51.1: *Invited Paper:* Bistable LCDs based on a New Alignment Technology

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Abstract

Several new nematic bistable liquid crystal displays based on a new alignment surface have been demonstrated. Nano-textured alignment surfaces enable the generation of arbitrary pretilt angles and arbitrary anchoring energy. Based on such surfaces, three types of bistable devices have been developed. They are bistable bend-splay, bistable twist-twist and bistable bend-twisted displays.

1. Introduction

Liquid crystal display with only one stable state such as TN, OMI, STN, SBE, VA have no pixel memory. Constant refreshing of the display is needed. In order to obtain high multiplexing levels, i.e. VGA, XGA, QXGA, active matrix driving is needed in these displays. Bistable display device on the other hand does not require any refreshing, and can provide high resolution without cross talk by passive addressing. It is prefect for applications requiring flicker free and static image at unlimited resolutions. Several bistable display solutions are available in the literature, e.g. cholesteric, bistable twisted nematic (BTN) and zenithal bistable display (ZBD).

In this paper, we would like to demonstrate three new types of bistable displays based on nematic LC. They are bistable bend-splay (BBS), bistable twist-twist (BTT) and bistable bend-twist (BBT) displays. They all require large and controllable pretilt angles. This can be achieved with nano-structured alignment layer which we have developed recently [1]. Such special alignment surface makes different deformation of liquid crystal equally stable under the same boundary condition. Moreover, by making use of dual frequency liquid crystal, switching between the two bistable states can be effected easily. We shall also demonstrate that the process window for obtaining the bistability can be quite large, resulting in better manufacturability.

2. Arbitrary pretilt angle and unit sphere representations

The generation of controllable high pretilt angle has been a long standing problem in LCD research. We recently discovered that nano-structures of vertical and horizontal alignment PI can produce predetermined pretilt angles of any value [1]. With the availability of large pretilt angles, many bistable structures become possible. The situation can be visualized in the unit sphere representation of LC alignment [2]. Fig. 1 shows the stable alignments of the bistable TN, bistable BS and bistable bend-twist situation. The red and blue paths have equal elastic deformation energies and are therefore bistable. It should be noted that on the unit sphere, point (θ, ϕ) is equivalent to ($-\theta$, $\phi+\pi$). So the boundary conditions, which are end-points in the unit sphere curve, can have multiple representations. This is the basis of bistability. Obviously, higher pretilt angles allows much higher degree of freedom in choosing the end points for the various curves.

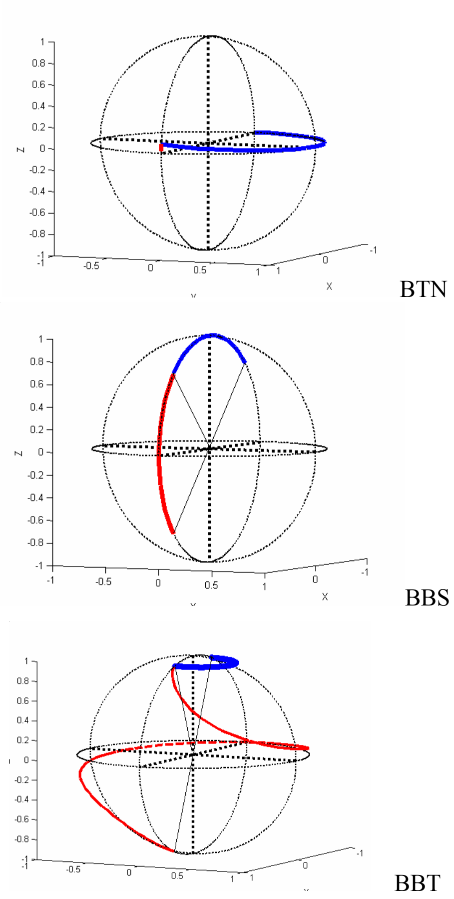

Figure 1. Unit sphere representation of the BTN, BBS and BBT stable alignments.

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3. Bistable bend splay Display

The two stable alignments of the BBS are shown in Fig. 1. A dual frequency bistable bend-splay device has been reported recently [3]. It uses strong anchoring parallel high pretilt angle for both top and bottom boundaries. The pretilt angle required is as high as 52^o. Due to the high pretilt boundary conditions, bend and splay state are both stable without external electric field. Using a dual frequency LC, it is able to obtain the bend state by applying a low frequency AC waveform i.e. ($\boldsymbol{v}_B$ < crossover frequency $\boldsymbol{v}_C$). On the other hand, the device can be switched to the splay state by applying a high frequency AC waveform such as ($v_S > v_C$).

