P-130: Large-Cell-Gap Bistable TN-LCD Based on Dual-Frequency Operation

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Abstract

A bistable twisted nematic liquid crystal display based on dual frequency driving electronics has been demonstrated. By using special combinations of alignment layers and liquid crystals, bistability can be achieved readily with cell gaps as large as 5µm.

1. Introduction

Liquid crystal displays (LCDs) that are bistable under zero voltage bias conditions are desirable for many applications such as in low power displays and electronic-paper. There are many LCD configurations that are bistable and possess two stable states under no voltage conditions. Examples include bistable cholesteric LCD, bistable ferroelectric LCD, zenithal bistable display and bistable bend splay LCD. Each technology has its own merits and shortcomings.

Bistable twisted nematic (BTN) LCD can be either 2π-BTN or π-BTN. 2π-BTN is metastable while π-BTN is truly bistable. However π-BTN requires very small cell gaps of less than 2µm as well as asymmetric anchoring for switching. In this paper, we demonstrate a large cell gap BTN LCD by using a dual frequency LC. The low twist or high twist states can be achieved by the using of the alignment properties of the dual frequency LC and different driving frequencies. Similar to the other bistable devices, this BTN has excellent viewing angles and contrast ratios. It can be operated in a low driving voltage.

The application of dual frequency LC is not new. Last year, we reported a dual-frequency bistable bend-splay liquid crystal display using materials with a relatively low crossover frequency to allow switching between the bend and splay states [1]. Here, we demonstrate the use the same material to make a bistable TN-LCD that switches between two twist states. The cell gap of this BTN can be as large as 5µm. No special weak anchoring polymer [2] or photo-alignment layer [3] is required.

2. Asymmetric anchoring alignment layer

The switching of BTN depends critically on the polar anchoring energies of the alignment layers. The anchoring energy is a measure of how strong the anchoring condition is. If the anchoring energy is large, then it is difficult to deviate from the original rubbing condition and the alignment angles are given by the easy axis directions. For weak anchoring, the actual polar and azimuthal angles of the liquid crystals on the surface may deviate considerably from the easy axis. For π-BTN, asymmetric anchoring is needed. Surface anchoring breaking is an important part of the operation of the bistable twisted nematic display. We thus require that the alignment layers on the two sides of the liquid crystal cell be made with different materials, preferably polyimide alignment materials. In our experiment, the anchoring energies on the two glass surfaces are provided by two different PIs. One is strong while on the other surface the anchoring is weaker. For reliable switching, the difference in anchoring energy should be at least a factor of two. For example, one side may have a polar anchoring energy of $1.2x10^{-3}$ J/m^2, while the other may have an anchoring energy of $2.4x10^{-3}$ J/m^2.

Asymmetric anchoring is an important feature and has to be carefully designed in order to allow our bistable device to work properly. There are several methods of obtaining such asymmetric anchoring for the liquid crystal cell. The simplest method is making good use of ordinary polyimides. Polyimide is well known in its ability to align liquid crystal molecules by mechanical rubbing. A rubbed polyimide layer can induce an alignment direction and a pretilt angle in the order of 0-5 degrees. The anchoring energy of the polyimide is determined by the chemistry of the polyimide material. Thus it is possible to select different polyimides for the two surfaces of the liquid crystal cell so that there is asymmetric anchoring.

The rubbing directions of the top and bottom alignment layers determine the twist angle of the liquid crystal layer. The twist angle and retardation of the liquid crystal cell can be calculated in order to obtain bistability [4-7]. In our study, we use the values listed in Table I. The d/p ratio is used to control the bistability of the liquid crystal layer. This ratio has to be within the range of 0.5-0.6 in order for bistability to occur for the π-BTN display.

