16.2: Bistable Twisted Nematic Liquid Crystals Display with Permanent Grayscales and Fast Switching

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Abstract

Permanent grayscales in a π bistable twisted nematic liquid crystal display have been demonstrated. This display can be switched between –22.5° and 157.5° twist states by means of a combination of strong in-plane electric fields and vertical electric field for creating both the planar anchoring breaking and an electro-hydrodynamic flow. The switching of the twist states during the Frederiks transition is sufficiently inhomogeneous such that domains of –22.5° twisted and 157.5° twisted states are formed. The ratio of these domains can be controlled by the vertical electric field. Fast switching of 1 ms was achieved for gray scales. These grayscales have very long lifetime.

1. Introduction

Bistable twisted nematic (BTN) liquid crystal displays (LCDs) traditionally have bistable twist states that differ in twist angle by 2π. However, the major problem of these BTN is that the ϕ and the ϕ+π twist states are metastable with short lifetime. Dozov et al[1] demonstrated BTN where the bistable twist states differ by π. This π-BTN is permanently bistable since there is no stable "middle state"[2]. In the Dozov case, switching was accomplished using a thin LC cell and a combination of strong and weak surface anchoring, together with large pretilt angles. Recently, Guo et al[2] reported a 3-terminal BTN LCD, which made use of a combination of strong in-plane electric fields and vertical electric field for switching between the ϕ and the ϕ+π twist states. The lifetimes of two bistable twist states are infinite.

In order to be used in electronic-book or electronic-newspaper, it is necessary to have intrinsic gray scales for truly bistable display devices to display high quality picture. Previously, only one BTN display with gray scales of an infinite lifetime has been proposed by Barberi et al[3], where one alignment layer is evaporated SiO, for which coating condition is close to that necessary to obtain the oblique bistable nematic anchoring. Unfortunately, the evaporation technique is not compatible with large-scale production of commercial devices. Xie et al[4] and Hock[5] respectively reported gray scales in 2π-BTN cell, but both gray scales are metastable. In this paper, we reported permanent gray scales in comb-on-plane (COP) BTN cell. The gray scales and its fast switching can be controlled by an applied electric field.

2. Experimental

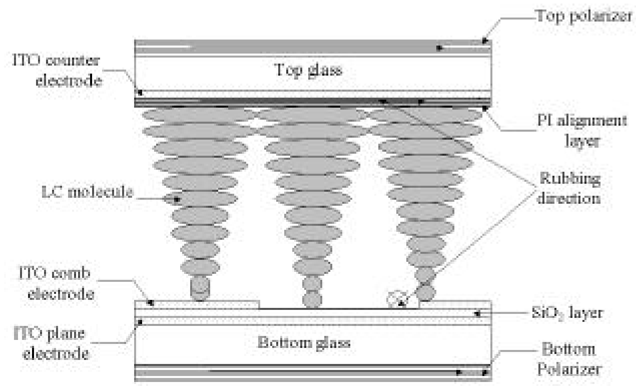

Figure 1 Cell structure of COP-BTN LCD Cell

The basic cell structure of the COP–BTN is shown in Figure 1, consisting of a top counter electrode and the bottom pair of comb and plane electrodes. In the present implementation, the 2μm comb electrodes are spaced 2μm apart, resulting in a pitch of 4μm. This cell structure is the same as a 3-terminal BTN except that the bottom substrate does not have any polyimide (PI) coating. The bottom ITO or SiO_2 layer is rubbed in a direction parallel to that of the comb fingers to provide weak anchoring. The top alignment layer is made of PI with strong anchoring condition, and its rubbing direction depends on the LC twist angle ϕ, which can be optimized to give perfect optical properties 6. In this work, the first optimal mode is chosen. Therefore the bistable twist angles are -22.5° and 157.5°. The output polarizer angle α and the input polarizer angle γ were 112.5° and 45°, respectively.

