Lateral field effects on the horizontal switching of the bistable chiral splay nematic device

Chul Gyu Jhun[1], Yi-Jun Kim[1], Kwan-Sik Min[1], Sugn Sik Shin[1], Jae Chang Kim[2] and Soon-Bum Kwon[1]
[1]School of Display Eng., Hoseo University, Asan-shi, Chungnam, 336-795, Korea
TEL:82-41-540-5899, e-mail: cgjhun@hoseo.edu
[2]Dep. of Electronics Eng., Pusan National University, Busan, 609-735, Korea

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Abstract

In this paper, with a bistable curve of the bistable chiral splay nematic liquid crystal (BCSN LC) device, we clarify how the twist-to-splay transition is achieved under a horizontal field. By a sufficiently high horizontal electric field, the bistable property becomes monostable. The transition can be achieved.

1. Introduction

There has been increasing interest about bistable liquid crystal displays (LCDs), because memory effects enables to lower the power consumption and makes multiplexing capability in passive matrices unlimited [1]. Recently, a bistable chiral splay nematic liquid crystal (BCSN LC) device was proposed as a novel bistable device [2]. The splay and π twist textures are the two stable states of this device.

To change one of the memory states into the other, a vertical or horizontal electric field is required. Therefore, for the effective switching, the three-terminal electrode structure should be provided for each pixel.

Splay-to-twist switching occurs by relaxation from a bend state after the bend transition. If a sufficiently high vertical electric field is applied to the initial splay state, the splay state changes into a bend state. In the BCSN LC device, transition from the splay state to a bend state by a vertical field is the same phenomenon as the bend transition of pi cell or optically compensated bend (OCB) mode [3]. However, there is no theoretical study pertaining to the transition from the twist state to the splay state by a horizontal field.

In this paper, we clarify how the horizontal switching can be achieved by calculating bistable a curve with respect to a horizontal electric field. When a sufficiently high electric field is horizontally applied to the splay state of the BCSN LC device, an applied field dwindles a bistable curve to monostable which means a bistable property of the BCSN LC cell becomes a monostable one.

2. Experimental

To switch the memory states, a three-terminal electrode structure is provided for each pixel as shown in Fig. 1. The three-terminal electrode structure is consists of top electrode and bottom one with a patterned electrode. Bottom electrode is used for the ground. For insulation, the ground electrode was covered with SiO_2 layer. Both the width and gap of the electrode pattern are 4 um. Top and bottom substrates are coated with a PI alignment layer. The rubbing directions of the top and bottom substrates are perpendicular to the patterned electrode direction.

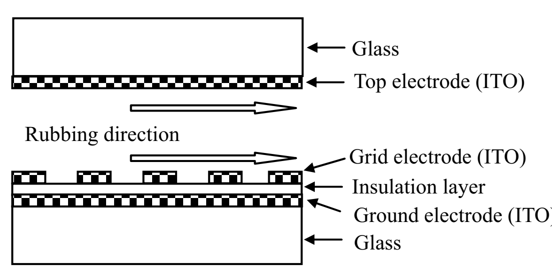

Fig. 1. Pixel structure of BCSB device

Figure 2 shows the texture transition process by applying a corresponding field to each texture of the BCSN device. By applying a vertical field, the splay state (bottom left) is changed into a bend state (top). Then, if we remove the applied voltage, the bend state relaxes into the π twist state (bottom right). Finally, by applying a horizontal field, the π twist state will return back to the initial splay state.

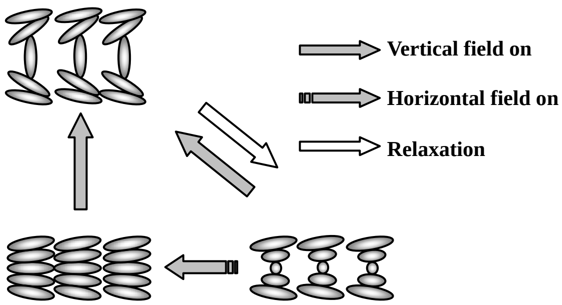

Fig. 2. Transition process with respect to a vertical field and a horizontal field.

Splay-to-twist switching occurs by relaxation from a bend state after the bend transition. If a sufficiently high vertical electric field is applied to the initial splay state, the splay state changes into the bend state accompanying the motion of disclination line. In the BCSN LC device, transition from the splay state to a bend state by a vertical field is the same phenomenon as the bend transition of pi cell or optical compensated bend (OCB) mode [3]. However, there is no theoretical study pertaining to the transition from the twist state to splay state by a horizontal field.

