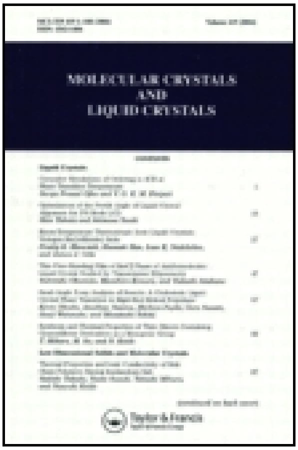

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# Parameter Optimization of a Bistable Chiral-Splay Nematic Liquid Crystal Cell for Permanent Bistability

Chul Gyu Jhun [a] , Seo Hern Lee [a] , Sang Ho Kang [a] , Jong Lac Lee [a] , Min-Cheol Oh [a] , Jae Chang Kim [a] & Tae-Hoon Yoon [a]

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

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# Parameter Optimization of a Bistable Chiral-Splay Nematic Liquid Crystal Cell for Permanent Bistability

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

*In order to realize permanent bistable state in a bistable chiral-splay nematic liquid crystal device, influences of liquid crystal parameters are analyzed. We found that large twist elastic constant and low cell gap are efficient to increase the retention time of the metastable twist state, which is understood by the study of the azimuthal anchoring strength.*

**Keywords:** bistability; liquid crystal display; nematic liquid crystal



## INTRODUCTION

The feature of all bistable liquid crystal (LC) devices is the existence of two bistable states under no voltage-applied condition. However, bistable LC devices using the volume switching [1–4] as the bistable mechanism have a serious problem that the bistable states are metastable with short lifetimes unlike relatively stable bistable states of the surface switching-type devices [5–9] using the effect of surface

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

anchoring. Although Wang *et al*. [10] tried to increase the retention time of two bistable states using the multidimensional alignment method, the manufacturing process was troublesome in comparison with the conventional LC cells, and the application was still limited.

In this paper we describe the optimization of the various parameters of the device to realize permanent bistable states in a bistable chiral-splay nematic liquid crystal (BCSN-LC) device [11]. Although this device is of the volume switching type, we can achieve the permanent bistable device by using the optimized LC parameters.

## SIMULATION AND EXPERIMENTS

Figure 1 illustrates the transition process of the proposed chiral-splay cell. With an appropriate combination of the applied voltage and the pulse duration, the bend state is formed (right top). After the bend state is generated, it returns to the splay state (left bottom) which is one of stable state through the 180° twist state (right bottom) of the other stable state during the voltage-off state. In a previous work [11], we analyzed that flow velocity vy in the y direction plays an important role in forming the 180° twist state by numerically solving the Ericksen-Leslie hydrodynamics equations with a natural twist term [13,14] of a nematic cell. It seems that the origination of the twist state is also affected by the boundary conditions. It can be also understood from the fact that under the parallel-rubbed boundary conditions, there are three possible alignment configurations of splay,

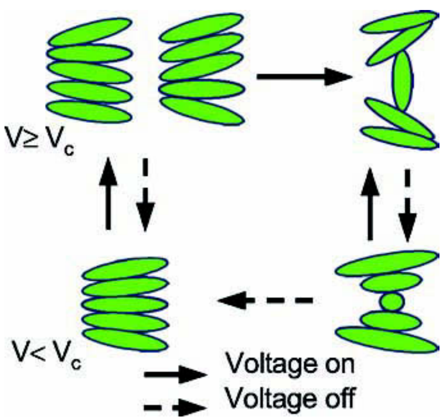


**FIGURE 1** Transition process of a BCSN cell: (a) splay state, (b) reverse tilt-like domains, (c) bend, (d) twist state.

bend, and 180° twist. Because of topological equivalence between the bend and 180° twist states, it is possible to transform from the bend state to 180° twist state.

