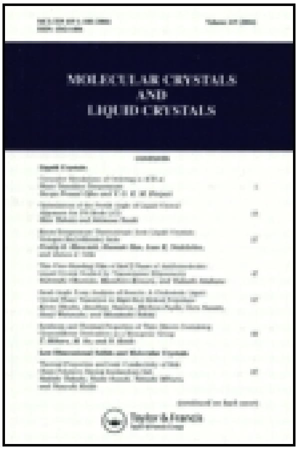



Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

# Effects of Pixel Boundary on Memory Time of Bistable Chiral Splay Nematic Liquid Crystal Cell

Chul Gyu Jhun [a] , Chao Ping Chen [b] , Seong Ryong Lee [b] , Tae-Hoon Yoon [b] & Jae Chang Kim [b]

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

[b] Department of Electronics Engineering, Research Institute of Computer, Information and Communication, Pusan National University, Busan, Korea

Version of record first published: 22 Sep 2010

To cite this article: Chul Gyu Jhun, Chao Ping Chen, Seong Ryong Lee, Tae-Hoon Yoon & Jae Chang Kim (2007): Effects of Pixel Boundary on Memory Time of Bistable Chiral Splay Nematic Liquid Crystal Cell, Molecular Crystals and Liquid Crystals, 476:1, 85/[331]-93/[339]

To link to this article: http://dx.doi.org/10.1080/15421400701734007

*Mol. Cryst. Liq. Cryst.*, Vol. 476, pp. 85/[331]–93/[339], 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701734007



# Effects of Pixel Boundary on Memory Time of Bistable Chiral Splay Nematic Liquid Crystal Cell

**Chul Gyu Jhun**
School of Display Engineering, Hoseo University, Chungnam, Korea

**Chao Ping Chen**
**Seong Ryong Lee**
**Tae-Hoon Yoon**
**Jae Chang Kim**
Department of Electronics Engineering, Research Institute of Computer, Information and Communication, 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. With a d/p ratio of 0.25, truly bistable characteristics of BCSN mode can be obtained. However, we make the splay state more stable than the π twist state with a d/p ratio of 0.2 for the effective transition from the π twist state to the splay state. Memory time of π twist state is limited because the π twist state is likely to be replaced by the splay state from the pixel boundary. We have theoretically and experimentally investigated how the pixel boundary affects memory time of the π twist state with a subpixel model.*

**Keywords:** bistable device; liquid crystal display; subpixel model

## INTRODUCTION

The common feature of bistable liquid crystal displays (LCDs) is the existence of the two stable states without external field. The two stable

This research was supported by a grant (F0004052) from the Information Display R&D Center, one of the 21st Century Frontier R&D Programs funded by the Ministry of Commerce, Industry and Energy of the Korean Government and supported in part by the Second Phase BK21 Program of the Ministry of Education & Human Resources Development, Korea.

Address correspondence to Jae Chang Kim, Department of Electronics Engineering, Research Institute of Computer, Information and Communication, Pusan National University, Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea. E-mail: jckim@pusan.ac.kr

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].

In the bistable chiral splay nematic (BCSN) mode, the splay and $\pi$ twist states are used for the two stable states which is a volume switching type of a bistable device [7–11]. With a d/p ratio of 0.25, truly bistable characteristics of the BCSN mode can be obtained. However, we make the splay state more stable than the $\pi$ twist state with a d/p ratio of 0.2 for the effective transition from the $\pi$ twist state to the splay state [7–11]. Though infinite memory time of the splay state can be achieved, memory time of the $\pi$ twist state is limited because the $\pi$ twist state is likely to be replaced by the splay state from the pixel boundary.

In this article, we have theoretically investigated how the pixel boundary affects the memory time of the $\pi$ twist state with a subpixel model. With a multi-domain structure, the free energy can be minimized when a disclination line is located on the domain boundary of the two different domains in our model. We also experimentally demonstrated that by forming a $\pi/2$ twist domain around the pixel of the BCSN mode, permanent memory time of the $\pi$ twist state can be achieved.

