Photoaligned Large Cell Gap Permanent Grayscale in Bistable TN Liquid Crystal Display

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ABSTRACT

Large cell gap permanent Bistable Twisted Nematic Liquid Crystal Display (π-BTN) using photo-alignment technology has been demonstrated. This display can be switched between ϕ and $\pi + \phi$ twisted states by means of a combination of in-plane electric field and vertical electric field for creating both polar anchoring breaking and an electro-hydrodynamic flow. Such device is cell gap independent. Permanent grayscales can be achieved by controlling the ratio of domains of the ϕ twisted and $\pi + \phi$ twisted states.

INTRODUCTION

In these few years, people have put great efforts in making the BTN truly bistable. Dozov et al[3,4,5]. developed a surface-controlled bistable nematic display (SCBN). The device consists of two states: U- and T- state. Few milliseconds electric pulses break the surface anchoring energy and activate the U- and T- transition. However, a high pretilt angle and a small cell gap are necessary to produce the bistability and switching between the 0 and π twisted states. Guo et al[6] developed a kind of three terminal bistable twisted nematic liquid crystal displays. Their structure solves the high pretilt angle and thin cell gap problem. However, their driving voltage is high and the electrodes are difficult to make.

In this article, we report a new structure of transmissive π-BTN. It is similar to SCBN, in the sense that their bistable twist states differs by 180^{O} in twist angle. However, our U-T transition is achieved using a new three terminals structure. Such device is cell gap independent. 2μm and 5μm π-BTN cell are successfully fabricated. The lifetimes of the two bistable states are infinite. The new configuration of electrodes is also easy to make. Normal STN drivers can accomplish the switching.

Furthermore, by carefully adjusting the driving voltage, we can control the creation and annihilation of twisted and un-twisted domain within the pixel when breaking the surface anchoring. Such mechanism results in producing an intrinsic permanent grayscale in the device.

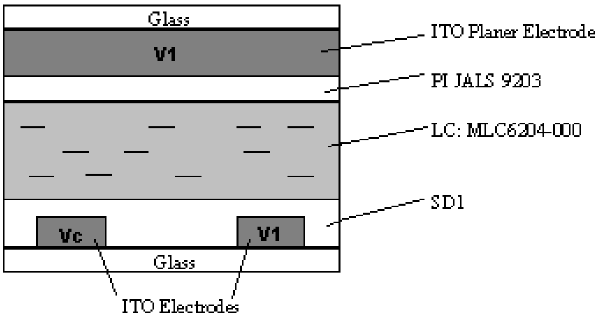

Fig.1 Cross Section of the π-BTN

EXPERIMENTS

The cells are made by two parallel transparent plates (Fig. 1), which contain the nematic liquid crystal MLC 6204-000 (from Merck) and a chiral additive S-811 (Merck). The concentration of S-811 is varied in order to adjust a proper ratio of the cell thickness to inherent pitch (d/P_o). The electrodes (V_1, V_2 and V_c) are thin transparent indium-tin-oxide (ITO) films deposed on the boundary glass plates. The upper glass substrate is coated with a commercial polyimide JALS-9203 with well- known pretilt angle 5-6 degrees. The lower glass substrate is a kind of photo-alignable polymer SD-1, such alignment layer provides 0~1 degrees pretilt angle and adjustable polar anchoring energy (from 6.5×10^{-4} to 1.8×10^{-3}J/m^2)[1,2]. The cell thickness can be varied between 2μm to 5μm.

Two stable states of the cells can be clearly distinguished by the birefringence effect in the system composed of the cells and polarizers. The input and output polarizer axes are angles of α and γ to the input director of the liquid crystal cell. The transmission of this optical system can be formulated as (1):

$$T = \left| \begin{pmatrix} \cos\gamma & \sin\gamma \end{pmatrix} \cdot M_{LC} \cdot \begin{pmatrix} \cos\alpha \\ \sin\alpha \end{pmatrix} \right|^2 \qquad (1)$$

where M_{LC} is the Jones matrix of the LC model. In our case, $\alpha=\pi/4$ and $\gamma=\alpha+\pi/2$.

RESULTS AND DISCUSSION

In order to prove the theoretical results, two transmissive π-BTN cells with different cell gap (2μm and 5μm) are fabricated as shown in Fig. 2 and Fig. 3. The experimental results closely matched with our simulated results.