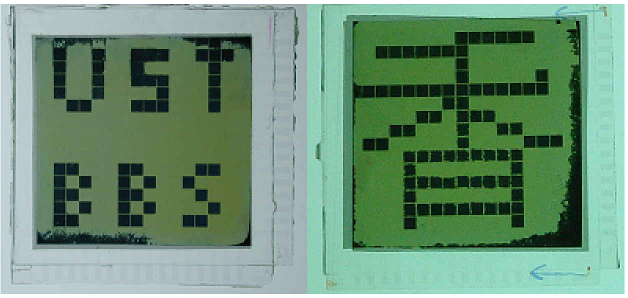

Figure 2 16x16 BBS shows permanent pixel memory.

Figure 2 shows two 16x16 dots matrix BBS device. They are good contrast and permanent pixel memory. The response time for the S-B and B-S switching under different driving frequency are also measured. The results are shown in Fig. 3. It is found that S-B switching can be as fast as 2ms. But for B to S, the switching time is over 100ms and needs to be improved.

The advantage of this bistable device is cell gap insensitive. The contrast is as high as 42 [3]. The bistability only depends on the surface tilt angle at the boundaries. Therefore it is suitable for making flexible bistable display device.

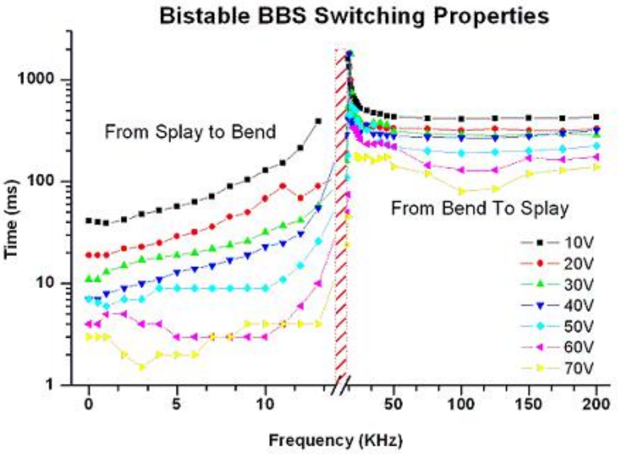

Figure 3. BBS Switching Properties

4. Bistable twisted nematic Display

BTN has been studied by many groups [4-11]. While the 2π-BTN is only metastable, the π-BTN is truly bistable. One major problem with the manufacturing of π-BTN is the low cell gap required. Here we propose the use of dual frequency LC to produce the switching. According to the prior art [4-6], switching of BTN is based on the surface polar anchoring breaking. Therefore, a weak polar anchoring energy alignment material is a key factor for the success of such display. We recently found that a dual frequency liquid crystal is able to provide an alterative to polar anchoring breaking. It was found that switching of the BTN could be done even with strong alignment materials. More importantly, the cell gap can be over 4μm for the π-BTN, thus making it compatible with STN manufacturing.

Figure 4 shows an example for the U and T state interchanging diagram. $\boldsymbol{v}_H$, is the waveform such that the frequency is higher than the cross over frequency of the DFLC. $\boldsymbol{v}_L$, is the waveform such that have lower frequency than $\boldsymbol{v}_c$. The transition of U and T has been carefully studied intensely previously [6-9]. There is modification of the transition such that there is a high frequency drive at U to T transition. The external high frequency electric field induced the electric displacement D in backflow direction, which indeed helps the U-T transition. In other words, it is possible to undertake U-T transition in more general conditions, such as large cell gap.

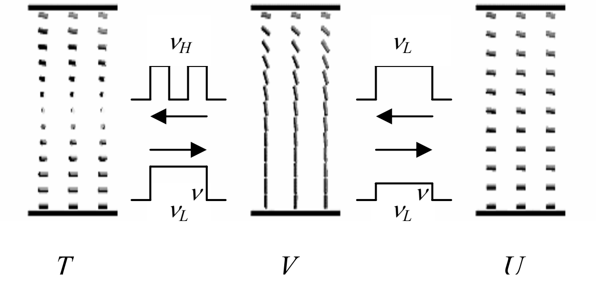

Figure 4. Transitions in the Dual Frequency Bistable Twisted Nematic Display

We have successfully fabricated a 16x16 DFBTN, Figure 5, in mode B [10] with 2.5μm cell gap. This cell gap is not the optimal for best optical properties. However we are limited by the choice of DF LC. The optical quality as well as the switching speed can be improved if better LCs can be found. We also confirmed the passive matrix driving schemes. By using such method we can handle the frequency modulation problems [11]. It is found that such a device can have good cross talk rejection properties and is ideal for dual frequency liquid crystal passive matrix display driving.