Parameter	Value	Units
Twist angle	22.5º, 202.5º	degrees
Polarizer angle	45º	degrees
Analyzer angle	67.5º	degrees
Cell gap – birefringence product	0.546	µm
d/p ratio	0.5625	

Table I. Specifications of the π-BTN LCD**.**

3. Dual frequency effect of LC

The driving method reported here is based on the dual frequency effect of liquid crystal. It has a positive dielectric anisotropy when the driving voltage is a low frequency AC signal of sinusoidal or pulsed type. It has a negative dielectric anisotropy when the

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driving voltage is a high frequency AC signal of sinusoidal or pulsed type. The crossover frequency of this dual frequency liquid crystal can be any value between 50 kHz to 500 kHz. The dependence of the dielectric anisotropy $\Delta\varepsilon$ on the operating frequency ν is shown in Fig. 1. Actually most liquid crystal materials exhibit this behavior, except that the crossover frequency may not be at the desired values. It is well known that liquid crystals having positive $\Delta\varepsilon$ will align themselves along the direction of the electric field. For liquid crystal with negative $\Delta\varepsilon$, they will align themselves perpendicular to the direction of the electric field due to the dielectric force. The general expression of the dielectric anisotropy is given by

$$\Delta\varepsilon = -\varepsilon_1 + \frac{\varepsilon_2}{1+\omega^2\tau^2} \qquad (1)$$

where ε_1 , ε_2 , and τ are parameters with positive values, and $\omega = 2\pi\nu$ where ν is the driving frequency. For $\varepsilon_2 > \varepsilon_1$, the dielectric anisotropy $\Delta\varepsilon$ is positive at low frequency and negative at high frequency. In our experiment, LC with critical frequency (ν_c) about 20 kHz is used.

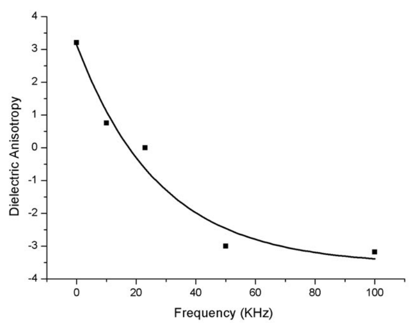

Figure 1. Relationships between Dielectric Anisotropy and Frequency

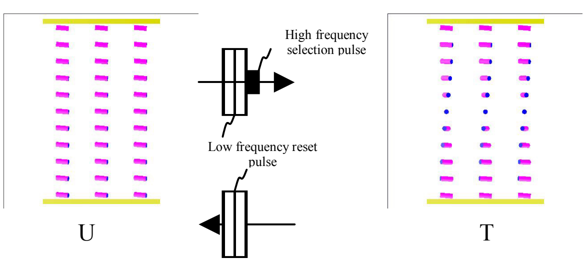

Figure 2. Driving waveform for low (U) and high twist (T) transition.

Figure 2 shows an example of the driving pulse of this bistable twisted nematic display. The driving scheme involves first a high voltage pulse that can reset the entire line into the homeotropic state (V). A selection pulse is then applied. If the selection pulse has a high frequency than ν_c, then the pixel will be switched to the high twist state (T). If the selection pulse has a lower frequency than ν_c , then the dielectric force is along the direction perpendicular to the liquid crystal cell, and the low twist state will be favored.

4. Multiplex driving Scheme

Figure 3 shows an example of the multiplex driving pulse of this BTN display. The driving scheme involves first a high voltage pulse that can set the entire line to the homeotropic state. A selection pulse is then applied.

