Bistable property in a splay cell with a chiral additive

***Seo Hern Lee*[1]*, Tae Jin Kim*[1]*, Jong Lac Lee*[1]*, Mi Jun Jung*[1]*, Kyoung-Ho Park*[1]**
***Tae-Hoon Yoon*[1,2] *and Jae Chang Kim*[1,2]**
[1]Department of Electronics Engineering, Pusan National University, Pusan, Korea
[2]Research Institute of Computer, Information and Communication, Pusan National University, Pusan 609-735, Korea
Phone : +82-51-510-1700 , E-mail : seohern@hanmail.net

Abstract

The bistability in a chiral-splay nematic liquid crystal cell, which is obtained by adding a chiral additive to a splay cell, is proposed. In this paper, we describe a new horizontal way of switching between the two states of the bistable chiral-splay cell, one state being characterized by a non-twisted director field with splay, the second state showing a director-field with 180° twist.

1. Introduction

Since it was shown that nematic liquid crystal cells could be switched between two metastable twist states in early 1980s,[1] there has been increasing interest in bistable liquid crystal devices. Up to now, the volume[2-4] and surface switching types[5-6] have been mainly demonstrated as the bistable devices. In the case of the volume switching type, it has a serious problem that the ϕ-π and ϕ+π twist states are metastable with a short lifetime. Although Wang *et al.*[7] achieved a long-term bistability by using the multidimensional alignment method to prevent the nucleation of the ϕ twist state, the application was still limited. The surface switching type[8] using the effect of surface anchoring, except for a surface-controlled bistable nematic (SCBN) cell[6] in which standard anchoring layers have been demonstrated, have still the demerit that the manufacturing process for the surface alignment is troublesome in comparison with the conventional liquid crystal cells. In this paper, we propose a bistable chiral-splay nematic(BCSN) liquid crystal device using a new horizontal switching, which overcomes the weak points of the volume and surface switching bistable devices. This device is similar to SCBN in that the two bistable states are the 0° state and the 180° twist state. However, unlike SCBN that uses the breaking of surface anchoring conditions using high voltage with short pulse width, the proposed bistable cell can achieve the metastable 180° twist state with a low voltage of only 5V under the experimented sample size of 3×3 cm^2 or 2 V/μm under the normal pixel size of 100×100 μm^2. Hence, the bistable mechanism of this device is irrelevant to the breaking of surface anchoring.

2. Transition process

Figure 1 illustrates the transition process of the proposed chiral-splay cell. When no voltage is applied, the splay cell is in a parallel state, where the molecules are all aligned with the rubbing direction. In such geometry, when the voltage above V_c is applied to the cell, it transforms to the bend state through the middle state with reverse tilt-like domains. The transition time from the splay state to the bend state depends on the applied voltage, pulse duration, and LC materials. For example, in the case of our sample cells of 3x3 cm^2, in order to transform the splay state to the bend state it is necessary to apply a voltage of 12 V square wave of 1kHz for about 12 seconds. In the case of the voltage of about 5 V, it takes about 40 seconds to transform the splay state to the bend state. In general, once the applied voltage is above 4 V, we can obtain the bend state by the control of the pulse duration. After the bend state is generated, during the voltage-off state, it returns to the splay state through the 180° twist state. While the retention time of the twist state is few seconds in the pure splay cell without a chiral additive, in the splay cell blended a chiral additive with a cell thickness over pitch (d/p) of 0.1, it increases above about ten times. However, if d/p ratio is above about 0.25, careful treatment is needed since the initial state with no voltage may be the twist state. The twist state is more stable as d/p ratio increases. As a result, since the voltage for transforming the twist state to the splay state can be increased in the switching of the chiral-splay cell, it is important to optimize d/p ratio.