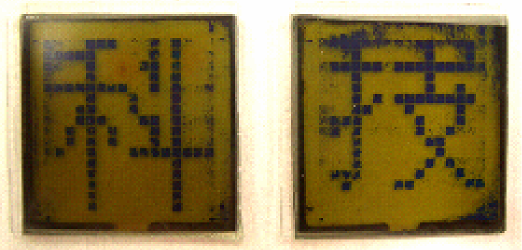

Figure 5. Pictures of bistable TN display.

5. Bistable bend twist display

The bistable bend-twist LCD is an interesting study in topological inequivalence. The bistable states are depicted on the unit sphere in Fig. 1. It can be seen that the twist state is also highly splayed, and the bend state is also somewhat twisted. The relative stability of the bend, splay and twist states depend strongly on the elastic constants. By using liquid crystal with suitable elastic constants, and by adjusting the d/P ratio, such as 0.75 to 1.3, and by having appropriately large pretilt angles, bistability can be achieved. In particular, it is possible to make the bend and 2π twisted states to have more or less equal elastic energy. Figure 6 shows a simulation of the elastic energy for bend and 2π twisted state under different boundary conditions. It shows that the elastic energy of bend and 2π twisted state are equal at pretilt angle of 70°.

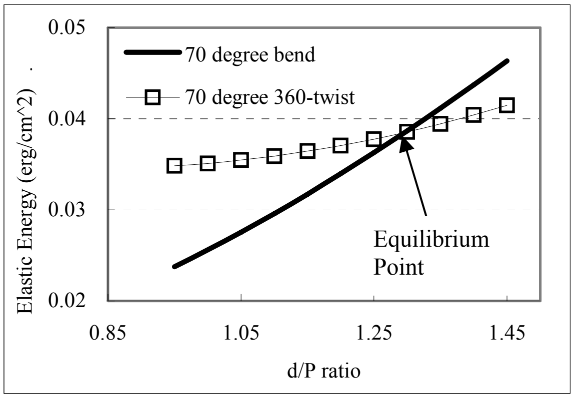

Figure 6. Elastic energy of bend and 2π twisted state at different d/P ratio

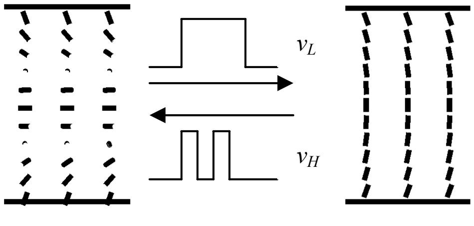

Figure 7. Transitions in the Dual Frequency Bistable Bend Twisted Nematic Display

The alignment surface for 70° pretilt angle is prepared by the polyimides H-V mixing technique [1]. The switching method is the same as DFBBS using a dual frequency LC. Fig. 7 shows that, when applying low frequency pulse, the dual frequency liquid crystal will exhibit positive dielectric anisotropy. It induces a twist to bend transition. On the other hand, when a high frequency pulse chains v_H is applied, a bend to twist transition will occur. It is because that the liquid crystal exhibits negative dielectric anisotropy.

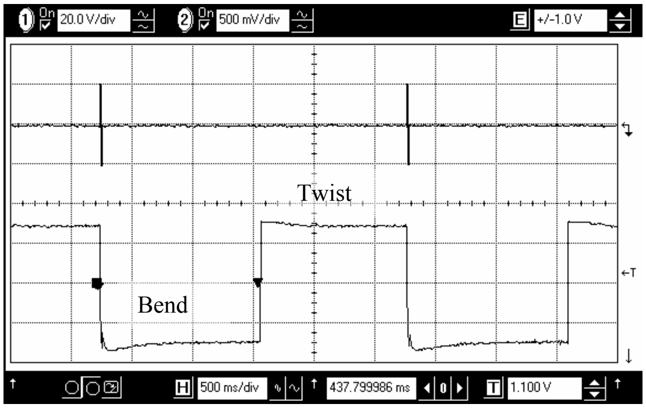

Figure 8. Switching behaviors of the BBT. Upper line is electrical pulse. Bottom line is the optical respond.

