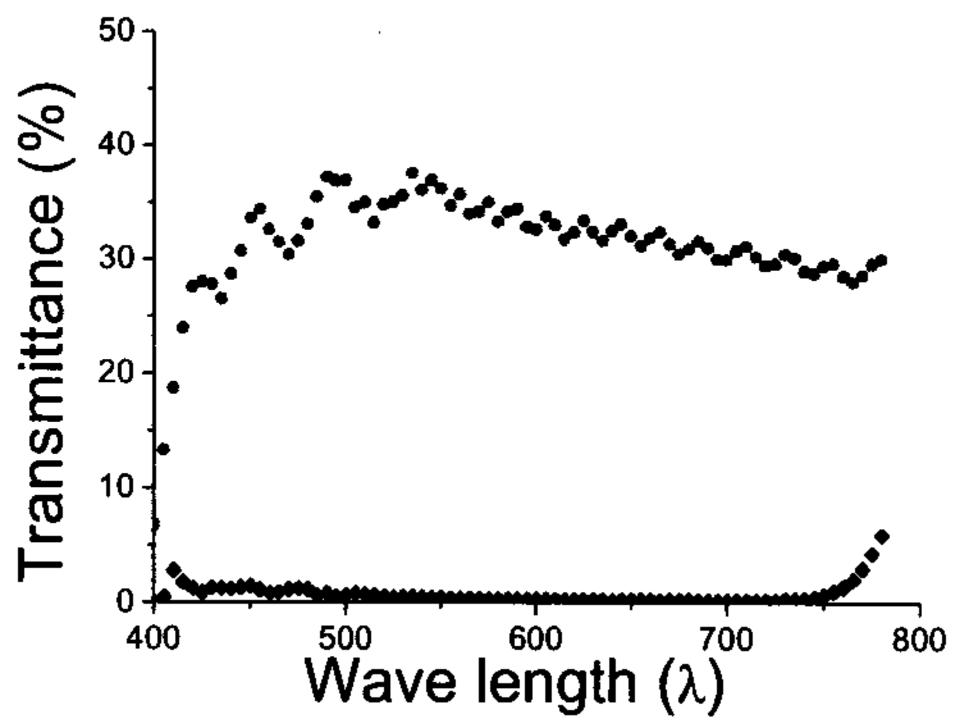


Fig. 4. The spectroscopic characteristics by simulation of (a) a conventional AFLCD and (b) a dual AFLCD. (Dark state (♦), and bright state (•) for each curve)



(a)



(b)

Fig. 5. The spectroscopic characteristics by experiments of (a) a conventional AFLCD and (b) a dual-AFLCD: (Dark state (♦), and bright state (•) for each curve. A square wave of ±15V and 0.25 KHz is applied for the bright state)

6. Conclusion

The dual-AFLCD improves the low transmittance efficiency of the surface-stabilized AFLCD and the inferior dispersion characteristics in both dark and bright states. This configuration will provide better performance for not only displays, but also optical switching devices or optical modulators which use AFLC materials. A number of applications can be derived from this configuration.

7. Acknowledgements

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