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Gray Scale of Bistable Chiral Splay Nematic Device in the Splay Transition

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In the bistable chiral splay nematic mode, the splay and π twist states are used for the two stable states. The transition between two memory states is strongly dependent on the strength of electric fields. In this paper, we investigated the correlation between the in-plane electric fields strength and the bistable property by calculating bistable curve. We also demonstrated the gray scale of bistable chiral splay nematic liquid crystal display by varying strength of the in-plane electric fields created by an inter-digital electrode with varying electrode spacing.

Keywords Gray scale; liquid crystal display; memory effects; transition

Introduction

More and more research attention has been drawn to bistable liquid crystal displays (LCDs) because memory effects enable to lower the power consumption and make multiplexing capability in passive matrices unlimited [1]. Up to date, a number of bistable modes have been proposed in the relevant research areas [1–6].

In the bistable chiral splay nematic (BCSN) mode, the splay and π twist states are used for describing the two stable states. Although, with the d/p ratio of 0.25, ideal bistable properties can be obtained, we purposefully choose the d/p ratio of 0.2 for the effective splay transition of BCSN mode [6]. In general, memory time of the twist state with the d/p ratio of 0.2 is limited. It is found that when the d/p ratio is less than 0.25, the splay state is more stable than the twist state. For this reason, the twist state is replaced by the splay state accompanying a motion of the disclination line starting from the pixel boundaries.

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Recently, for the two memory states with the d/p ratio of 0.2 to have infinite memory time, we have proposed the double rubbing method [7,8] and the double cell gap structure [9]. The multi-domain structure sustains memory time of the two states due to the fact that the disclination line is stranded on the domain boundary. However, only one of the two states is allowed in the pixel, which, as a result, also restrains the gray scale of BCSN liquid crystal display (LCD).

In this paper, with the d/p ratio of 0.25, we investigated the functionality of gray scale of BCSN LCD in the splay transition process. Study is also made on what effects the in-plane electric fields may impose on the bistable property by virtue of calculating bistable curve. Research efforts are mainly exerted in this work on utilizing the varying strength of the in-plane electric fields created from the inter-digital electrode with variant gap to achieve the gray scale of BCSN LCD.

The bistable curve represents the characteristics of bistable devices [10,11]. We have calculated the bistable curve with respect to in-plane electric fields. The general form of free energy with a in-plane electric field for nematic LC cell in one dimension is defined as:

$$F = \int_0^d \left(\frac{f(\theta)}{2} \left(\frac{\partial \theta}{\partial z} \right)^2 + \frac{g(\theta)}{2} \left(\frac{\partial \phi}{\partial z} \right)^2 + e(\theta) \left(\frac{\partial \phi}{\partial z} \right) + \frac{K_{22} q_0^2}{2} \right) dz + F_s + F_e, \tag{1}$$

where

$$f(\theta) = K_{11} \sin^2 \theta + K_{33} \cos^2 \theta, \tag{2}$$

$$g(\theta) = (K_{22} \sin^2 \theta + K_{33} \cos^2 \theta) \sin^2 \theta, \tag{3}$$

$$e(\theta) = -q_0 K_{22} \sin^2 \theta. \tag{4}$$

θ and Φ are the polar and azimuthal angles of molecule directors, respectively. K11, K22, and K33 are the splay, twist and bend elastic constants of liquid crystal, respectively, and q_0 is the chirality related to the pitch P_0 by $q_0 = 2\pi/P_0$. The surface anchoring energy, F_s, is taken into account by the Rapini-Papoular surface potential [12]:

$$F_s = \frac{1}{2} A_p \sin^2(\theta - \theta_0) + \frac{1}{2} A_a \sin^2(\phi - \phi_0). \tag{5}$$

Here, A_p and A_a are the polar and azimuthal anchoring coefficients, respectively. The electric energy, F_e, is considered for a in-plane field [13] for:

$$F_e = -\frac{1}{2} \varepsilon_0 \varepsilon_\perp E_x^2 - \frac{1}{2} \varepsilon_0 \Delta\varepsilon (n \cdot E_x)^2. \tag{6}$$

Using Eqs. (1)–(6) and given the director profiles, with various in-plane fields, the variations of the Gibbs free energy per unit area with respect to the twist angle, namely, the bistable curve, can be obtained by a straightforward calculation [10,11].