A cells gap (d) of 2.5μm was used. The rubbing conditions on both substrates were such that the -22.5° twist angle was favored. A liquid crystal MLC-7500/000 with positive dielectric anisotropy was filled and a chiral additive S811 was used to control the d/p ratio of the cells and resulting in a dΔn value of 0.26μm.

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3. Results and Discussions

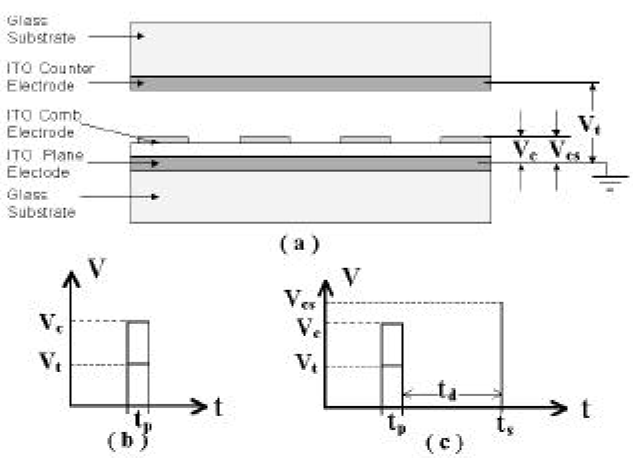


Figure 2. COP-BTN. (a) Electrode schematic. (b) Switching waveform. (c) Fast switching waveform.

The driving method used to switch COP-BTN is shown in Figure 2. As shown in Fig. 2a, two independent signals V_t and V_c can be employed to drive the device, with the plane electrode set to ground. For the switching waveform shown in Fig. 2b, V_c and V_t have different amplitudes, but with the same pulse duration t_p. V_c and t_p are fixed at 40 V and 30 ms, respectively. For the switching waveform shown in Fig. 2c, a short pulse with delay time t_d is added to that of the waveform in Fig. 2b. t_s and V_{cs} represent the time and amplitude of the short pulse, respectively.

A typical electro-optic curve of a COP-BTN cell switched using the waveform in Fig. 2b is shown in Fig. 3. Clearly, the 157.5° twist state corresponding to low transmittance is selected within a finite V_t amplitude range between 10 and 20V. Beyond this range, the -22.5° twist state is obtained. This includes the low voltage ranges of below 1.2V and high voltage range of above 25V. It is interesting to note that varying V_t from 1.2V to 10V can lead to various intermediate transmittance values. The gray levels thus obtained are repeatable and permanent.

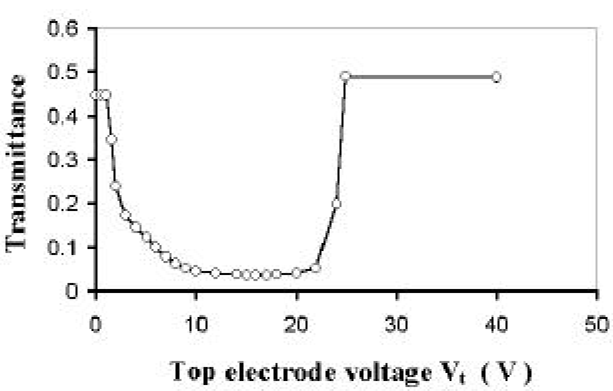


Figure 3. Typical electro-optic curve of a COP BTN cell.

