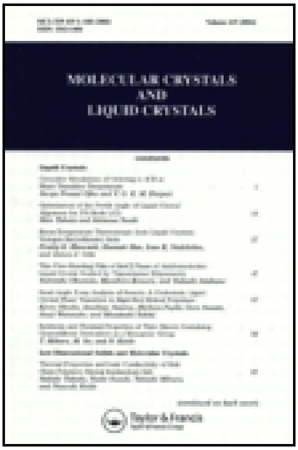

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Chul Gyu Jhun [a], Sun-Kyung Kim [a], Sang-Hyun Park [a], Kwan-Sik Min [a], Soon-Bum Kwon [a], Tae-Hoon Yoon [b] & Jae Chang Kim [b]

[a] School of Display Engineering, Hoseo University, Asan, Chungnam, Korea

[b] Department of Electronics Engineering, Pusan National University, Busan, Korea

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Chul Gyu Jhun[1], Sun-Kyung Kim[1], Sang-Hyun Park[1], Kwan-Sik Min[1], Soon-Bum Kwon[1], Tae-Hoon Yoon[2], and Jae Chang Kim[2]
[1]School of Display Engineering, Hoseo University, Asan, Chungnam, Korea
[2]Department of Electronics Engineering, Pusan National University, Busan, Korea

In the bistable chiral splay nematic (BCSN) mode, the splay and π twist states are used for the two stable states. The transition between the memory states accompanies the motion of the disclination line, due to the topologically inequivalent from each other. The switching time is consistently coupled with the propagation velocity of the disclination line, which strongly depends on the amplitude of the applied voltage. In this paper, we demonstrate the gray scale of BCSN liquid crystal display (LCD) by the control of the domain density of the splay and twist states during the transition process.

Keywords: grayscale; liquid crystal display; memory effects

INTRODUCTION

The common feature of bistable liquid crystal displays (LCDs) is the existence of the two stable states without an external field. The two stable states have the memory effects which can reduce power consumption and make multiplexing capability in the passive matrices unlimited so that there has been increasing interest about bistable LCDs. A number of bistable modes have been proposed until now [1–7].

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Address correspondence to Soon-Bum Kwon, School of Display Engineering, Hoseo University, Asan, Chungnam 336-795, Republic of Korea. E-mail: sbkwon@hoseo.edu

In the bistable chiral splay nematic (BCSN) mode, the splay and π twist states are used for the two stable states [7–12]. The two states have infinite memory time with the multi-domain structure by the double rubbing method [8,9] or double cell gap structure [10]. Due to the topologically inequivalent states from each other, the transition between the states accompanies the motion of the disclination line. The velocity of the disclination line depends on the energy difference between two states [11]. An applied voltage plays an important role in the change of the energy difference [12].

In this paper, we investigated the gray scale capability of the BCSN LCD. With various domain densities of the two memory states, which are caused by the propagation of the disclination line during the transition process in the pixel, the gray scale of the BCSN LCD is achieved. We demonstrate the gray scale of the BCSN LCD by coexistence of the splay and 180° twist domains with variable ratios.

VELOCITY OF DISLINATION LINE

The velocity of the disclination motion can be derived from the energy balance between the loss rate of free energy and dissipation. By creating an identity which describes the balance of the time rate of the free energy, $\dot{F}$, stored within a space and the dissipated energy, D, in the same space, a simple model is derived as follows [11,13–15]:

$$\dot{F} + D = 0 \tag{1}$$

If the flow effect is neglected [15], the dissipation energy can easily be given by the volume integral of the viscous torques acting on the director:

$$D = \gamma \int \dot{n}^2 dV, \tag{2}$$

where γ is the rotational viscosity and $\dot{n}$ is the time derivative of n. Corresponding to D, $\dot{F}$ becomes

$$\dot{F} = -\gamma \int \dot{n}^2 dV = -\gamma v^2 \int \left(\frac{\partial \theta}{\partial x}\right)^2 dV, \tag{3}$$

where the motion of the disclination line is along the x-axis. The integral term in $\dot{F}$ is assumed to be the damping factor, G [16], and the damping factor is related to the device parameter by