## SUBPIXEL MODE

To explore how the pixel boundary affects memory time of the $\pi$ twist state, we introduce a subpixel model. Within this model, two subpixels of which dimensions $L \times L \times d$ are used are adjoined to each other as shown in Figure 1. Total energy of the subpixel model can be obtained

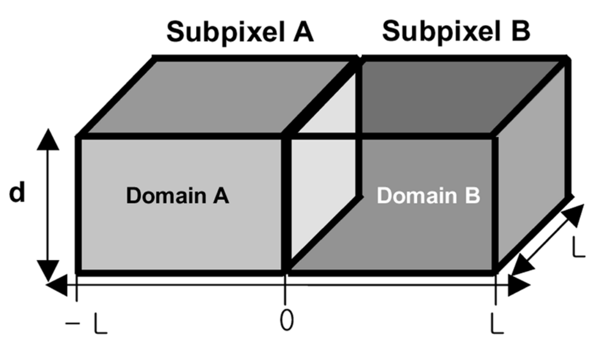



**FIGURE 1** Subpixel mode.

by adding the energy of each subpixel pixel and the disclination energy [11,12].

$$F_{total} = F_{subpixel\ A} + F_{subpixel\ B} + F_{disclination}. \tag{1}$$

The energy of each subpixel per unit area can be calculated by following equation [13].

$$f_{subpixel} = f_b + 2f_s. \tag{2}$$

The bulk energy of the subpixel can also be calculated as:

$$f_b = \int_0^d \left( \frac{g(\theta)}{2} \left( \frac{d\theta}{dz} \right)^2 + \frac{h(\theta)}{2} \left( \frac{d\phi}{dz} \right)^2 + i(\theta) \frac{d\phi}{dz} + \frac{K_{22}}{2} q_0^2 \right) dz, \tag{3}$$

where

$$g(\theta) = K_{11} \sin^2 \theta + K_{33} \cos^2 \theta, \tag{4}$$

$$h(\theta) = (K_{22} \sin^2 \theta + K_{33} \cos^2 \theta) \sin^2 \theta, \tag{5}$$

$$i(\theta) = -q_0 K_{22} \sin^2 \theta. \tag{6}$$

$\theta$ and $\phi$ are the polar and azimuthal angles of the directors, respectively. $K_{11}$, $K_{22}$, and $K_{33}$ are the splay, twist and bend elastic constants of liquid crystal, $q_0$ is the intrinsic twist. The surface anchoring energy was taken into account by the Rapini-Papoular surface potential [14] as:

$$f_s = \frac{1}{2} A_p \sin^2(\theta - \theta_0) + \frac{1}{2} A_a \sin^2(\phi - \phi_0). \tag{7}$$

where $A_p$ and $A_a$ are polar and azimuthal achoring coefficients, and $\theta_0$ and $\phi_0$ are the polar and azimuthal angles of the easy axis on the boundary, respectively.

With one constant approximation, we assumed the tilt angle on the boundary is to be zero and there is no variation of the polar angle through the cell. Therefore, elastic energy density per unit area in each subpixel can be simplified as:

$$f_{subpixel} = \frac{1}{2} K \left( q_0 - \frac{\phi}{d} \right)^2 \cdot d + A_a \sin^2 \phi_d. \tag{8}$$

$\phi_d$ is the deviation angle of the director from the easy axis at the boundary layer. The disclination energy is given by [15]

$$F_{disclination} = 8 E_c L. \tag{9}$$

where $E_c$ is the disclination core energy per unit length. The core energy is approximately represented by [15]