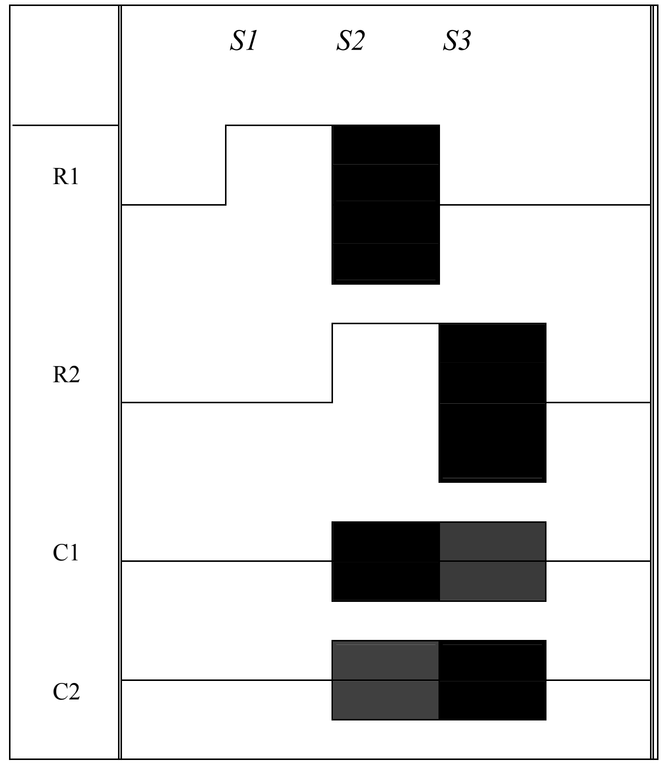

Figure 3. Example of multiplex driving scheme of BTN-LCD.

In the present example, a display device with resolution of 2x2 is assumed, as shown in Fig. 4. It consists of two rows **R1** and **R2** and two columns **C1** and **C2** and the pixels are labeled as **P1**, **P2**, **P3** and **P4**. The timeslots are labeled as **S1 S2** and **S3**. In the first timeslot **S1**, **R1** is in the reset phase. A high voltage is applied in order to set the entire row to homeotropic state **V**, **X** is an unknown state which can be either **U** or **T**. During the second timeslot **S2**, **R1** performs data writing. High frequency waveform is applied to **R1**, at the same time, an out of phase high frequency waveform is applied to column **C1. C2** is connected to an in phase high frequency waveform. At shown in Figure 4, pixel **P1** experiences high enough voltage to perform surface anchoring energy breaking and switch to high twist state. On the other hand, **P2** have a resultant pixel voltage lower than the threshold voltage of surface anchoring energy breaking, therefore it remains at the low twist state. In order to reduce the row scan time, a pipelining schedule can be designed. When **R1** is doing the data writing, **R2** is set to be in the reset phase at the same time. At the timeslot **S3**, **R2** performs data writing phase. According to the driving waveform of the columns, **C1** is in phase high frequency waveform and **C2** is out of phase high frequency waveform. Therefore, the pixels **P3** and **P4** are driven from homeotropic state to low twist and high twist state respectively.

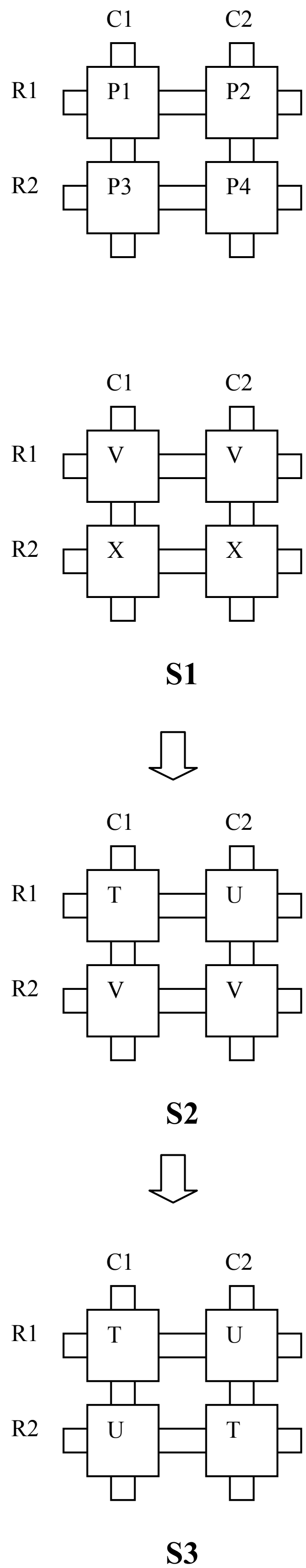

Figure 4. Resultant pixels appearance after the driving scheme applied.

