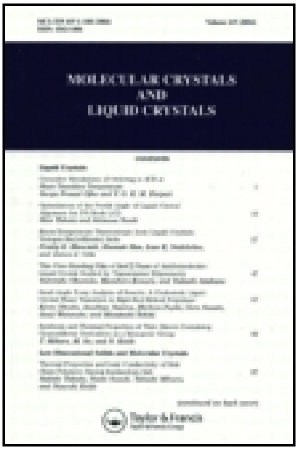

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We propose a transflective dual mode liquid crystal display, which is composed of a transmissive part for dynamic mode and a reflective part for a memory mode in a pixel. The proposed configuration has single cell gap and single rubbing direction in both parts. In order to make the reflectance minimized and maximized for dark and bright states of memory part, the parameters of LC layer and retardation film are optimized by using the Jones matrix method. Moreover, the operating voltage of dynamic part is found to depend on the retardation values of compensation films. With this configuration, the dynamic and memory modes show high contrast ratio of 1100:1 and 20:1, respectively, by calculation, while 220:1 and 10:1, respectively, by experiment.

Keywords: BCSN; dual mode; liquid crystal display; tristate

1. INTRODUCTION

Liquid Crystal Display (LCD) modes can be classified into two categories. One is the dynamic mode with monostable characteristics, and the other is memory mode with bistable characteristics. Generally, the dynamic mode such as Twist Nematic (TN), In-Plain

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Switching (IPS), Vertical Allign (VA), and Optical Compensation Bend (OCB) mode [1–4] requires a fast switching time for moving picture. And, the memory mode such as Bistable Twist Nematic (BTN), Bistable Nematic (BiNem), Zenithal Bistable Display (ZBD), and Bistable Chiral Splay Nematic (BCSN) [5–8] requires a long memory time to display a picture without refreshing.

Recently, we proposed a dual mode LC cell to realize the dynamic and memory mode in a pixel [9]. This novel device has not only a long retention time for memory mode but also a fast switching time for dynamic mode. Figure 1 shows the basic structure and operating scheme of the dual mode LC cell. It has a common electrode at top substrate, and ground and grid electrodes at bottom substrate. Positive LC was filled in between the top and bottom substrates of the same rubbing direction with an adequate chiral doping ratio. Under these conditions, the LC cell can have three textures of splay, bend and π-twist.

The dynamic mode uses bend texture to generate a gray scale between black and white states, which are realized by using vertical electric field between common and ground electrodes. On the other hands, the memory mode uses the splay and π-twist textures for the two stable states. The switching from splay to π-twist occurs by the LC relaxation after eliminating the vertical electric field and the

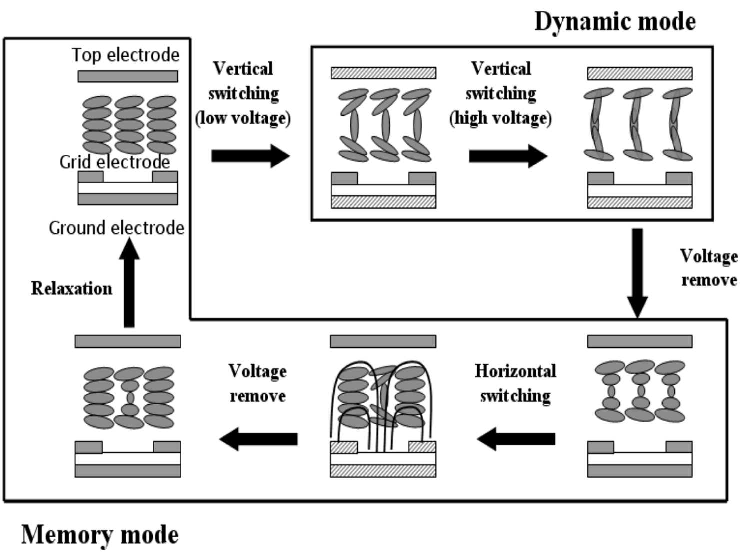

FIGURE 1 Operational scheme of the dual mode LCD.

switching from π-twist to splay occurs by the horizontal electric field between grid and ground electrodes.

The basic concept and configuration of the transflective dual mode LCD has been proposed in previous paper [9,10]. It has a good optical performance at both indoor and outdoor. Especially, the memory mode using reflective type may have ultra-low power consumption. However, there has been no optimization for enhancing the optical characteristics such as wavelength dispersion, driving voltage and contrast ratio in the previous research. As a result, it has shown a poor contrast ratio of under 5:1.