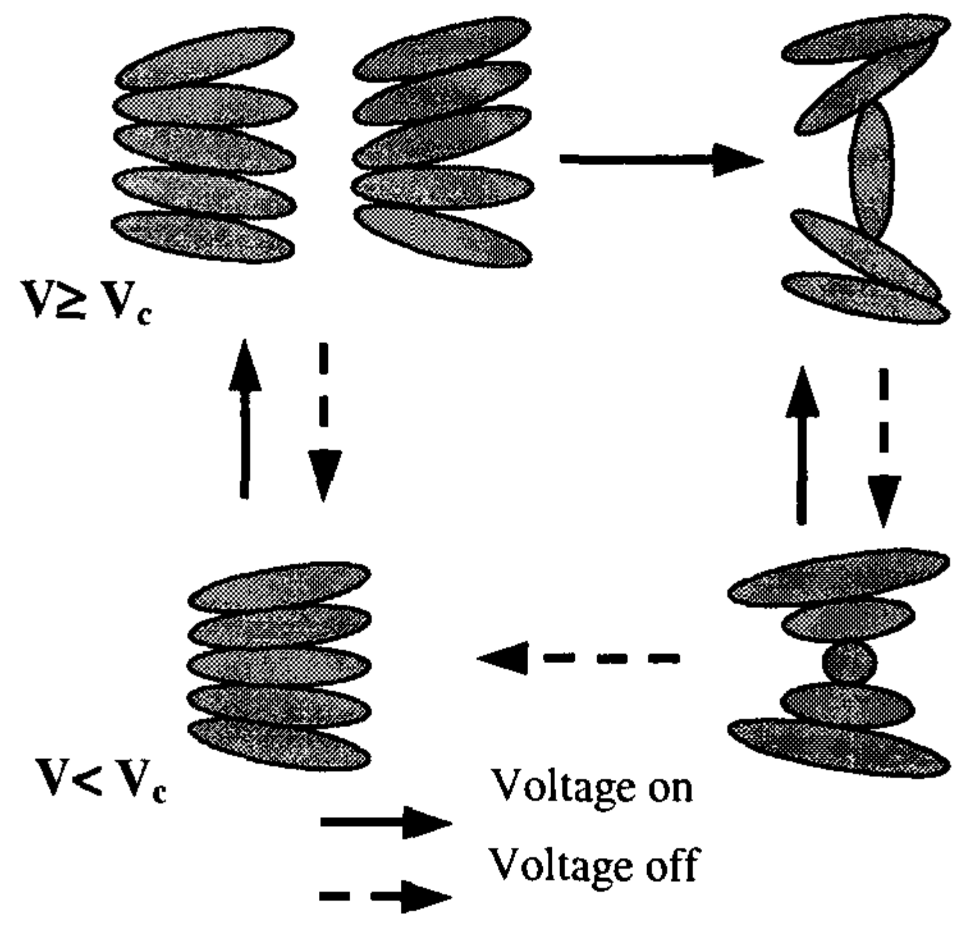


Figure 1 The transition process of the BCSN LC cell

3. Transition mechanism in 180° twist state

By numerically solving the Ericken-Leslie hydrodynamics equations with a natural twist term of a nematic sample of thickness d aligned parallel along the x axis, we can understand how this BCSN cell switches from the initial 0° splay state to the metastable180° twist state. The hydrodynamics equations may be expressed by four equations[9], which is composed of the two equations for shear force(σ) across the liquid crystal cell and the other two balance equations of elastic, viscous, and electric torques. By using these equations and after trivial calculations, we obtain :

$$V_x' = \frac{(\sigma_{zx}\gamma_1 - T_{13}\lambda_1 - T_{14}\lambda_2)(T_{22}\gamma_1 - T_{23}T_{32} - T_{24}T_{42})}{\xi_1} - \frac{(\sigma_{zy}\gamma_1 - T_{23}\lambda_1 - T_{24}\lambda_2)(T_{22}\gamma_1 - T_{23}T_{32} - T_{24}T_{42})}{\xi_1} , \quad (1)$$

$$V' = \frac{(\sigma_{zx}\gamma_1 - T_{13}\lambda_1 - T_{14}\lambda_2)(T_{21}\gamma_1 - T_{23}T_{31} - T_{24}T_{41})}{\xi} - \frac{(\sigma_{zy}\gamma_1 - T_{23}\lambda_1 - T_{24}\lambda_2)(T_{11}\gamma_1 - T_{13}T_{31} - T_{14}T_{41})}{\xi_2} , \quad (2)$$