$$E_c \cong \frac{1}{2}\alpha S^2(\pi\xi^2) = \frac{1}{2}K\pi. \tag{10}$$

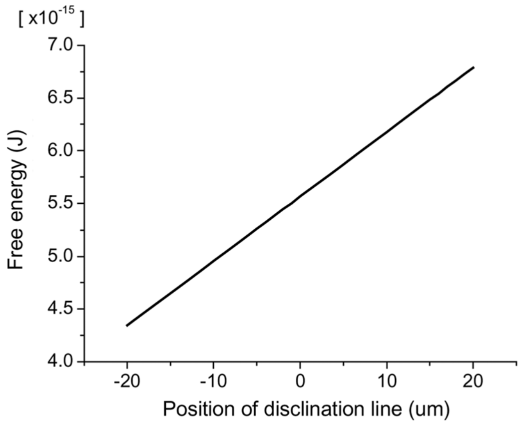
where $\alpha S^2/2$ is the first term of the nematic Landau free energy in which S is the order parameter and $\xi$ is nematic correlation length. By taking $2\xi$ as core diameter $\xi^2$ becomes $K/\alpha S^2$ [15,16].

## SIMULATION RESULTS

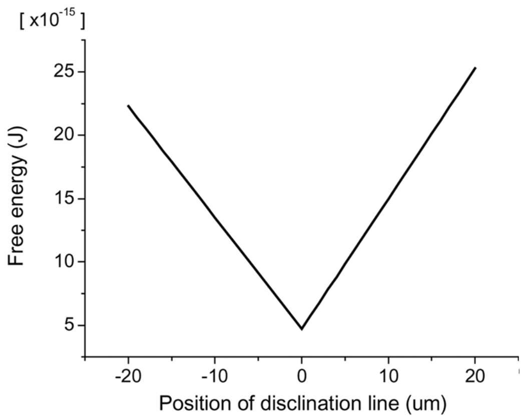
In order to investigate, how the pixel boundary affects memory time of the $\pi$ twist state for both single domain and multi-domain structures with the subpixel model. We have calculated the free energy with respect to the position of disclination line for each configuration. Initially, the domain A of the $\pi$ twist state is in the subpixel A and the domain B which is a domain of pixel boundary is in the subpixel B as shown in Figure 1. If we place the origin of the horizontal axis at the adjoining boundary of the two subpixels in Figure 1, the disclination line can be located from $-L$ in the subpixel A to L in the subpixel B. A domain of the pixel boundary in the subpixel B can penetrate into the subpixel A as the disclination line moves from adjoining boundary along $-L$ direction and vice versa if the disclination line moves along L direction. Parameters used in the numerical calculations are as follows; K: 10 pN, d/p: 0.2, pretilt angle: $0^\circ$, L: 20 μm, d: 3.25 μm, $A_a$: $1 \times 10^{-4}$ J/m$^2$.

For uniformly aligned structure, two subpixels have the same boundary condition under which easy axes of two substrates are parallel to each other. The domain A and B are the $\pi$ twist and splay states, respectively. The free energy of each domain can be minimized when deviation angle on each boundary layer in subpixel A and B are $2^\circ$ and $3^\circ$, respectively, because the two kinds of torques caused by bulk elastic energy and surface energy balanced out. Figure 2(a) shows the calculated free energy of simple model as one of domains penetrates into the opposite subpixel according to the propagation of disclination line. As a result, if subpixel A and B are filled with the splay state, minimum energy can be obtained.

We compared the energy of the multi-domain structure with that of the uniform aligned structure in which the boundary condition of the subpixels is different from each other. Though the easy axes of each substrate in the subpixel A are parallel, their direction is perpendicular to each other in the subpixel B. For the case of our multi-domain structure, the $\pi$ twist state is in the subpixel A and the $\pi/2$ twist state is in the subpixel B. The deviation angle of subpixel A is $2^\circ$ which is the same value in the numerical calculation for the uniformly aligned condition. However, that of each boundary layer in subpixel B was $0.5^\circ$.




(a)




(b)

**FIGURE 2** Free energy calculated by the subpixel model with respect to the position of disclination line, when two subpixels have (a) the same and (b) different boundary conditions.