In this letter, we optimize the configuration and optical parameters of the transflective dual mode LCD. The reflective memory part is designed to have high contrast ratio and the transmissive dynamic part is designed to have low driving voltage. Two parts have the same cell gap and same rubbing direction. We calculate the optical performance by varying the parameters of the LC cell and retardation films, and optimize them. The calculated results are verified by the measured ones of the fabricated LC cell using the designed configuration.

2. OPTICAL DESIGN OF DUAL MODE LC CELL

2.1. Configurations of Dual Mode LC Cell

Figure 2 shows the proposed configuration of a transflective dual mode LC cell. The right and left half parts are operated as reflective memory

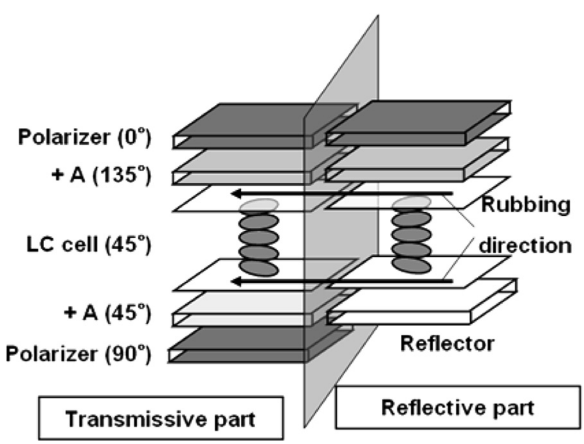

FIGURE 2 Proposed configuration of the transflective dual mode LCD.

and transmissive dynamic modes, respectively. To achieve easy fabrication process, the memory and dynamic modes share the same film configuration, single cell-gap and the same boundary condition with parallel rubbing direction. Between one polarizer and the mirror near it, we designed the compensation film for the reflective memory part. The transmissive dynamic part was designed using the same upper compensation film and a bottom positive a-plate. The reflective memory part has two stable states of splay and π-twist. The splay and π-twist states are selected as dark and bright states, respectively. The optic axes (OAs) of the upper polarizer and positive a-plate were aligned at the angles of 90 and 135°, respectively. The transmissive dynamic part was designed on the condition that the LC parameters and the cell-gap were the same as those of the reflective part. We designed the high- and low-bend states as dark and bright states, respectively. To obtain a high contrast ratio, we use a positive a-plate on the bottom layer. Its OAs is aligned at an angle of 45°.

2.2. Optical Design of Reflective Memory Part

Then, we inquire closely into the proposed configuration. Based on the limited condition, such as Δnd, rubbing direction of 45° angle with respect to the transmission axis of the polarizer for a good brightness in the transmissive dynamic part, the splay and 180° twist state used as the dark and bright state for easy compensation conditions, we designed the reflective memory part. Table 1 shows the initial condition for the reflective memory part. To design the splay state as a dark state, we found that the Δnd of upper positive a-plate should satisfy the following condition:

$$R_{LC} - R_{film} = \frac{\lambda}{4} \tag{1}$$

where, R_{film} and R_{LC} are the retardation values of the upper positive-a plate and liquid crystal, respectively, and λ is the wavelength. If this condition is satisfied, the polarization state will be rotated by 90° after a double pass through the cell. Then the polarizer will block the

TABLE 1 Initial Conditions for the Reflective Memory Part

Parameter	Δnd	Rubbing direction	Dark state	Bright state
Initial condition	550 nm $\leq \Delta$nd	45°	Splay state	180° Twist State

reflected light so that a dark state can be achieved. To achieve good reflectance when the LC is at π-twist state, we investigated the change of reflectance by varying the retardation values. The reflectance of the output polarized light passing through a positive a-plate can be represented using the Jones matrix method as follows [11–12].

$$R = \left|(1 \quad 0) J_{film} J'_{twist} J_{twist} J_{film} (1 \quad 0)^t\right|^2 \tag{2}$$

$$J_{film} = \begin{pmatrix} \cos\Psi & -\sin\Psi \\ \sin\Psi & \cos\Psi \end{pmatrix} \begin{pmatrix} e^{-i\Gamma_f/2} & 0 \\ 0 & e^{i\Gamma_f/2} \end{pmatrix} \begin{pmatrix} \cos\Psi & \sin\Psi \\ -\sin\Psi & \cos\Psi \end{pmatrix} \tag{3}$$