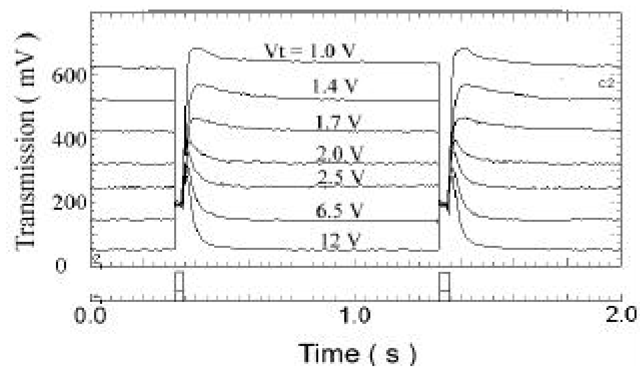


Figure 4. Optical responses curves with several gray scales in COP-BTN cell. (V_c = 40 V, t_p = 30 ms)

Examples of optical responses with seven gray scale levels produced by a top electrode voltage variation between 1.0 and 12V are shown in Fig. 4. After the electric field is removed, the transient time to dark state is about 70 ms and that to bright state is about 20ms. After the transient, steady state gray levels are obtained. We found that the lifetime of each gray level was more than three months. In principle, the contrast ratio for COP-BTN cell should be very high, however from our experimental results, the contrast ratio between bright and dark states is about 13. The reason should be that some deviation exists in the dΔn value of the cell.

A set of microscope-pictures of a COP-BTN cell is shown in Fig. 5. Clearly, there are dark and bright domains in the cell. The bright domains correspond to the –22.5° twist state, and the dark ones correspond to the 157.5° twist state. All of the domains have certain directionality along that of the comb electrode fingers. The shape of both kinds of domains is lath-like with the width of integer-multiple period of the comb electrode and indefinite length. Moreover, as V_t increases within the range of 2 V to 10V, the ratio between dark and bright domain will increase as shown in Fig. 5a to Fig. 5c. Therefore by controlling the electric field, the ratio of dark to bright domains can be adjusted to give rise to various gray levels.

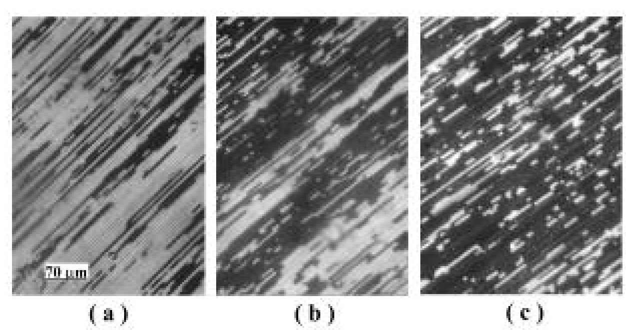
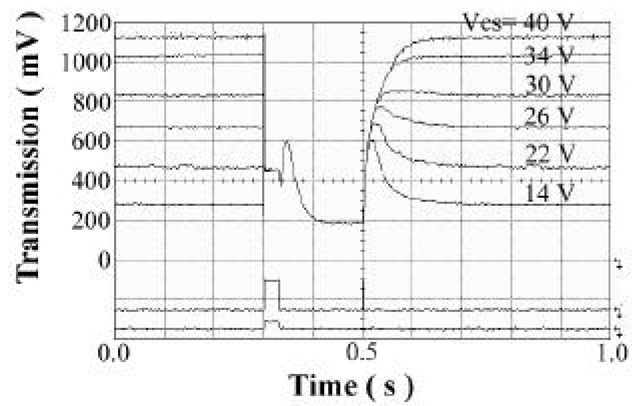


Figure 5. Different ratios between dark to bright domains are shown in picture (a), (b) and (c).

In order to understand the mechanism of gray scale control, it is better to first explain the switching principle of the COP-BTN cell. When V_c and V_t are applied to the COP-BTN cell, a desired electric field is set up[7, 8] near the bottom pair of electrodes. The field emanates from the comb fingers and terminates on the exposed ground electrode in between the fingers. Near the edges of the comb fingers, the electric field is largely horizontal and perpendicular to the long axes of the comb fingers. The magnitude of the field decays rapidly in the direction normal to the bottom surface. If V_c is strong enough, the weak anchoring on the bottom surface will be broken, and the LC molecules will re-align to an intermediate $\phi+\pi/2$ twist state. At the same time, near the top surface vertical electric field is set up. Due to the strong anchoring condition of the top PI alignment layer, the first layer molecules is fixed at this PI surface and nearly molecules will be re-oriented to produce some deformation. The strength of the deformation is largely dependent of the amplitude of V_t.