Figure 2(b) describes the free energy with the multi-domain structure with respect to the position of the disclination line in our model. If one of two domains would invade into the opposite subpixel, in order to maintain the initial domain in the opposite subpixel, high energy should be stored in the surface energy with the large deviation angle. The free energy will be increased as one of domains would invade the opposite subpixel. The energy can be minimized when the disclination line is located on the adjoining boundary of the two subpixel. Therefore, one can expect infinite duration of the $\pi$ twist state can be achieved with multi-domain structure.

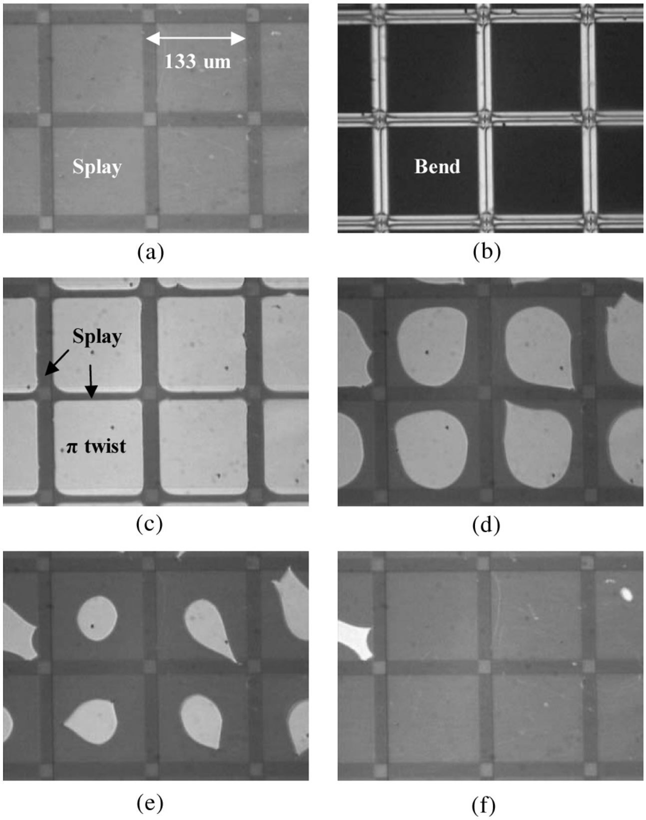



**FIGURE 3** For the single domain BCSN cell, the twist state replaced by propagating the splay from the pixel boundary: the pictures were captured (a) before applying any voltage, (b) for applying 8 V, (c) just after removing the voltage, (d) 5 s, (e) 10 s, and (f) 15 s after removing the voltage.



## EXPERIMENTAL RESULTS

To clarify the effect of the pixel boundary on memory time of the $\pi$ twist state. We prepared several test cells. The test cells filled with LC material of ZLI 4803-000 was fabricated with cell gap of 3.25 μm. The polyimide of SE-3140 (Nissan Chemicals Co.) and chiral additive of S-811 are used to make the d/p ratio 0.2.

Figure 3 shows finite memory time of the $\pi$ twist state in the single-domain BCSN cell. The retardation of the $\pi$ twist state for the single domain BCSN cell was 550 nm and the angle between the rubbing direction and transmissive axis of one of the crossed polarizers was