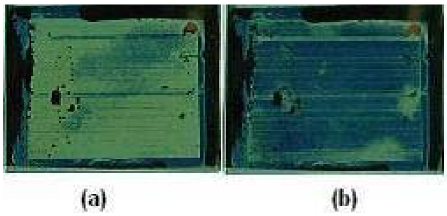
(a) (b)

Fig. 2 π-BTN cell with 2μm cell gap

The size of the cell is 15mm x 14mm (a) Low twisted state (b) High twisted state

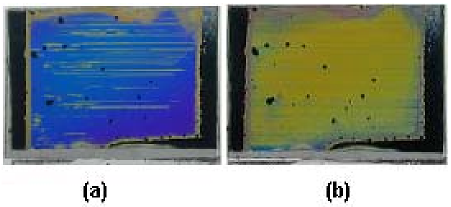
(a) (b)

Fig. 3 π-BTN cell with 5μm cell gap

The size of the cell is 15mm x 14mm (a) Low twisted state (b) High twisted state

The liquid crystal used for fabricating the π-BTN cells is MLC6204-000 with a birefringence Δn of 0.1487. The ideal d/p ratio, from a heuristic point of view, should be given by

$$\frac{d}{p} = \frac{90^o}{360^o} = 0.25 \qquad (2)$$

However, as the high twisted state usually has a higher elastic energy, the liquid crystal has to be doped in a way that the high twisted state is more favored. Therefore, a larger d/p ratio should be used in order to achieve bistability. In our case, we choose 0.295 as our d/p ratio

Fig. 4 shows the 2μm π-BTN cell measured and simulated spectrum at dark and bright states. The maximum contrast ratio is 131.8 (measured value) at wavelength 630nm.

Fig. 5 shows the 5μm cell measured and simulated spectrum at dark and bright states. The maximum contrast ratio is 45.2 (measured value) at wavelength 630nm. The contrast ratio can be further improved by optimized LP1 – LP2 switching. The details of the optimization can be referenced to another paper from Tang et al[7].

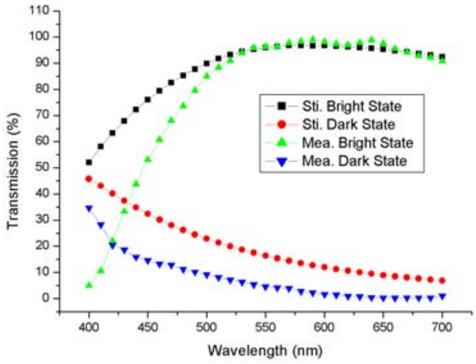

Fig. 4 Transmission spectrum of the π-BTN cell with 2μm cell gap

Fig. 6 and Fig. 7 demonstrated the switching behavior of the two π-BTN cells. It can be seen that both the on and off states show true bistability without any decay of transmittance for a long period of time. The driving voltage for 2μm cell is around 15V. And the driving voltage for 5μm cell is around 25V.