Meanwhile, we assume that the polar and tilt angles of LC directors vary in a linear fashion throughout the cell. The parameters used in the numerical calculation are as follows: liquid crystal MLC-6204-000; elastic constants $K_{11} = 7.5$ pN, $K_{22} =$ 6 pN, $K_{33} = 14.8$ pN; d/p 0.25; pretilt angle 5°; cell gap 7.9 µm. Both polar and

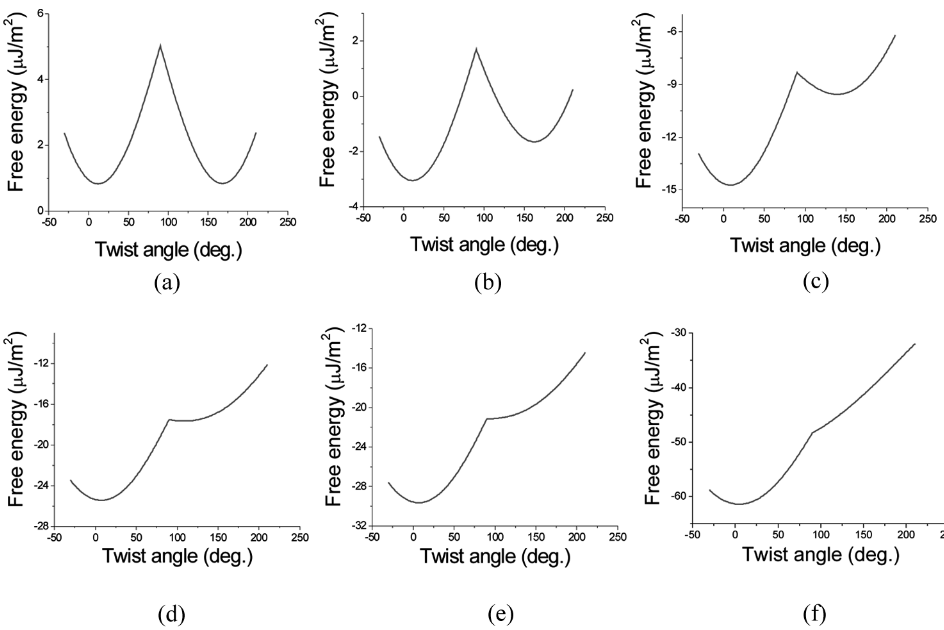

Figure 1. Bistable curve of BCSN LCD when the in-plane electric field of (a) 0, (b) 0.5×10^5 V/m, (c) 1×10^5 V/m, (d) 1.3×10^5 V/m, (e) 1.4×10^5 V/m, and (f) 2×10^5 V/m were applied.

azimuthal anchoring coefficients are set to be 1×10^{-5} J/m^2, and the anchoring energy on the top and bottom substrates is assumed to be symmetrical.

The bistable curves calculated with respect to the strength of the in-plane fields are shown in Figure 1. Without using an in-plane field, the ideal bistable properties are obtained. In the case of applying a in-plane electric field is applied to the BCSN LCD. The bistable properties of the in-plane field gradually shift to monostable ones. In theory, if the in-plane field is higher than 1.5×10^5 V/m, the BCSN LC cell exhibits the monostable properties instead.

From the simulation results, the transition from the twist state to the splay states is strongly coupled with the strength of in-plane electric fields. If a in-plane field stronger than critical value is applied to the twist state, the twist-to-splay transition occurs accompanying a motion of the disclination line starting from defects.

Gray Scale of BCSN LCD

The BCSN LCD with the d/p ratio of 0.25 is used for observation purposes. In the case of no electric field applied, the ideal bistable property is obtained as shown in Figure 1(a). Therefore, as two memory states can simultaneously co-exist in the same pixel, by manipulating the texture ratio of splay and twist states, multi-stable properties of the BCSN LCD can as a result be obtained.