where,

$$\xi_1 = (\gamma_1 T_{11} - T_{13}T_{31} - T_{14}T_{41})(T_{22}\gamma_1 - T_{23}T_{32} - T_{24}T_{42}) - (\gamma_1 T_{21} - T_{23}T_{31} - T_{24}T_{41})(T_{12}\gamma_1 - T_{13}T_{32} - T_{14}T_{42}) ,$$

and

$$\xi_2 = (\gamma_1 T_{12} - T_{13}T_{32} - T_{14}T_{42})(T_{21}\gamma_1 - T_{23}T_{31} - T_{24}T_{41}) - (\gamma_1 T_{22} - T_{23}T_{32} - T_{24}T_{42})(T_{11}\gamma_1 - T_{13}T_{31} - T_{14}T_{41}) .$$

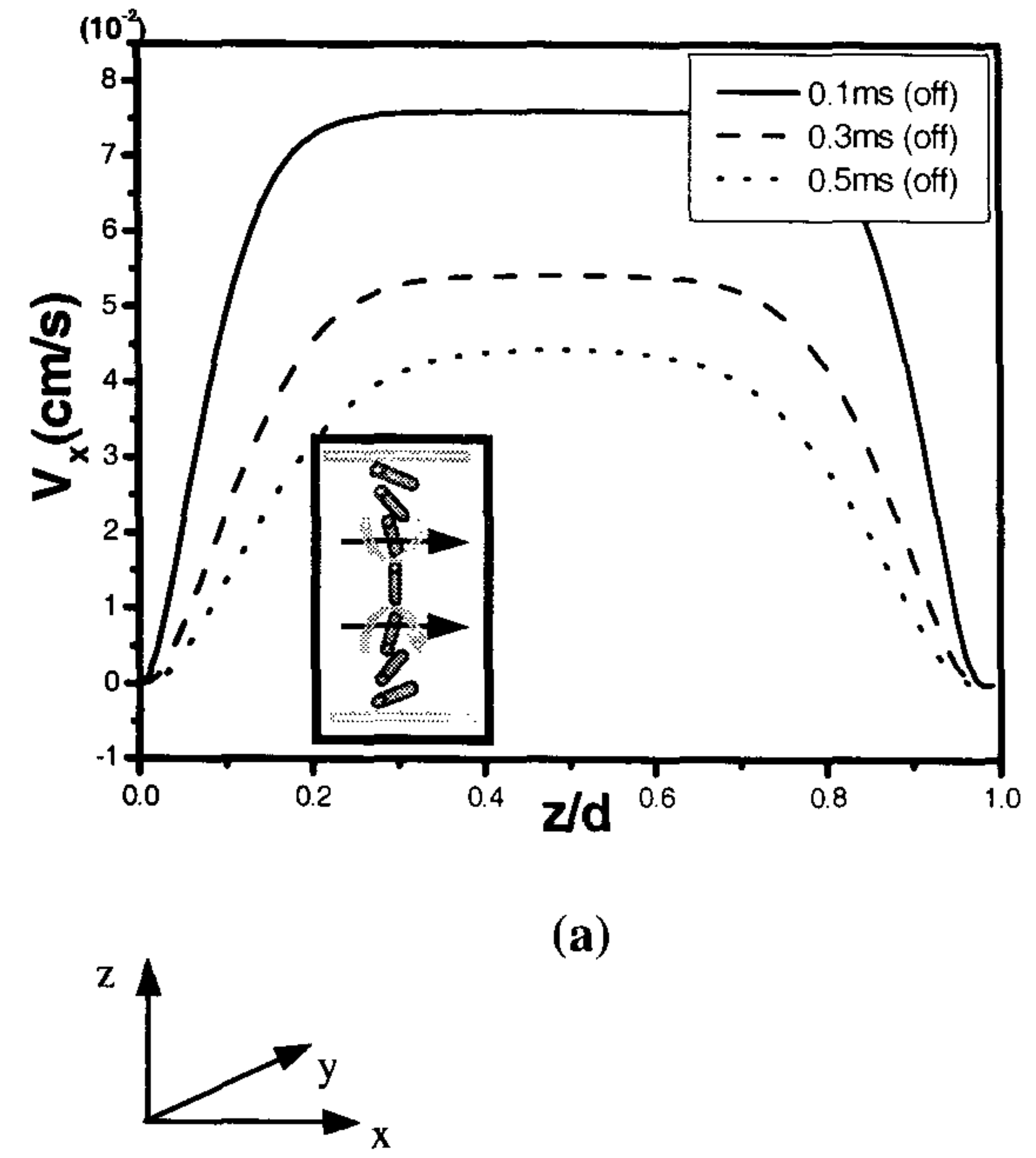
The σ's are the shear forces across the cell and V_x and V_y represent the flow velocities parallel to the x and y axes in the surfaces of the cell. All of the T's and λ's are functions of θ (tilt angle) and ϕ (twist angle). They are given in the appendix of the ref. 9. With these equations, we can find the influence of flow effects in transforming the bend state to the twist state in the field-off state.