In order to obtain the permanent bistable states, we optimize the parameters such as elastic constants, dielectric anisotropy, pretilt angle, and cell gap. The influences of these parameters on bistable states have not been still analyzed in detail. Figure 2 shows the dependence of $v_y$ on the variation of the pitch in cell gap 6.4 μm and pretilt angle 5°. Even in the splay cell of a cell gap over pitch (d/p) of 0.007, which corresponds to natural pitch, we find that the velocity component $v_y$ is generated. As the pitch is decreased, $v_y$ increases. From the simulation, we can expect that the more the pitch decreases, the more the twist state remains stable, and its variations have an effect on the retention time of the twist state. To confirm the influence of the d/p ratio on the retention time of the 180° twist state, test cells filled with liquid crystal ZLI-1557 were fabricated as we vary the pitch. Cell gap of the test cells was fixed by spacer thickness of 4.2 μm. As expected, we can see that as the pitch is decreased, the retention time of the twist state is increased, as shown in Figure 3. In other words,

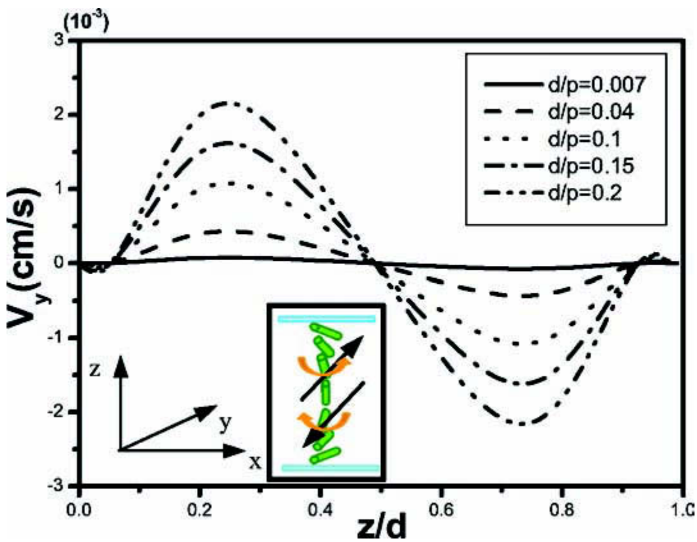


**FIGURE 2** Dependence of $v_y$ on the variations of pitch in cell thickness 6.4 μm. As the d/p ratio increases, the flow velocity component $v_y$ increases. It is presumed that the increment of d/p ratio is able to give positive effects for the retention time as well as the generation of the twist state.

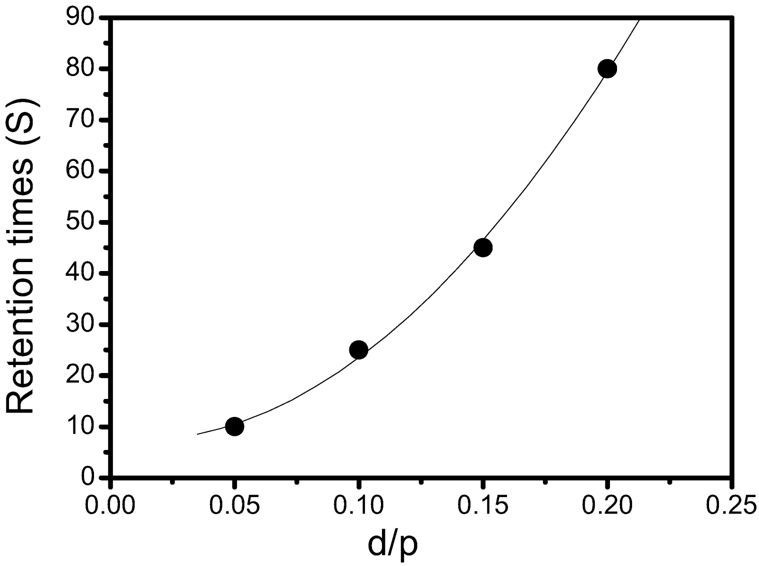


**FIGURE 3** The retention time of 180° twist state in test cells with spacer thickness 4.2 μm. d/p ratio is increased by 0.05 up to 0.2. As the d/p ratio is increased, the retention time of the twist state increases.

the more the velocity component $v_y$ increases, the more the retention time of the twist state increases.