To control the domain ratio of two states by selectively switching from the twist state to the splay state, we propose an inter-digital electrode structure with the varying-space between electrodes. The fabricated electrode structure on the substrate is shown in Figure 2. In our design scheme, the width of the transparent electrode

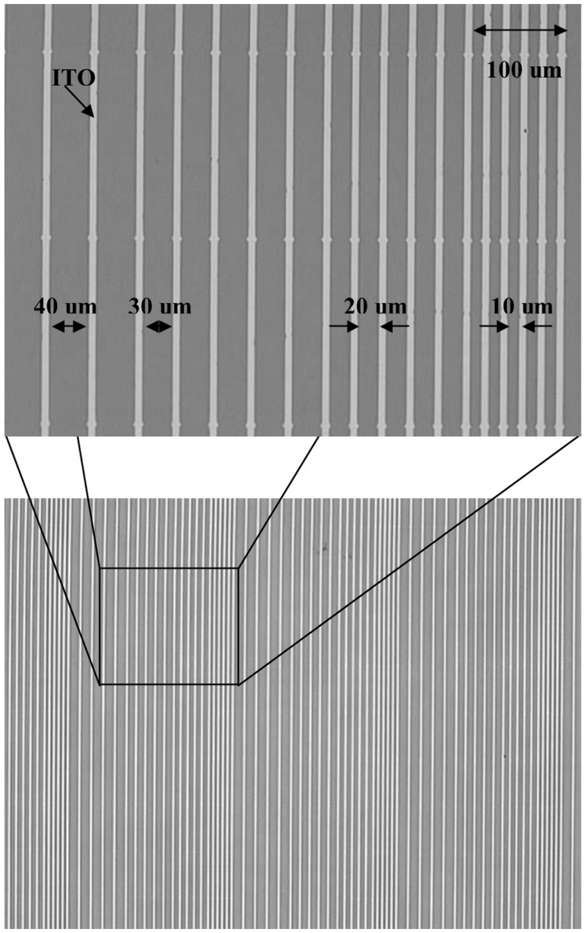

Figure 2. Fabricated inter-digital electrodes with varying electrode spacing.

was set for 10 um, and the electrode gap were chosen to be 10 um, 20 um, 30 um, and 40 um.

To verify the experimental results with the selective switching of the BCSN LCD, we fabricated test cells using the inter-digital electrode structure of the varying space as shown in Figure 2. The test cell was filled with MLC-6204-000 (Merck Co.), and the d/p ratio and cell gap were configured for 0.25 and 7.9 um, respectively.

Figure 3 shows CCD pictures of the twist-to-splay transition with respect to various driving voltages applied for several seconds, and the frequency of which was 1 kHz. When 8 V was applied to the twist state as shown in Figure 3(b), the changing strength of in-plane electric fields is confirmed. If a voltage of 15 V was applied instead to the twist state, the splay transition locally occurs only locally. The gray scale of BCSN LCD is observed and recorded in accordance with the the inter-digital electrode with varying gap. The splay transition always occurs combined with a motion of the disclination line starting from defects. The defects also play a crucial role in the transition process. For the precise control of implementing the gray scale realization, the defect creation should be taken into consideration.

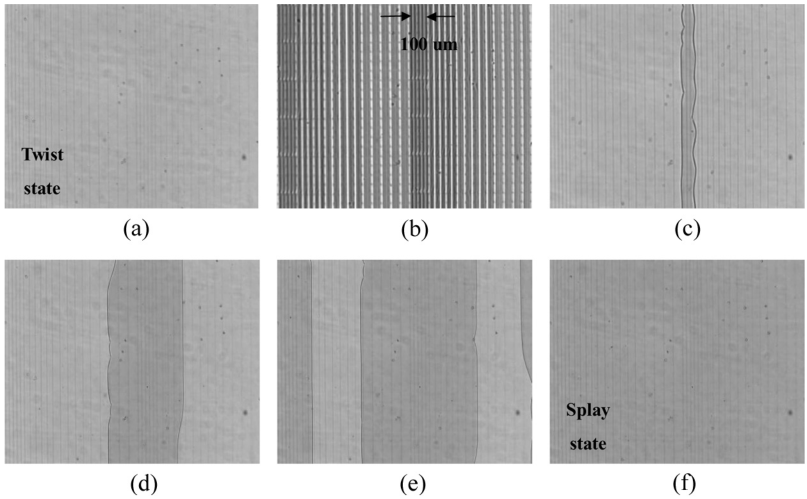

Figure 3. Gray scale of BCSN LCD: (a) twist state, (b) twist state with 8 V, (c), after splay transition with (c) 15 V, (d) 20 V, (e) 25 V, and (f) 30 V.

Conclusion

With the d/p ratio of 0.25, we demonstrated the technique of applying gray scale of BCSN LCD in expression of the varying strength of in-plane electric fields. It is found that the splay transition from the twist state is strongly coupled with the amplitude of the in-plane electric field. Gray scale is achieved by implying the variant strength of the in-plane electric field resulting from the inter-digital electrode structure of the varying space between electrodes.

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