$$\begin{aligned} J_{twist} = & \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \\ & \times \begin{pmatrix} \cos X - i\frac{\Gamma_L}{2}\frac{\sin X}{X} & \phi\frac{\sin X}{X} \\ -\phi\frac{\sin X}{X} & \cos X + i\frac{\Gamma_L}{2}\frac{\sin X}{X} \end{pmatrix} \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \end{aligned} \tag{4}$$

$$\begin{aligned} J'_{twist} = & \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \\ & \times \begin{pmatrix} \cos X - i\frac{\Gamma_L}{2}\frac{\sin X}{X} & -\phi\frac{\sin X}{X} \\ \phi\frac{\sin X}{X} & \cos X + i\frac{\Gamma_L}{2}\frac{\sin X}{X} \end{pmatrix} \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \end{aligned} \tag{5}$$

where, R, J_{film}, J_{twist}, J'_{twist} are the reflectance, Jones Matrixes of positive a-plate, 180° twisted LC cell and mirror image 180° twisted LC cell, respectively. (1 0) and $(1\ 0)^t$ are Jones vectors of the input and output polarizer upon reflection, respectively.

$$\Gamma_f = \frac{2\pi R_{film}}{\lambda}, \quad \Gamma_L = \frac{2\pi R_{LC}}{\lambda}, \quad X = \sqrt{\phi^2 + \left(\frac{\Gamma_L}{2}\right)^2} \tag{6}$$

Also, Ψ, Φ and α are the angle between the OA of the positive a-plate and the transmission axis of the polarizer, the twisted angle of the LC layer and the angle between the direction of the LC director and the transmission axis (TA) of the polarizer. The reflectance with respect to the retardation values of LC cell are shown in Figure 3. When the retardation value of the LC cell is about 1000 nm, the reflectance reaches the maximum. Therefore, we can obtain an optimized reflective memory part, where the retardation values of the positive a-plate

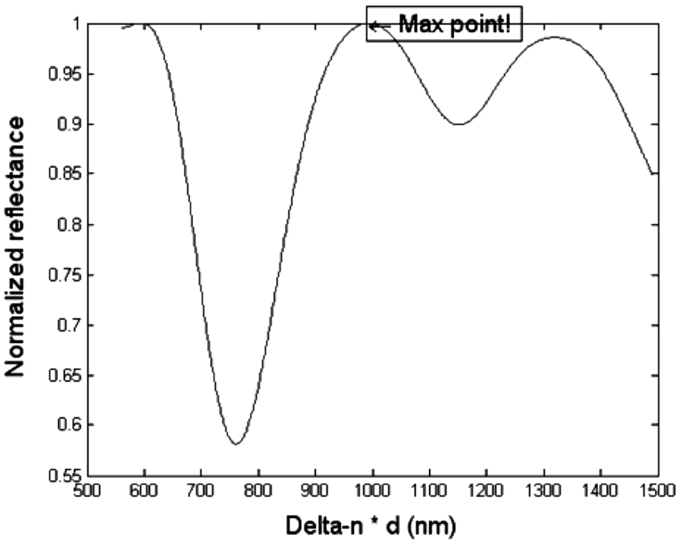

FIGURE 3 Calculated reflectance of the reflective memory.

and the LC cell are 1000 and 862.5 nm, respectively, and a contrast ratio of 20:1 is obtained.

2.3. Optical Design of Transmissive Dynamic Part

To design the transmissive dynamic part of the transflective dual mode with the same cell gap, rubbing direction and compensation film, the Δnd of the positive a-plate and LC cell designed in the previous reflective memory part are used. The bottom compensation film of the transmissive dynamic part is represented by the following equation.

$$R_{bottom} + R_{LC-S} = R_{film} \tag{7}$$

where, R_{bottom}, R_{film} are the Δnd of bottom positive a-plate and upper positive a-plate, respectively. And $R_{LC\text{-}S}$ is the Δnd of the LC with no applied electric field. If the transflective dynamic part satisfies Eq. (7), we can obtain a dark state under cross polarizer condition. In Figure 4, the dark state voltages are compared with regard to the retardation values of the bottom positive a-plate. The voltage in the dark state is dependent on the retardation values of the bottom positive a-plate. A voltage of 5.5 V is chosen as a reasonable low applied voltage. Then we designe the transmissive dynamic part. The designed Δnd of bottom positive a-plate is 807 nm and the voltages for bright and dark states are 1.3 and 5.5 volts, respectively. The transmittance of the bright state is about 30% and a contrast ratio of 1100:1 is obtained.