BBT switching is generally much faster than BTN and BBS. Fig. 8 shows the results for a 5μm cell gap sample. The upper line is the electrical pulse; the bottom line is the optical respond. The optical and electrical pulse switching time is summarized in Table 1. Comparing to the BBS with 1.5μm cell gap, the electrical pulse for Bend to Splay time at 20V is around 300ms (Figure 3). However, for the BBT, Bend to Twist electrical pulse chain only require 500μs. There is 600 times improvement on the switching speed.

	Bend to Twist	Twist to Bend
Optical Respond	<3.1ms	<7.4ms
Electrical Pulse	500μs @ 75KHz	2ms @ 500Hz

Table 1. Summery of switching properties of DFBBT

The slow switching in the BBS is because, for bend to splay switching, there is an intermediated twist state. This twist state is needed because the bend and splay states are topologically inequivalent. Therefore the B-S switching is much slower than S-B transition. For the case of BBT, the intermediate twisted state is a stable state. Therefore, the switching time can be enhanced.

6. Conclusion

We have shown three new kinds of bistable displays. Two of them require a high pretilt angle. All of them rely on a dual frequency liquid crystal for switching. However, dual frequency liquid crystals have several problems, such as small dielectric anisotropy, relatively high viscosity and temperature sensitivity. The crossover frequency of the liquid crystal can vary with temperature. That variation is described by the equation:

$$v_C = \exp\left(-\frac{E}{kT}\right) \quad (1)$$

where E is the activation energy.

Therefore, from 0^{O}C to 40^{O}C the crossover frequency v_C will have a ±10% change. In order to ensure the display function properly, it is required to select driving frequencies either far higher or far lower than the crossover frequency. This can avoid the temperature dependence problem of the display device.

Finally, we present a comparison of the three types of bistable displays for their relative merits. It can be seen that the BBT holds the most promise as far as switching speed and operating voltage is concerned. But it is more sensitive to the processing parameters. If we can improve the process window of the nano-structured alignment layer, BBT should provide the best opportunities.

	Voltage	Pretilt angle	Dopant	Cell Gap Sensitivity	Switching Time
BBS	Low	45^{o}	No	No	Slow
BTN	medium	Low	Yes	Yes	Medium
BBT	Low	$50\text{-}70^{o}$	Yes	Yes	Very Fast

Table 2. Comparsion of different bistable display devices.

Acknowledgements

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References

[1] F. S.Y. Yeung, F.-C. Xie, H. -S. Kwok, Jones Wan, Ophelia Tsui and Ping Sheng, *SID05 Digest*, Vol. **XXXVI**, pp. 1080-1083 (May, 2005).

[2] Julian Cheng and R. N. Thurston, J. Appl. Phys. 52, 2756 (1981).

[3] F. S. Yeung, Y. W. Li and H. S. Kwok, *SID05 Digest*, Vol. **XXXVI**, pp 1770-1773, (2005).

[4] F S Yeung, Feng Chao Xie, Hoi Sing Kwok, Jones Wan, Olphelia Tsui and Ping Sheng, Eurodisplay 2005, pp. 514-516 (Sept, 2005), F. S. Yeung and H. S. Kwok, *SID04 Digest,* Vol. **XXXV**, pp 878-881, (2004).

[5] I. Dozov, M. Nobili and G. Durand, Applied Physics Letters, **70**, pp 1179, (1997).

[6] I. Dozov, Ph. Martinot-Lagarde, E. Polossat, I. Lelidis, M. Giocondo and G. Durand, , Proceedings of SPIE **3015**, 61 (1997).

[7] C. Joubert et al., SID Intl Symp Digest Tech Papers, **33**, no. 1, pp. 30-33 (2002).

[8] Ph. Martinot-Lagarde, I. Dozov, E. Polossat, M. Giocondo, I. Lelidis, G. Durand, J. Angelé, B. Pecout and A. Boissier, SID Intl Symp Digest Tech Papers, **41** (1997).

[9] M. Giocondo, I. Lelidis, I. Dozov, G. Durand, Eur. Phys. J. AP 5, 227 (1999).

[10] S. T. Tang, H. W. Chiu, and H. S. Kwok J. App. Phys. **87**, 215 (2000).

[11] Fion S. Y. Yeung, Y. W. Li and H. S. Kwok, SID06 Digest.