Figures 3(a)-(d) are the photographs taken under CCD camera during the twist-to-splay transition by horizontal switching. The LC material used in experiment is ZLI-4803 with d/p of 0.2 and thickness of 3.25um. This transition is decomposed into two processes in sequence [4]. In the early stage, we observed that a nucleated transition accompanying motion of disclination line occurs from the apices of the zigzag electrodes and then traveled along the patterned electrodes. When the horizontal voltage was removed, the splay domain propagated into the twist domain in the direction transverse to the patterned electrodes. Though the propagation of the splay domain toward the twist domain is clarified by subpixel mode [5], there has been no theoretical approach to reveal the how the transition nucleus appears.

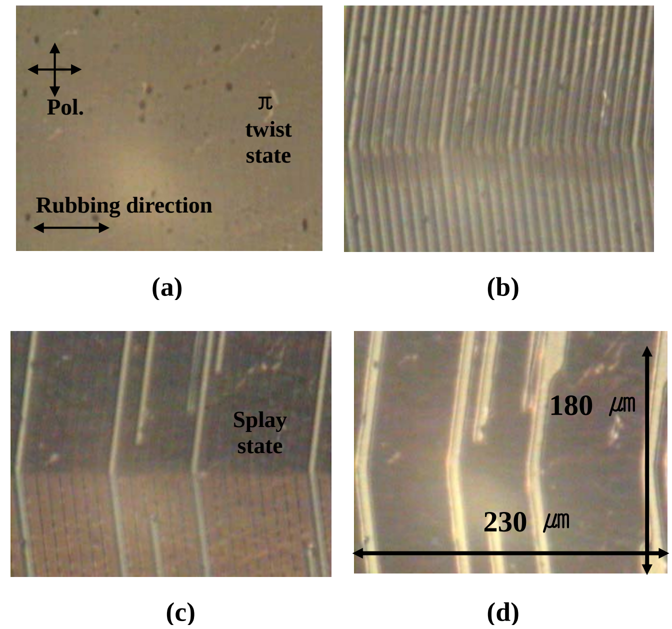

Fig. 3. Photographs of twist-to-splay transition process: (a) twist state, (b) and (c) splay transition when horizontal voltage is being applied and (d) removed.

3. Simulation

The bistable curve represents the feature of bistable devices in its own right [6, 7]. We have calculated the bistable curve with respect to a horizontal electric field. The general form of free energy with a horizontal electric field for nematic LC cell in one dimension is defined as:

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

Where

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

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

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

Θ and Φ are the polar and azimuthal angles of LC 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 $q_0 = 2\pi/P_0$. Fs and Fe are surface and electric energy, respectively.

The surface anchoring energy is taken into account by the Rapini-Papoular potential [8]:

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

Here, A_p and A_a are the polar and azimuthal anchoring coefficients, respectively. The electric energy is considered for a horizontal field:

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

With eqs. (1) – (6) and given the director profile, With various horizontal 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 [6, 7].

Meanwhile, we assume 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 ZLI-2293; elastic constants K_{11} = 12.5 pN, K_{22} = 7.3 pN, K_{33} = 17.9 pN; d/p 0; pretilt angle 5°; cell gap 4.2 μm. Both polar and azimuthal anchoring coefficients are 1×10^{-5} J/m^2, and the anchoring energy on the top and bottom substrates is assumed to be symmetrical.

4. Results and discussion

Calculated bistable curves with respect to the horizontal fields were shown in Fig. 4. Without a horizontal field, there is local minimum energy at the twist angle of 180°. When horizontal electric field is applied to the BCSN LC device, the horizontal field dwindle the bistable curve to monostable. The bistable property of the BCSN LC cell becomes a monostable if the horizontal field is theoretically higher than 5×10^3 V/m. Therefore, if a strong fringe field is horizontally applied to the twist state, transition nucleus occurs from the domain boundary caused by the fringe field.