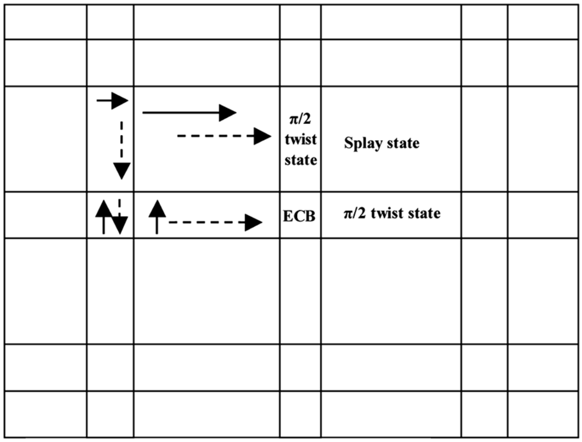



**FIGURE 4** Mask-rubbing directions for multi-domain structure of BCSN-LC cell.

$45^{\circ}$ to distinguish the splay state from the bend state. Before applying voltage, there is only the splay state indicated by color of magenta. When 8 V was applied to the panel for 3 s, the splay state in the pixel changed into the bend state represented by dark state. After removing the applied voltage, the transition from the bend state to the $\pi$ twist state occurs. However the LC texture between pixels returned into the splay state. Therefore, the $\pi$ twist state is replaced by the propagation of the splay domain from the pixel boundary. This agrees with the simulation result as shown in Figure 2(a).

In order to fabricate the multi-domain BCSN cell, A mask-rubbing technique was used [17,18]. First of all, in order to form the initial splay state in the pixel, upper and lower substrates were rubbed with the same direction. By crossing stripe patterned mask on the top and bottom substrates, the pixel boundary of both the substrates were rubbed again with opposite direction. This direction is perpendicular to the first rubbing direction of the pixel region. Finally, multi-domains of the splay, $\pi/2$ twist textures can be fabricated by sandwiching both the mask-rubbed substrates as shown in Figure 4.

Figure 5 shows the fabricated BCSN LC cell with the multi-domain structure under cross-Nicol. The rubbing direction of the splay state is coincident with the transmission axis of the bottom polarizer to optically distinguish the $\pi$ twist state from the $\pi/2$ twist state. The polarization of the incident light does not change after passing through the splay state, therefore dark state is achieved by the splay state. The fabricated pixel size of the splay domain was $2\,mm \times 2\,mm$. The $\pi/2$

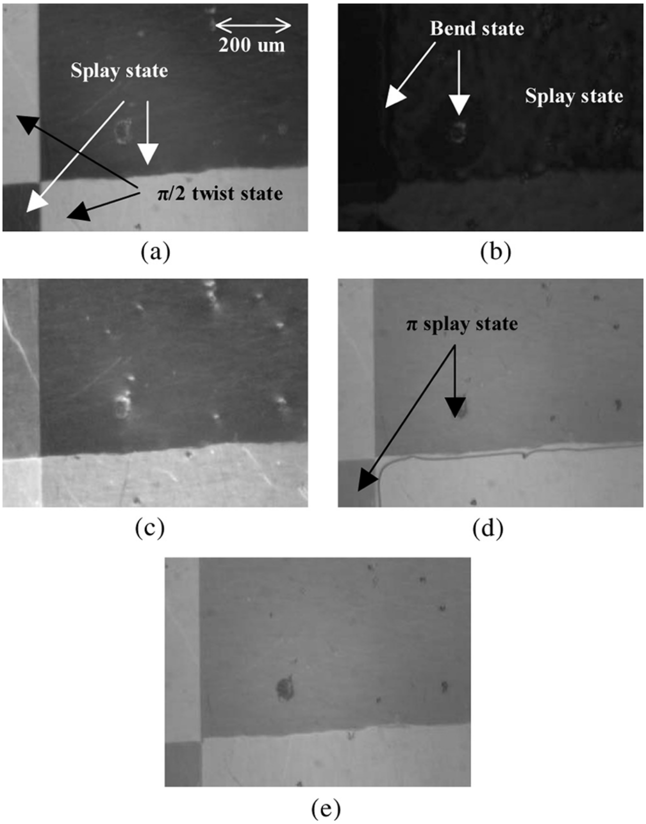



**FIGURE 5** Infinite memory time of $\pi$ twist state with multi-domain structure: pictures was captured (a) before applying any voltage, (b) for applying 15 V, (c) just after removing the voltage, (d) 5 s, and (f) 1 m after removing the voltage.



twist states were also observed around the pixel boundary in Figure 5(a). When 15 V was applied to the panel, the bend transition occurs. By removing the applied voltage after the bend transition, the bend state relaxed into the $\pi$ twist state. The LC texture between pixels returned into the initial state of the $\pi/2$ twist state. The $\pi/2$ twist domain around the pixel of BCSN LC device prevents from nucleation of defects and the subsequent motion of disclination line. The minimum energy can be realized when disclination line was located on the adjoining boundary of the two different domains as simulated before. Therefore, infinite memory time of the $\pi$ twist state can be embodied by multi-domain structure.