3. RESULTS OF EXPERIMENT

To show the feasibility of the proposed configuration as a display device, we fabricated a transflective dual mode cell. The Δnd of the LC cell is about 1000 nm. Liquid crystal used in the experiment was MLC 6204–000 (Δn = 0.1478, Merck Co.). The Δnds of the upper and bottom positive a-plates are 860 and 810 nm, repectively. Figures 5(a) and 5(b) show the measured optical performances of dynamic and memory parts. The little mismatch of the results is due to the small difference in polarizer, retardation films, and LC layer from the designed values. Still, the experimental results show a good agreement with the simulated results. In the measured results, the bright and dark voltages of the dynamic part were 1.3 and 6 V. Also, the contrast ratios for the transmissive and reflective parts were 200:1 and 10:1, respectively.

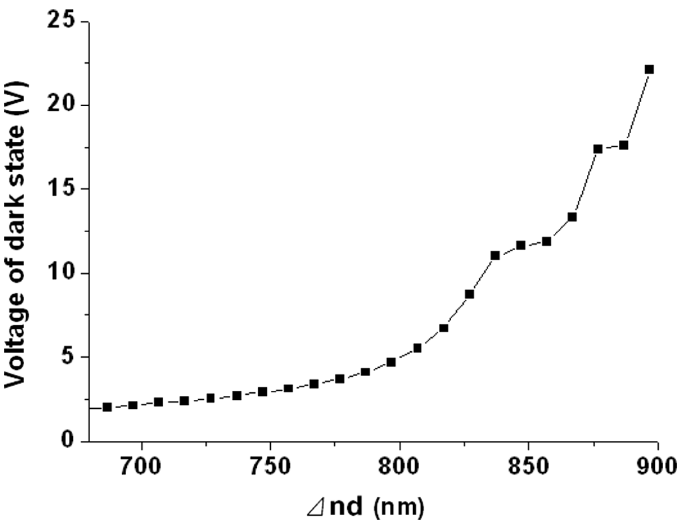

FIGURE 4 Voltage of the dark state for the transmissive part with the variation of the retardation value of the positive a-plate.

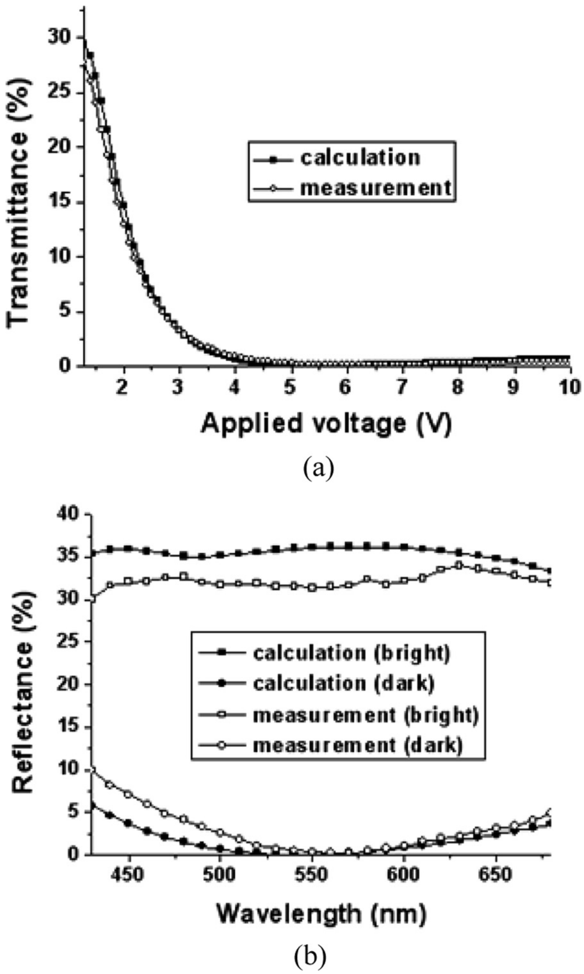

FIGURE 5 Calculated and measured characteristics of the proposed configuration: (a) Electro-optic characteristics of the transmissive dynamic part, and (b) wavelength dispersions of the dark and bright states of the reflective memory part.

4. CONCLUSION

We proposed a transflective configuration of dual mode LCD with a single cell gap structure and same rubbing directions at both transmissive and reflective parts. The parameters of each component are determined and optimized by the Jones matrix calculation.

The calculated contrast ratios of the dynamic and memory modes were 1100:1 and 20:1, respectively, while the measured results were 220:1 and 10:1, respectively, at each mode.

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