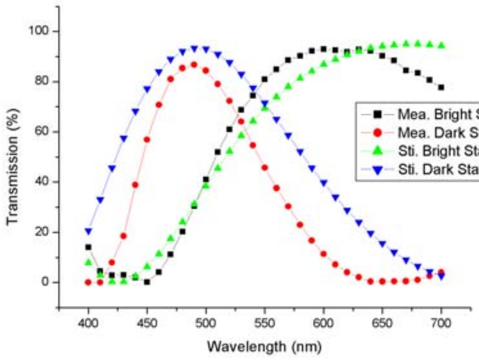

Fig. 5 **Transmission spectrum of the π-BTN cell with 5μm cell gap**

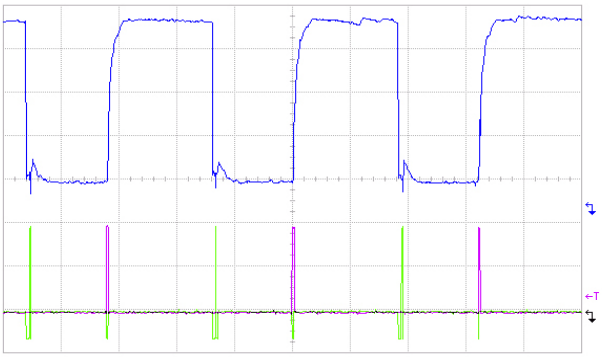

Fig. 6 **Switching Behavior of the π-BTN cell with 2μm cell gap.**

Top: Optical Response; Bottom: Switching pulses

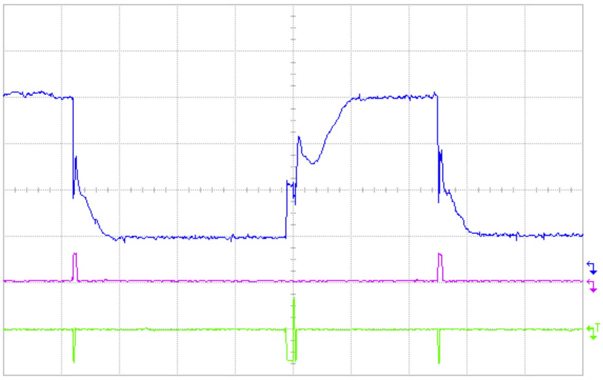

Fig. 7 **Switching Behavior of the π-BTN cell with 5μm cell gap.**

Top: Optical Response; Bottom: Switching pulses

The driving method is shown in Fig. 8. In the simplest case, V_c is kept constant, such as set to ground. The electrical pulse trains are applied to the others V_1, and V_2. When V_1 is ground and V_2 is applied either positive or negative, the electric field is in vertical direction. Such case will induce twisted state. When we apply electrical pulses to both electrodes V_1 and V_2 while V_1 have longer duration than V_2, we will induce two electric fields in different direction. Firstly it will be a vertical direction. Secondly, it will be a horizontal direction. Such pulse trains will favor the un-twisted alignment.

The electrically controllable grayscale in π-BTN cells are demonstrated in Fig. 9. By varying the V_1 from 0V to 15V, the density of dark state domains will gradually decrease while the bright state domains will increase in the pixel. The range of about 2V (9V to 11V) where, the ratio of the ϕ twisted and $\pi+\phi$ twisted states can be modulated to achieve a grayscale.

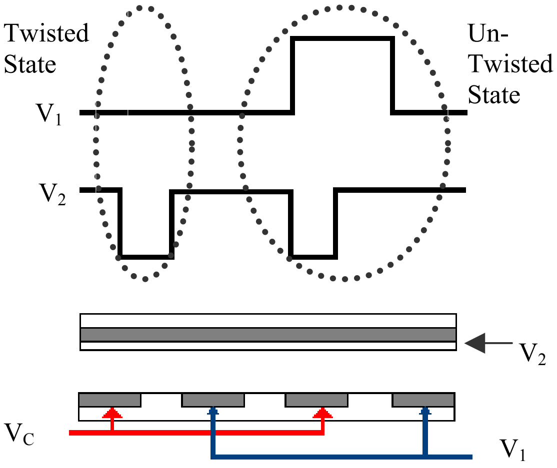

Fig. 8 **Driving Scheme.**

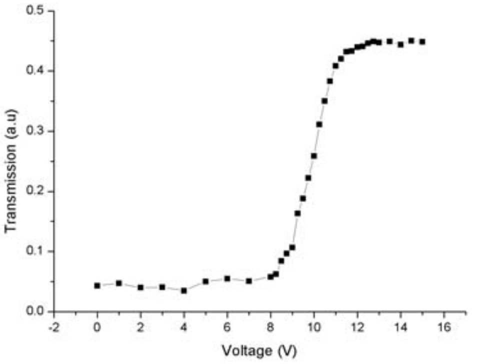

Fig. 9 Different permanent grayscales Behavior of the π-BTN cell with 2μm cell gap.

CONCLUSION

In this paper, a large cell gap permanent grayscale bistable LCD is demonstrated. More than sixteen grayscale levels have been achieved. It is an important milestone for the further development of color bistable display.

Furthermore, we believe truly bistable LCD devices have great potential to become the next generation of Liquid Crystal Displays. Such devices have several advantages such as high contrast, excellent viewing angles, low power consumption and permanent memory. As the thin cell gap problem has now been solved by our new structure, large-scale fabrication process now become practical.

ACKNOWLEDGEMENTS

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