Therefore, we calculate the optimized values of LC parameters to increase the flow velocity of $v_y$ in the y direction in a BCSN-LC device, resulting in the increase the retention time of the 180° twist state. Figure 4 shows the maximum value of $v_y$ as we vary LC parameters. The parameters of liquid crystal ZLI-1557 used in reference values for the simulation are shown in Table 1. From Figure 4, we find that the effect of the twist elastic constant $K_{22}$ is more dominant than that of the other parameters. If LC material with larger $K_{22}$ is used, it is expected for the retention time of the 180° twist state to be increased. The retention time of test cells with $d/p = 0.2$ and cell gap 4.2 μm fabricated with several LC materials with the different $K_{22}$ is shown in Figure 5. As expected, the retention time of a BCSN-LC cell fabricated with ZLI-2471 (E. Merck) of $K_{22} = 8.1\,\text{pN}$ is more durable than that of other LC cells. In addition to the twist elastic constant K22, cell gap may be considered as an external factor that is easy to control. We find that the flow velocity $v_y$ and cell gap are inversely related to each other as shown in Figure 4. Therefore, if we use LC material with larger $K_{22}$ and fabricate a BCSN-LC cell with low cell gap, we expect that the

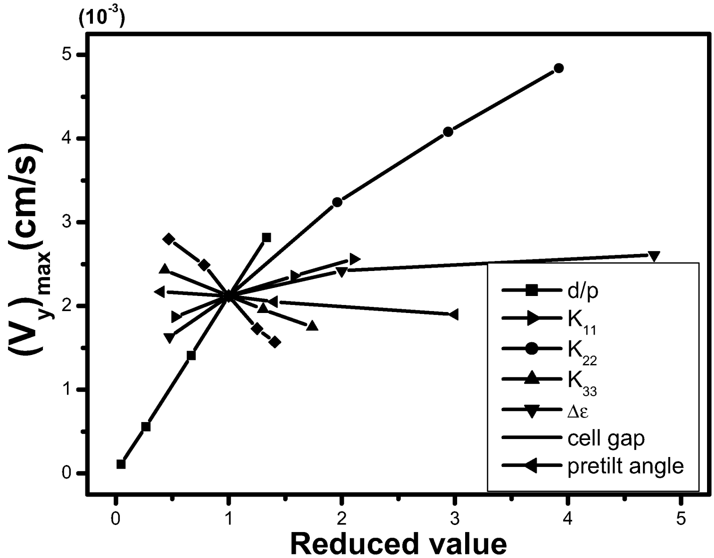


**FIGURE 4** The maximum value of $v_y$ for the variation of LC parameters. The parameters of liquid crystal ZLI-1557 is used as reference values for the simulation. Reduced value is defined as variation value of parameters over value of reference parameters.



retention time of the 180° twist state can be significantly increased. In practice, we could realize the permanent twist state in a liquid crystal (ZLI-2471) cell of cell gap 2.48 μm and a ZLI-2293 cell of cell gap 2.38 μm.

By analyzing azimuthal anchoring strength of a BCSN-LC cell, we can understand why this permanent phenomenon is occurred, and how the retention time of the 180° twist state is related to parameters such as, particularly, the cell gap and the twist elastic constant. We consider a LC cell with planar anchoring and any alignment directions

**TABLE 1** The Parameters of ZLI-1557 Used as Reference Values for the Simulation

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $K_{11}$ | $9.5 \times 10^{-12}$ N | cell gap | 6.4 μm |
| $K_{22}$ | $5.1 \times 10^{-12}$ N | pretilt angle | 5° |
| $K_{33}$ | $11.5 \times 10^{-12}$ N | $\Delta\varepsilon$ | 4.2 |
| d/p | 0.15 | | |

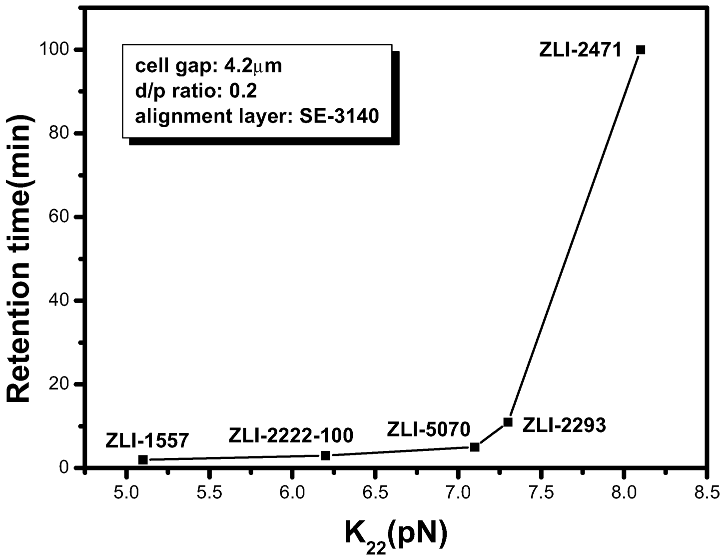


**FIGURE 5** The retention time of the 180° twist state as the variation of twist elastic constant in test cells with spacer thickness 4.2 μm. As the magnitude of $K_{22}$ is increased, the retention time of 180° twist state is increased.