Figure 2 shows the calculated flow velocities after applying the voltage of a 15V to a test cell of d/p=0.1, cell thickness 6.4㎛ and pretilt angle 5° for the bend state and subsequently disconnecting the voltage source. The parameters used in the simulation are shown in Table 1. Due to lack of the Leslie coefficients of ZLI-1557, these coefficients are taken from the values of MBBA[10]. There is an obvious influence of flow velocities in the x direction and y direction in the relaxation. The velocity component V_x in the x direction is the same at the both sides of the cell.

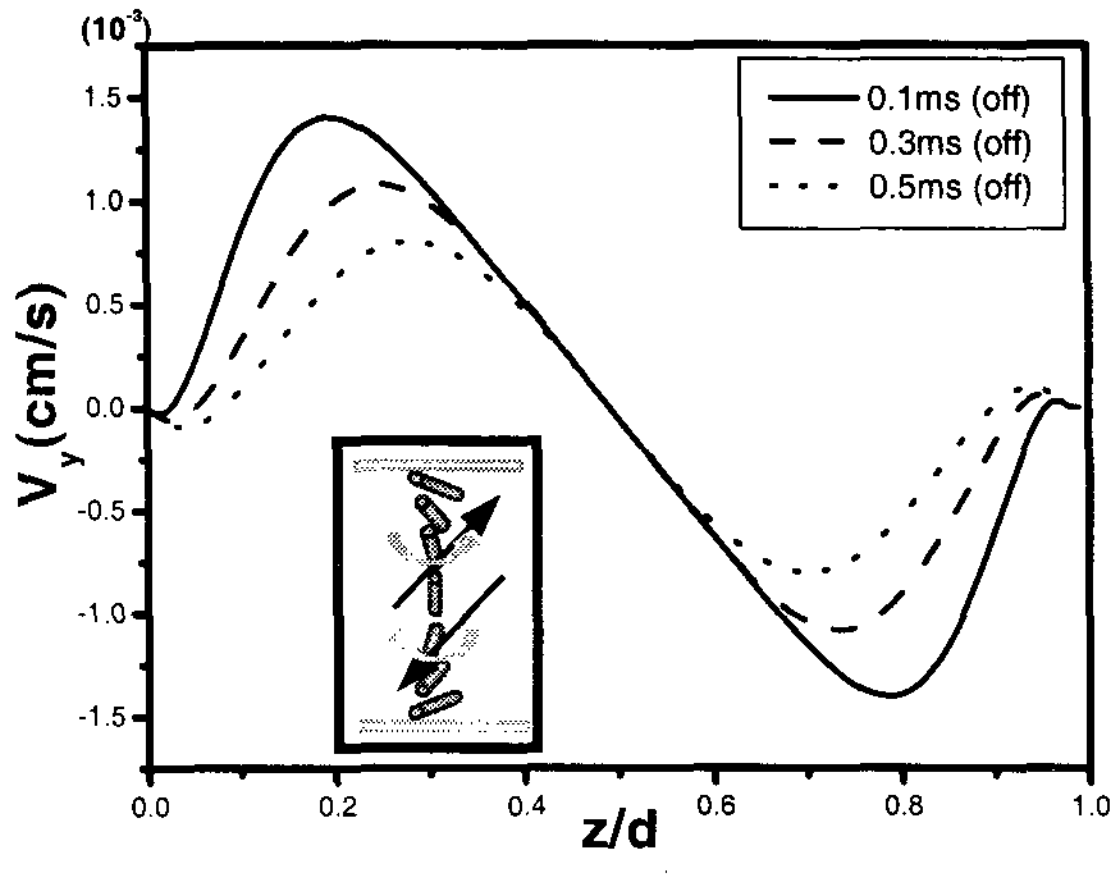
Table 1. The simulation parameters of the liquid crystal