For the case of N rows, the switching time T_u of the low twisted state requires is longer than that for the high twist state T_h. The critical time for the pipelining scheme is equal to switching time of the low twisted state. The frame time will become N*T_u. However, it is known that the fastest frame time for the pipelining scheme is N* T_h. In order to achieve this goal, more rows should be involved in the reset phase at the same time. The exact number of rows M should obey the following rules: Case 1, if T_u to T_h is smaller than N, then the fastest frame rate can be obtained by setting M to the ratio of the switching time of low twist state and high twist state. Case 2, if the ratio of them is bigger than N, this implies that whole screen should be reset before the data writing phase for each row.

Case 1:

$$\text{If } \frac{T_u}{T_h} < N \quad \rightarrow \quad M = \frac{T_u}{T_h}$$

Case 2:

$$\text{If } \frac{T_u}{T_h} \geq N \quad \rightarrow \quad M = N$$

5. Experimental result

To confirm the theoretical results, a 16x16 passive matrix transmissive BTN with a 2.5μm cell gap was fabricated. This cell gap is used because the birefringence of the LC used is too large. Larger cell gaps can be used presumably if the birefringence is smaller. The switched display is shown in Figure 5. It shows permanent bistability with no decay of transmittance for a long period of time. The defects are due to cell gap non-uniformity.

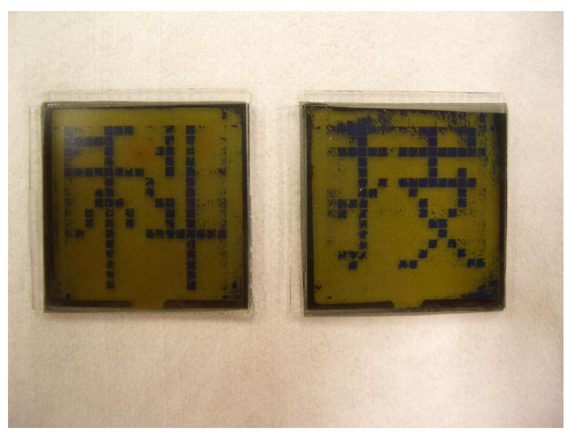

Figure 5. Bistable pattern shows permanent bistability.

6. Conclusion

In this paper, a bistable twisted nematic display using dual frequency liquid crystal is demonstrated. Passive multiplex driving of this display is possible. Such a display has excellent viewing angles and contrast ratios. Switching can be obtained at large cell gap such as 5µm.

Acknowledgements

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References

[1] F. S. Y. Yeung, Y. W. Li and H. S. Kwok, *SID Symposium Digest*, Vol. **36**. pp. 1770-1773, 2005.

[2] I. Dozov, M. Nobili and G. Durand, *Appl. Phys. Lett.*, **70**, pp. 1179, 1997.

[3] F. S. Y. Yeung and H. S. Kwok, *SID Symposium Digest*, Vol. **35**. pp. 878-881, 2004.

[4] H. S. Kwok, *J. Appl. Phys.*, **80**, pp. 3687, 1996.

[5] T. Z. Qian, Z. L. Xie, H. S. Kwok and P. Sheng, *Appl. Phys. Lett.*, **71**, pp. 596, 1997.

[6] Z. L. Xie and H. S. Kwok, *Jpn. J. Appl. Phys.*, **37**, pp. 2572, 1998.

[7] Z. L. Xie and H. S. Kwok, *J. Appl. Phys.*, **84**, pp. 77, 1998.