at the interface. For a finite anchoring strength, a competition between the surface anchoring strength and the volume elastic torque results in the deviation of the surface orientation from their easy axis. This deviation angle depends on the azimuthal anchoring strength. From this angle and by using Frank's elastic theory, the azimuthal anchoring strength can be obtained from the equation [12,13]

$$W_\phi = \frac{2K_{22}\phi}{d\sin 2\phi} \tag{1}$$

where $K_{22}$ is the twist elastic constant, d is the cell gap, $\phi$ is the actual twist angle of the director through the cell. After the bend state is generated, the 180° twist state is generated during the voltage-off state. Since the orientation of the director of the nematic phase without any applied external fields is governed by the boundary conditions at its interface, in order to increase the retention time of the metastable 180° twist state, the surface anchoring energy in the 180° twist state is comparable with the bulk elastic energy. Therefore, the more the azimuthal anchoring strength increases, the more the 180° twist state is stable. From Eq. (1), we find that large $K_{22}$ and low cell gap are efficient to increase the azimuthal anchoring strength. In test cells exhibiting the permanent twist state, the obtained anchoring energies are $7.4 \times 10^{-5}\,\mathrm{J/m^2}$ for a ZLI-2471 cell of cell gap 2.48 μm with $K_{22} = 8.1\,\mathrm{pN}$, and $7.0 \times 10^{-5}\,\mathrm{J/m^2}$ for a ZLI-2293 cell of cell gap 2.38 μm with $K_{22} = 7.3\,\mathrm{pN}$. It can be expected that if the anchoring energy of above $7.0 \times 10^{-5}\,\mathrm{J/m^2}$ is obtained, the permanent twist state can be realized.

To confirm the influence of the azimuthal anchoring strength on the retention time of the metastable 180° twist state, BCSN-LC cells filled with liquid crystal ZLI-5070 with $K_{22} = 7.1\,\mathrm{pN}$ were fabricated with spacer thickness of 4.2 μm. However, based on from the fact that the anchoring strength is proportional to the rubbing strength [14], the test cells were processed with different anchoring force by changing the cumulative number of rubs. The rubbing strength is given by [15]

$$n_f \approx (2r\delta)^{1/2} 2\pi N \nu r \sigma_f / s, \tag{2}$$

According to Eq. (2), the various cells with different rubbing strength were fabricated by changing the cumulative number of rubs (N). The indium-tin-oxide (ITO) glass was used as the substrates. The polyimide SE-3140 (Nissan Chemicals Co.) was coated on the bottom and top glass substrates, and rubbing was done in parallel direction. The pretilt angle of SE-3140 has been known as about 5°. The S-811 was used as a chiral additive in order to obtain the metastable 180° twist state in a splay cell.

The measured retention time of the 180° twist state as cumulative number of rubs (N) and the measured azimuthal anchoring strength for each cell is shown in Figure 6. Even though cell gap is about 4.2 μm, we find that the retention time of the 180° twist state is increased as cumulative number of rubs is increased. Considering that anchoring energy of above $7.0 \times 10^{-5}\,\mathrm{J/m^2}$ is guaranteed in order to realize long term twist state, the azimuthal anchoring strength of test cells with $N = 6$ or 7 times is nearly saturated in about $6.3 \times 10^{-5}\,\mathrm{J/m^2}$, becoming untwisted within 1 hour. If we experiment over again with BCSN-LC cells fabricated with liquid crystal of twist elastic constant larger than $K_{22} = 7.1\,\mathrm{pN}$, we can confirm that the retention time of the metastable 180° twist state is much longer than that of cells with $K_{22} = 7.1\,\mathrm{pN}$. As a result, it is expected that if we can increase the azimuthal anchoring strength anyway, the retention time of the 180° twist state is increased. We find that twist elastic constant and cell gap are efficient to increase the azimuthal anchoring strength, resulting in realizing a permanent bistable device.