$$G = \frac{\pi}{4} \ln\left(\frac{d}{2a}\right). \tag{4}$$

Here, a (=250 nm) is the diameter of the disclination core [13], and d is the cell gap. Using Eqs. (1)–(4), we finally arrive at the expression of the disclination velocity [11,13,16]:

$$v = \Delta F/\gamma G. \tag{5}$$

This clearly exhibits the dependence of the disclination velocity on the energy difference, ΔF, rotational viscosity, and damping factor G. The energy difference is closely associated with the d/p ratio, elastic constant of LC material, cell gap, and applied voltage. The applied voltage is the most influential parameter. Therefore, we can control the motion of the disclination line by changing the amplitude of an applied voltage.

GRAY SCALE OF BCSN LCD

Figure 1 illustrates the transition process of the BCSN LC cell. By applying a voltage (vertical filed) between the top electrode and ground one, the splay state is changed into the bend state via symmetric splay or asymmetric splay [16]. After the bend state is formed, the bend state is relaxed into the 180° twist state by removing the

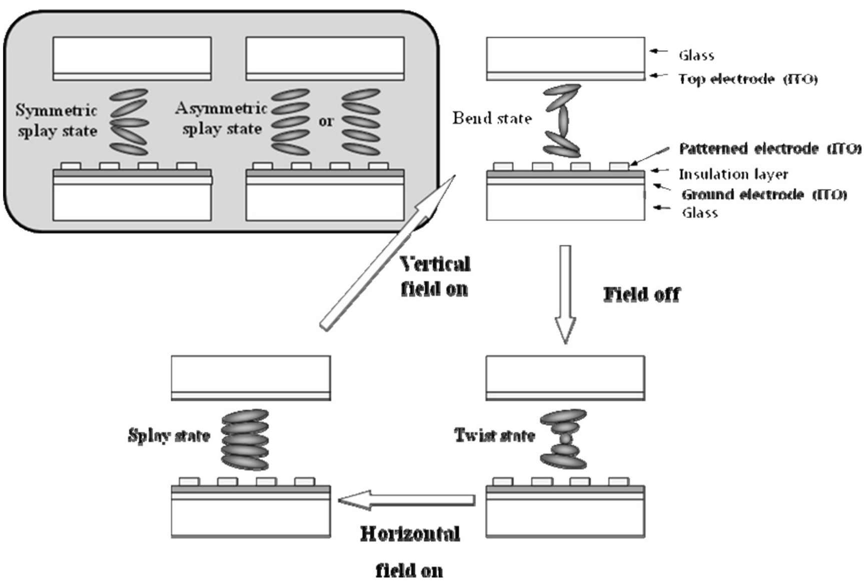


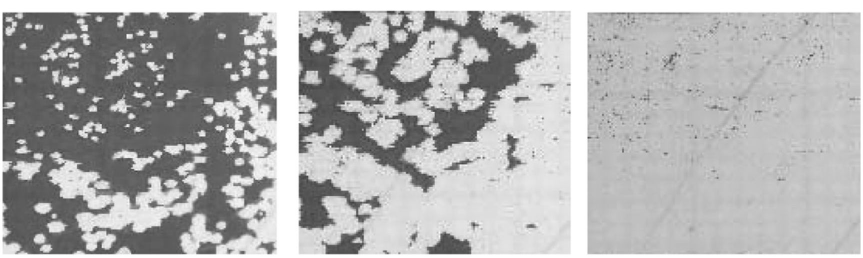
FIGURE 1 Transition process of the BCSN LCD with respect to a vertical field and a horizontal field.

applied voltage. The twist-to-splay transition can be achieved by applying a voltage (horizontal field) between patterned electrodes and ground plane on the bottom substrate. The transition between the states accompanies the motion of the disclination line, because two memory states are topologically inequivalent. The transition time is consistently coupled with the propagation velocity of the disclination line, which depends on the amplitude of an applied voltage, cell gap, and LC materials.