After the V_t and V_c are removed, the molecules near the PI surface will return rapidly to their original position to induce certain hydrodynamic “backflow”[9]. The strength of the “backflow” effect largely depends on the deformation of the LC molecule near the PI surface, and help to select ϕ or $\phi+\pi$ twist state on the bottom surface. If V_t is small enough (such as < 1.2V), the “backflow” effect triggered by the deformation of LC molecules will be very weak and cannot overcome some energy barrier[10]. Consequently, the ϕ twist state will be selected. If V_t is large enough (such as > 10V), the “backflow” effect should be strong enough to overcome some energy barrier, leading to the $\phi+\pi$ twist state. Therefore, the LC twist switching depends on three factors: weak anchoring on bottom surface, horizontal electric field near bottom surface and the “backflow” effect.

As shown in figure 5, the width of the domains can be several micrometers. In this dimension, the weak anchoring on the bottom surface cannot be thought as uniform by rubbing. Moreover, the horizontal electric field near bottom surface is not uniform[8]. Therefore, the state of the molecules on the bottom surface should be different at different locations and the influence of “backflow” effect should be different. Hence, if a small V_t, such as 1.4V, was applied, a weak “backflow” effect was induced to switch only a few of molecules to the 157.5° dark states. Consequently, the cell was closer to the bright state. If a large V_t (6.5 V) was applied, a stronger “backflow” effect was induced to switch a large number of molecules to the 157.5° dark states. The transmission of the cell was closer to the dark state. In this way, “backflow” effect can be adjusted by controlling the V_t amplitude to obtain various gray levels.



a

Figure 6. Optical responses curves with several gray scales in COP-BTN cell. Switching by waveform in Fig 2c. (V_c=40 V, Vt=10 V, t_p = 30 ms t_d= 170 ms, t_s=1 ms)

Gray scale can also be achieved by fast switching waveform in Fig 2c. The principle is explained as follow: Firstly, a couple of pulses is applied with very strong anchor breaking and “backflow” effects (V_c=40 V, V_t= 10 V). After a rather long delay time (170 ms), all molecules should be switched to the high twist state (dark state). If only one short pulse (1 ms) is added between comb and plain electrode to break the weak anchoring on bottom surface, the molecules should relax to the low twist state (bright state) due to the lack of “backflow” effect. As mentioned previously, the situation of anchoring and horizontal electric field on the bottom surface are not uniform, that means anchor-breaking should not be uniform. So as the short pulse voltage increase, more and more molecules break through the anchoring limit and relax to the bright state. Therefore the ratio between the bright and dark domains will increase until all molecules are switched to the bright state. Corresponding experimental results are shown in Fig. 6. Clearly, several gray levels were achieved by controlling a short pulse (t_s=1 ms) with different voltage amplitudes. All gray levels also have long lifetime.

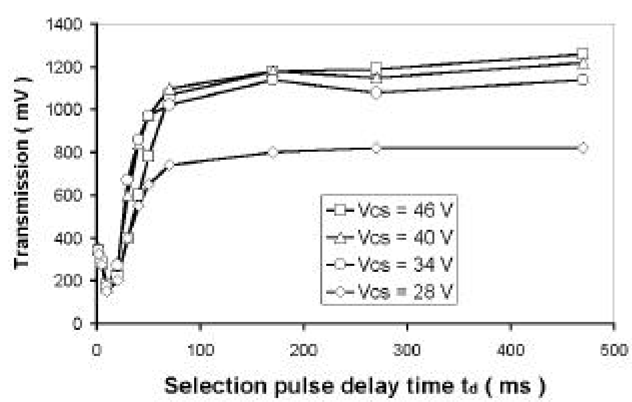


Figure 7. Relationship between transmission and delay time t_d for the cell under different V_{cs}.. (t_s=1 ms)