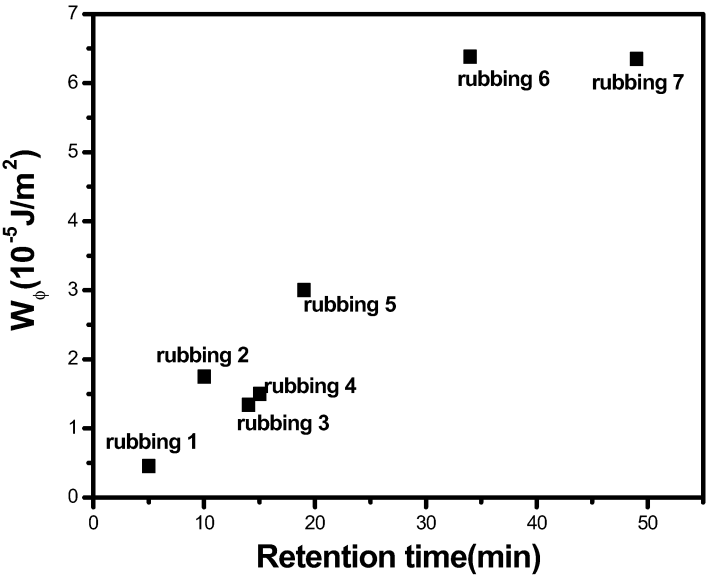


**FIGURE 6** The retention time of 180° twist state versus the azimuthal anchoring strength. The azimuthal anchoring strength is controlled by cumulative number of rubs.

## SIMULATION AND EXPERIMENTS

In summary we have investigated the influence of LC parameters on permanent bistable states in a bistable chiral-splay nematic liquid crystal device. From the relation of the magnitude of the flow velocity $v_y$ as the variation of LC parameters, we could estimate the retention time of the 180° twist state in advance. Through the analysis of the azimuthal anchoring strength, we can understand why this permanent phenomenon is occurred, and how the retention time of the 180° twist state is related to LC parameters. As a result, we can confirm that the twist elastic constant and the cell gap are very efficient as external factors to increase the retention time of the metastable 180° twist state.

## REFERENCES

[1] Berreman, D. W. & Heffner, W. R. (1981). *J. Appl. Phys.*, *52*, 3032.
[2] Qian, T.-Z., Xie, Z.-L., Kwok, H.-S., & Sheng, P. (1997). *Appl. Phys. Lett.*, *71*, 596.
[3] Bock, H. (1998). *Appl. Phys. Lett.*, *73*, 2905.
[4] Zhuang, Z., Kim, Y. J., & Patel, J. S. (1999). *Appl. Phys. Lett.*, *75*, 3008.

[5] Dozov, I., Nobili, M., & Durand, G. (1997). *Appl. Phys. Lett.*, *70*, 1179.
[6] Barberi, R., Giocondo, M., Li, J., Bartolino, R., Dozov, I., & Durand, G. (1997). *Appl. Phys. Lett.*, *71*, 3495.
[7] Guo, J.-X., Meng, Z.-G., Wong, M., & Kwok, H.-S. (2000). *Appl. Phys. Lett.*, *77*, 3716.
[8] Davidson, A. J. & Mottram, N. J. (2002). *Phys. Rev. E.*, *65*, 051710.
[9] Joubert, C., Angele, J., Boissier, A., Davi, P., Dozov, I., Elbhar, T., Pecout, B., Stoenescu, D., Vercelletto, R., & -Lagarde, P. M. (2002). *SID 02 Digest*, 30.
[10] Wang, B. & Bos, P. J. (2001). *J. Appl. Phys.*, *90*, 552.
[11] Lee, S. H., Park, K.-H., Yoon, T. H., & Kim, J. C. (2003). *Appl. Phys. Lett.*, *82*, 4215.
[12] Akahane, T., Kaneko, H., & Kimura, M. (1996). *Jpn. J. Appl. Phys.*, *35*, 4434.
[13] Newsome, C. J., O'Neill, M., Farley, R.-J., & Bryan-Brown, G. P. (1998). *Appl. Phys. Lett.*, *72*, 2078.
[14] Sato, Y., Sato, K., & Uchida, T. (1992). *Jpn. J. Appl. Phys.*, *31*, L579.
[15] Sinha, G. P., Wen, B., & Rosenblatt, C. (2001). *Appl. Phys. Lett.*, *79*, 2543.