Parameter	Value	Parameter	Value
K_{11}	9.5x10^{-7} dyne	α_1	6.5 ± 4
K_{22}	5.1x10^{-7} dyne	α_2	-77.5 ± 1.6
K_{33}	11.5x10^{-7} dyne	α_3	-1.2 ± 0.1
n_o	1.4993(λ=589nm)	α_4	83.2 ±1. 4
n_e	1.6140(λ=589nm)	α_5	46.3 ± 4.5
ε_o	3.7	α_6	-34.4 ± 2.2
ε_e	7.9		

As shown in the inset of the Fig. 2(a), the torque induced by the flow relaxes the liquid crystal directors in the x direction. The velocity component V_y in the y direction plays an important role in forming the 180° twist state. As shown in Fig. 2(b), the flow in the y direction is reversed symmetrically about the midplain of the cell, which is known as the backflow effect. Although its magnitude is smaller than that of V_x, the effect of the flow is enough to induce the relaxation of the directors symmetrically about the midplain in the y direction as shown in the inset of the Fig. 2(b). As a result, the twist state is generated due to the flow-induced viscous torque in the y direction. For comparison, we perform the computer simulation with the same conditions except that rubbing was done in antiparallel direction, which is called a homogeneous state. The calculated results show that the role of velocity components V_x in the x direction and V_y in the y direction is inverted unlike a splay cell. That is, in a homogeneous cell, the velocity V_x in the x direction is reversed symmetrically about the midplain in the x direction, and V_y in the y direction is the same at the both sides of the cell (not shown). Therefore, the flow-induced viscous torque in the x direction relaxes the liquid crystal directors in the same direction. The twist state is not generated due to velocity components V_y with the same direction at the both sides of the cell.



(a)



(b)

Figure 2 The calculated flow velocities and the illustrations of the relaxed directors (the inset) during the voltage-off state: (a) Component V_x in the x direction and (b) component V_y in the y direction of the flow velocity.

5. Horizontal switching between 180° twist state and 0° splay state

To confirm the validity of the mechanism, a splay cell filled with liquid crystal ZLI-1557(E. Merck) was fabricated with spacer thickness of 4.2 μm. 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 chiral additive in order to obtain the metastable 180° twist state in a splay cell. A He-Ne laser with wavelength 632.8nm was used as the light source.

To switch the proposed chiral-splay cell we need to use special electrode. Figure 3 shows the electrode structure of the bottom substrate to switch from the metastable 180° twist state to the 0° splay state. By the vertical switching between ITO layer of the top substrate and the second ITO layer of the bottom substrate, we can transform the 0° splay state to the bend state, and then obtain the twist state during the voltage-off state. By the horizontal switching between the first ITO layer and the second ITO layer of the bottom substrate, we can transform the 180° twist state to the 0° splay state. Figure 4 shows the equipotential lines which are calculated by 2DIMMOS in the horizontal switching on the used electrode. By the electric field in the horizontal direction, it can be transformed from the 180° twist state to the 0° splay state.