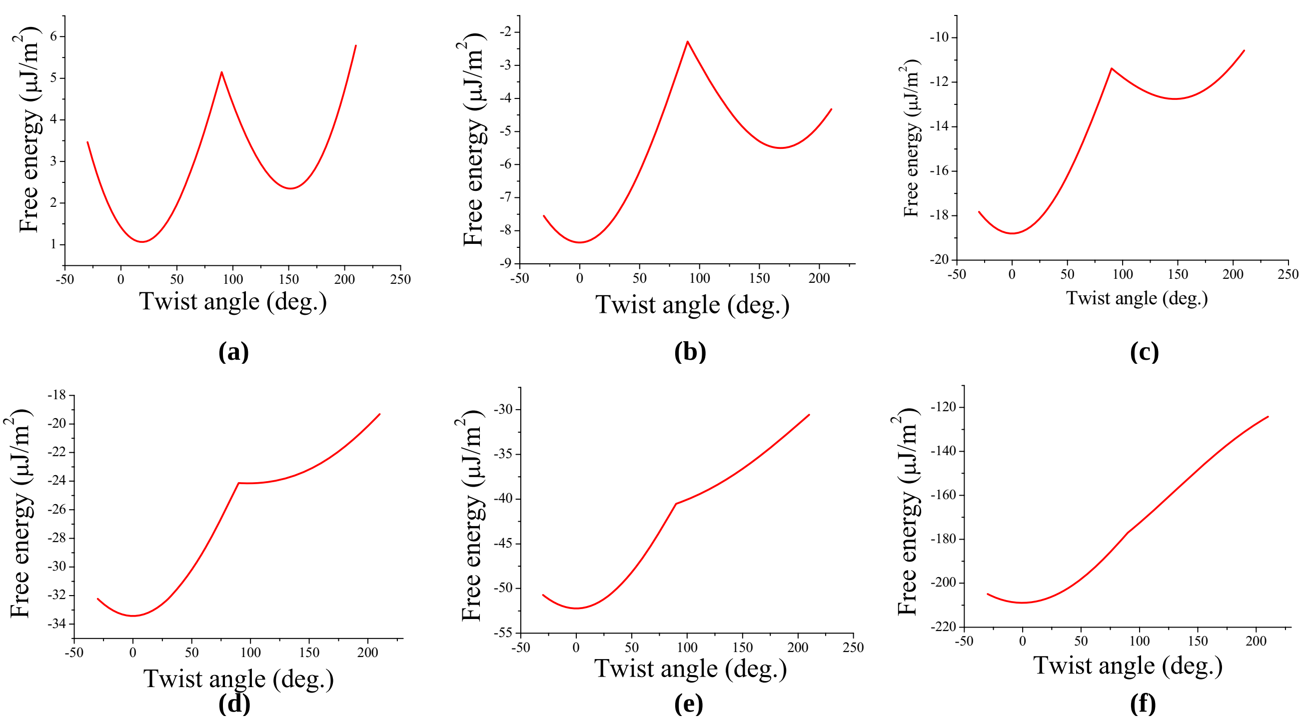

Fig. 4. Energy curve of BCSN LC mode when the horizontal electric field of (a) 0, (b) 2×10^3 V/m, (c) 3×10^3 V/m, (d) 4×10^3 V/m, (e) 5×10^3 V/m, and (f) 5×10^3 V/m is applied.

4. Summary

In this paper, we have clarified the mechanism of the twist-to-splay transition in the BCSN device. When horizontal electric field is applied to the BCSN LC device, the horizontal field dwindle a bistable curve to monostable. By a sufficiently high horizontal electric field, the bistable property of BCSN LC device becomes monostable. Therefore twist-to-splay transition can be achieved. The results can also be used to optimize electrode structure and invent driving method of the BCSN LC device.

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5. References

1. Ivan Dozov, *SID'03 Technical Digest*, Vol. **34**, p946 (2003).
2. S. H. Lee, K.-H. Park, T.-H. Yoon and J. C. Kim, Appl. Phys. Lett. **82[24]**, 4215 (2003).
3. H. Nakamura and M. Noguchi, Jpn. J. Appl. Phys. **39[11]**, 6368 (2000).
4. C. P. Chen, C. G. Jhun, T.-H. Yoon and J. C. Kim, *IDW'06 Technical Digest*, p613 (2006).
5. C. G. Jhun, C. P. Chen, T.-Y. Yoon and J. C. Kim, Jpn. J. Appl. Phys. **45[6A]**, 5117 (2006).
6. S. Saito, T. Takahashi, T. Chiba and S. Tsuchida, Jpn. J. Appl. Phys. **41[6A]**, 3841 (2002).
7. C. G. Jhun, C. P. Chen, S. L. Lee, J. I. Back, T.-H. Yoon and J. C. Kim, Jpn. J. Appl. Phys. **45[6A]**, 5063 (2006).
8. A. Papini and M. Papoular, J. Phys. (Paris) Colloq. **30** C4 (1969).