We fabricated test cells filled with MLC-6204-000 (Merck Co.), of which the d/p ratio and cell gap were 0.2 and 4.25 um, respectively. In the experiments, the angle between transmission axis of crossed polarizers and rubbing direction of the cell was 45°, to identify both the splay and bend states. For transition from the splay state to the bend state, it is necessary to apply an external field. When the voltage of 5 V was applied to the cell, it takes about 40 seconds to switch all the splay state to the bend state. If the applied voltage is removed, the bend state is relaxed into the 180° twist state.

Figure 2 shows CCD pictures of the splay-to-twist transition with respect to various driving voltages applied for a second. The observed cell size was $1\,cm \times 1\,cm$. We took the pictures just after the applied voltage was removed. The higher voltage is applied to the splay state, the more bend nuclei are created and the fast the motion of the disclination line becomes. Therefore, with a high voltage the more splay-to-twist transitions occur in the test cell. When the voltage of 9 V, whose frequency was 1 kHz, is applied to the splay state for 1 s, it is all changed into the twist state.

To measure the electro-optical characteristics, the test cell was placed between two crossed polarizers, where the rubbing direction and transmissive axis of input polarizer was 45°. A He-Ne laser was



(a) (b) (c)

FIGURE 2 Splay-to-twist transition with respect to various voltages: (a) 5 V, (b) 6 V, and (c) 9 V.

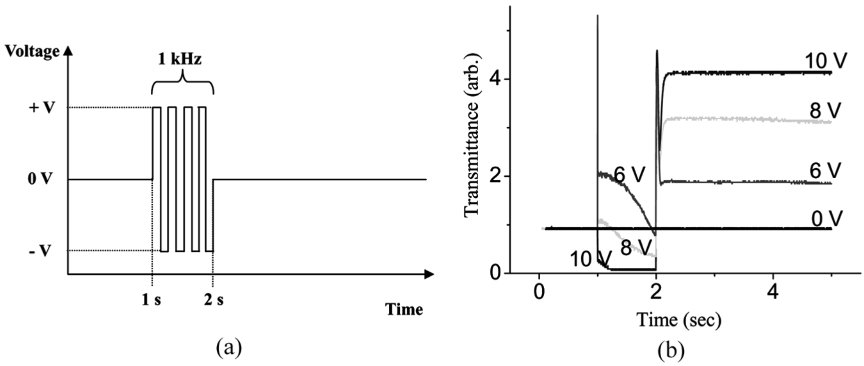


FIGURE 3 Gray scale of the BCSN cell: (a) waveform employed in the experiments and (b) optical response of the BCSN cell.

used as the light source. The transmitted light was measured using a photo-detector. Figure 3(a) shows the waveform employed in the experiments whose frequency was 1 kHz. The voltages were applied to the splay state from 1 s to 2 s. The gray scale of the BCSN cell is achieved by changing the driving voltage as shown in Figure 3(b). In the absence of a voltage, the optical response is not change. The test cell stays in the splay state, which indicates the lowest transmittance after 2 s. When a driving voltage higher than 4 V is applied to the splay state from 1 s to 2 s, transmittance decreases. As the splay state is changed into the bend state, the retardation value of the test cell is reduced. By removing the applied voltage at 2 s, the bend state relaxed into the twist state, which accompanies the optical bouncing [17]. With the voltage of 10 V, the bend transition from the splay state occurs within a half second. Therefore, the splay-to-twist transition completely occurs in the whole area, which represents the highest transmittance after 2 s. With the voltage of 6 V and 8 V, the splay state is partly changed into the twist state. Therefore, the gray scale is achieved with various domain densities of splay and twist states. The texture density of each memory state can be controlled by the amplitude of the applied voltage during the transition.

CONCLUSION

We demonstrated the gray scale capability of the BCSN LCD. The transition time is consistently coupled with the propagation velocity of the disclination line, which strongly depends on the amplitude of an applied voltage. The texture ratio of the splay state to twist state can be controlled by the applied voltage during the transition process. Therefore, by the control of the domain density in the same pixel, the gray scale of the BCSN LCD can be achieved.

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