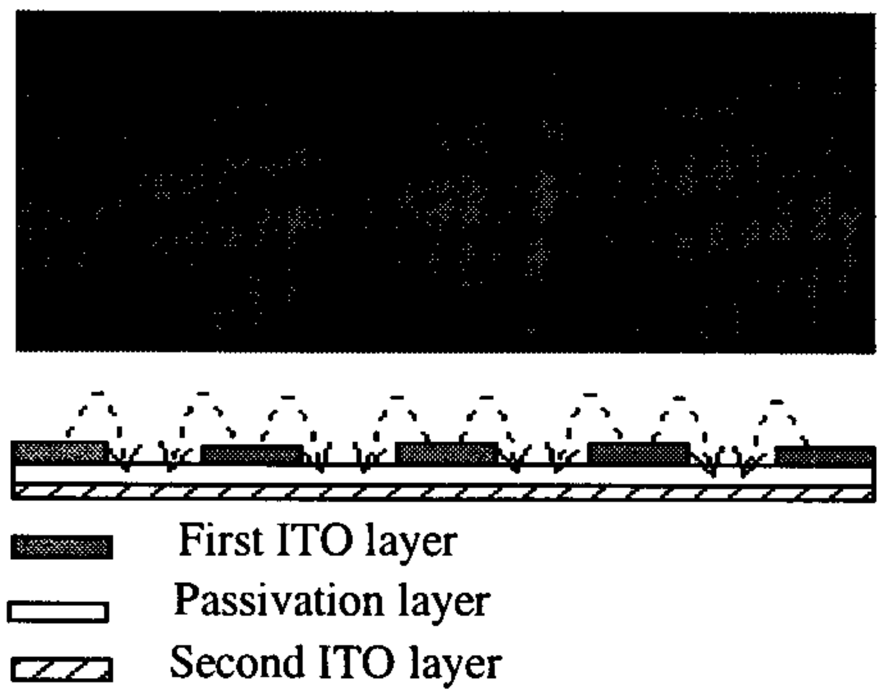


Figure 3 The electrode structure for the switching from the metastable 180° twist state to the stable 0° state

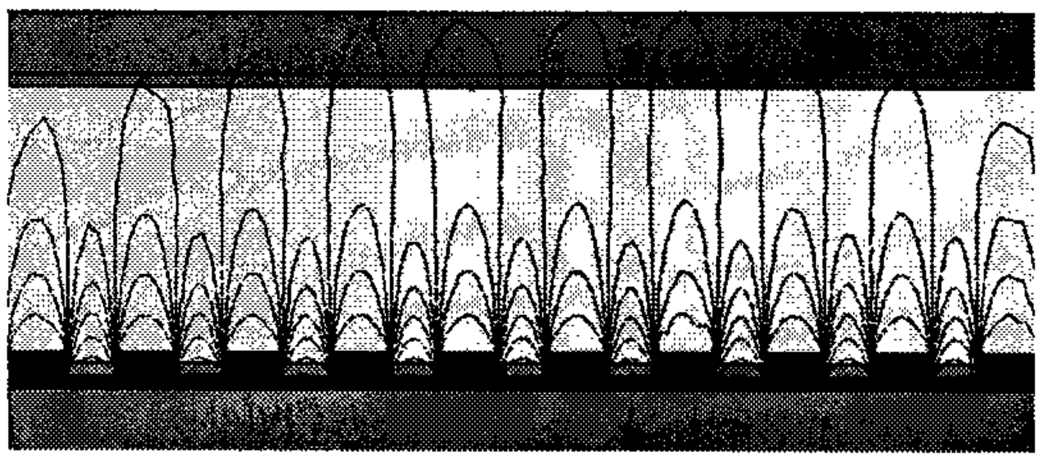


Figure 4 The calculated equipotential lines in the horizontal switching on the used electrode

Figure 5 shows the driving pulses used to switch the BCSN cell and the transmittance as a function of time. In Fig. 5, V_{st} and V_{ts} represent the vertical voltage for the transition from the 0° splay state to the metastable 180° twist state, and the horizontal voltage for the reverse process. Although, with low voltage of only 5 V, it can be switched into the twist state, we used the high voltage of V_{st}=20 V and V_{ts}=20 V for the fast switching. The driving pulse width was 150ms for V_{st} and 700ms for V_{ts}, respectively.