The effects of the delay times of the short pulse on the transmission of the cell were investigated as shown in Figure 7. Obviously, if the delay time was longer than 70ms (corresponding to response time from bright to dark state), the effects can be ignored. If the times were shorter than 70ms, basically the transmission increases with increasing delay time. If the delay time is shorter than 10ms, the transmission increases with decreasing the delay time. That means we can control gray scale by adjusting the delay time. This phenomenon is relative to the effect between "backflow" effect and the electric field induced by short pulse. In addition, as the pulse voltage increases, the slope of transmission vs. delay time increase.

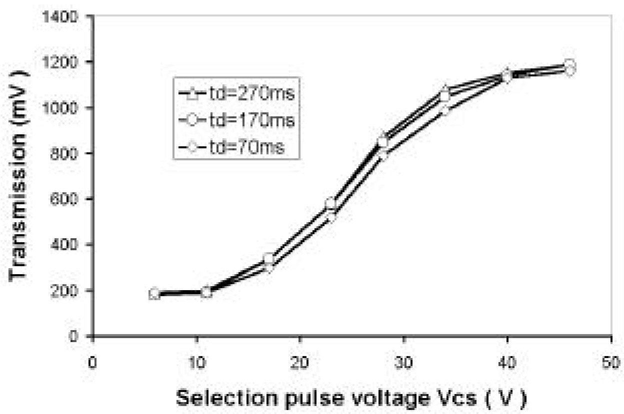


Figure 8. Electro-optic curves of the cell with different delay time t_d. (t_s=1 ms)

As shown in Figure 8, gray scales can be controlled within wide voltage range of the short pulse (from 10V to 40V). If the delay time large than 170ms, the relationship between cell transmission and pulse strength is constant.

The dependence of the transmission on the pulse voltage under different pulse time is shown Figure 9. Clearly, there is a trade-off between pulse time and voltage. That means faster switching need higher voltage (but lower). Moreover, if the pulse is too short (0.5ms), the transmission was fixed at a constant mid-level, even though the pulse voltage further increases.

4. Conclusion

Permanent gray scales in a COP bistable twisted nematic liquid crystal display have been demonstrated. This display can be switched between –22.5° and 157.5° twist states by means of a combination of strong in-plane electric fields and vertical electric field for creating both the planar anchoring breaking and an electro-hydrodynamic flow. The switching of the twist states during the Frederiks transition is sufficiently inhomogeneous such that domains of –22.5° twisted and 157.5° twisted states are formed. The ratio of these domains can be controlled by the vertical electric field. Fast switching of 1ms can be achieved by controlling pulse voltage or pulse delay time. These grayscales have very long lifetime. Possible applications are in e-book or e-newspaper.

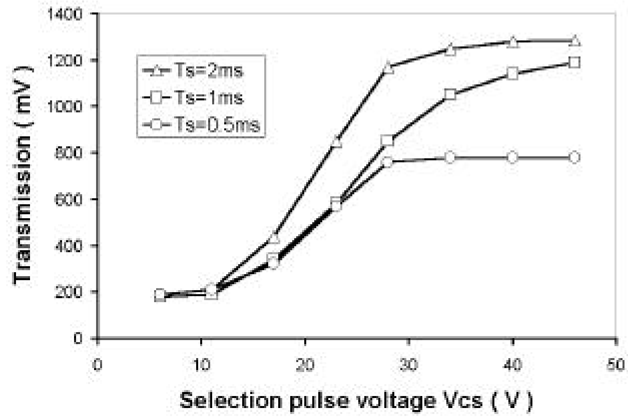


Figure 9. Electro-optic curves of the cell with different short pulse time t_s. (t_p=170 ms)

5. Acknowledgment

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6. References

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