## CONCLUSION

The bistable chiral splay nematic (BCSN) device is a volume switching type of bistable device using the splay and $\pi$ twist states as the two stable states for E-book or E-paper applications. With a d/p ratio of 0.25, truly bistable characteristics of BCSN mode can be obtained. However, we make the splay state more stable than the $\pi$ twist state with a d/p ratio of 0.2 for the effective transition from the $\pi$ twist state to the splay state. Stability of the $\pi$ twist state can be estimated by subpixel mode by which the total free energy can be calculated with respect to the location of disclination line. The stable $\pi$ twist state can be achieved with multi-domain structure. We also confirmed the validity of the subpixel model by comparing the memory time of single domain BCSN cell with that of multi-domain structure.



## REFERENCES

[1] Boyd, G. D., Cheng, J., & Ngo, P. D. T. (1980). *Appl. Phys. Lett.*, *36*, 556.
[2] Berreman, D. W. & Heffner, W. R. (1980). *Appl. Phys. Lett.*, *37*, 109.
[3] Bryan-Brown, G. P., Brown, C. V., Jones, J. C., Wood, E. L., Sage, I. C., Brett, P., & Rudin, J. (1997). *SID'97 Digest, Vol. 28*, 37.
[4] Dozov, I., Nobili, M., & Durand, G. (1997). *Appl. Phys. Lett.*, *70*, 1179.
[5] Greubel, W., Wolf, U., & Kruger, H. (1973). *Mol. Cryst. Liq. Cryst.*, *24*, 103.
[6] Clark, N. A. & Lagerwall, S. T. (1980). *Appl. Phys. Lett.*, *36*, 899.
[7] Lee, S. H., Park, K.-H., Yoon, T.-H., & Kim, J. C. (2003). *Appl. Phys. Lett.*, *82*, 4215.
[8] Lee, S. H., Lee, G.-D., Yoon, T.-H., & Kim, J. C. (2004). *Phys. Rev. E*, *70*, 041704.
[9] Jhun, C. G., Choi, J. H., Yoon, T.-H., & Kim, J. C. (2006). *Jpn. J. Appl. Phys.*, *45*, 128.
[10] Jhun, C. G., Chen, C. P., Lee, S. L., Back, J. I., Yoon, T.-H., & Kim, J. C. (2006). *Jpn. J. Appl. Phys.*, *45*, 5063.
[11] Jhun, C. G., Chen, C. P., Yoon, T.-H., & Kim, J. C. (2006). *Jpn. J. Appl. Phys.*, *45*, 5117.
[12] Cladis, P. E., van Saarloos, W., Finn, P. L., & Kortan, A. R. (1987). *Phys. Rev. Lett.*, *58*, 222.
[13] Sato, Y., Sato, K., & Uchida, T. (1992). *Jpn. J. Appl. Phys.*, *31*, L579.
[14] Rapini, A. & Papoular, M. (1969). *J. Phys. (Paris) Colloq.*, *30*, C4–54.
[15] Chen, J., Bos, P. J., Johnson, D. L., Bryant, D. R., Li, J., Jamal, S. H., & Kelly, J. R. (1996). *J. Appl. Phys.*, *80*, 1985.
[16] de Gennes, P. G. & Prost, J. (1993). *The Physics of Liquid Crystals*, Oxford University Press: New York, Chap. 3.
[17] Inoue, I., Miyashita, T., & Uchida, T. (2002). *Eurodisplay'02 Digest, Vol. 22*, 179.
[18] Kang, S. H., Jhun, C. G., Lee, S. L., Kim, J. C., & Yoon, T.-H. (2004). *IDW'04 Digest, Vol. 11*, 37.