6. Conclusion

In summary, we have investigated the bistable property in a splay cell with a small amount of chiral additive, and proposed a new way of switching between the two states of the bistable chiral-splay cell. The proposed chiral-splay cell has the advantage that unlike the conventional BTN, bistable property is easily obtained in both the large cell gap and the low voltage. By optimization of the various LC parameters, it is expected to obtain a noble BTN device with superior optical as well as electrical properties.

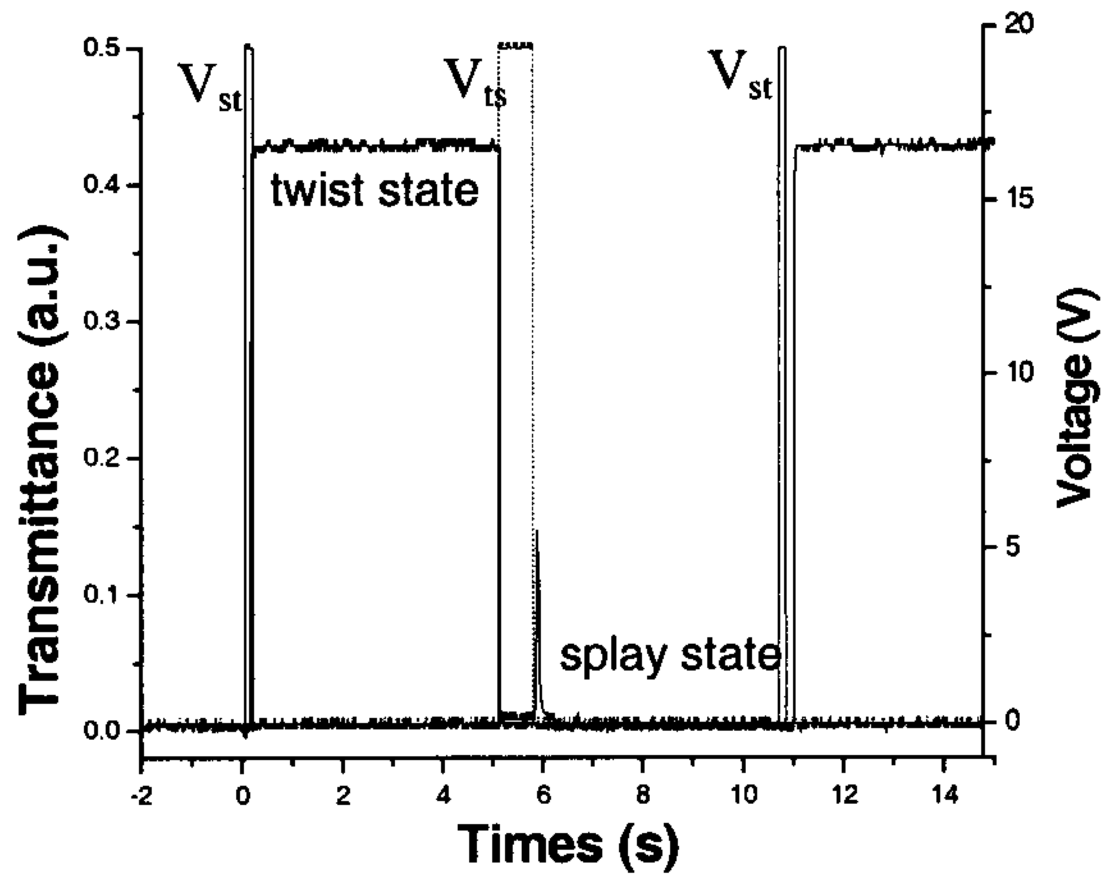


Figure 5 The driving pulses used to switch the BCSN cell, and the transmittance

7. Acknowledgements

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8. References

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