62.2: Dual-Frequency Bistable Bend-Splay LCDs

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Abstract
A bistable liquid crystal display based on the bend and splay configurations has been demonstrated using dual frequency liquid crystal. Unlike the previous three-electrode version, only two regular electrodes are needed in the present case. We also propose and demonstrate a convenient multiplex driving scheme for a BBS matrix display.

1. Introduction

There is much effort currently on making liquid crystal displays that are permanently bistable. Applications include all low power displays and in e-paper and e-book. Several bistable display technologies have been demonstrated, for example the bistable cholesteric display, bistable twisted nematic displays, zenithal bistability and ferroelectric liquid crystal displays. Non-liquid crystal bistable displays have also been demonstrate using electrophoretic effects. Each technology has its own merits and unique applications.

Last year, our group demonstrated a bistable bend-splay (BBS) device [1]. The bend state and the splay state are equally stable under some alignment conditions of the liquid crystal display. However in order to switch this device, a three electrodes structure is needed to provide the vertical and horizontal electric fields. The structure consists of top and interdigital bottom electrodes. The interdigital electrodes were 4μm wide and separated by 6μm. Unfortunately, such three electrodes structures are not desirable for mass production. As well, the driving electronics circuitry can be quite complicated.

In this paper, we demonstrate a new bistable bend splay LCD that requires only a set of ordinary top and bottom electrodes. Switching is based on the use of a dual frequency liquid crystal which can exhibit positive as well as negative dielectric anisotropy depending on the drive frequency. Thus the bend or splay state can be achieved by applying voltage pulses of different driving frequencies. The construction of this BBS is otherwise exactly the same as in conventional LCD. Similar to the three-terminal electrodes device, this BBS has excellent viewing angles and contrast ratios, lower operating voltages than the other bistable displays based on the twisted nematic effect.

The application of dual frequency LC is not new. Almost all nematic liquid crystal material exhibits some dual-frequency behavior, a change in the sign of the dielectric anisotropy with changing frequency of the applied voltage. However, the crossover frequency f_c is often very large, such as greater than 100kHz. In this paper, we use a commercial dual-frequency liquid crystal material. Such liquid crystal has a relatively low crossover frequency and large negative dielectric anisotropy. It allows switching between two bistable states conveniently. We demonstrate simple matrix driving of this BBS. This BBS can compete well in terms of quality of the display and ease of driving with other bistable devices.

2. Theory and Experiments

Assuming that the boundary conditions of an untwisted liquid crystal cell are $\theta(0)=\alpha$ and $\theta(d)=-\alpha$. If the splay and bend elastic constants are the same, then the following two polar angle distributions in the LCD hold.

$$\theta(z)=\alpha\left(1-\frac{2z}{d}\right), \tag{1a}$$

$$\theta(z)=\alpha+(\pi-2\alpha)\frac{z}{d} \tag{1b}$$

Equation (1a) represent splay cell and (1b) represent bend cell.

It is well understood that the elastic energy per unit wall area of an untwisted LC is:

$$E=\frac{1}{2}\int_0^d\left(K_{11}\cos^2\theta+K_{33}\sin^2\theta\right)\dot{\theta}^2\,dz \tag{2}$$

where K_{11} is splay elastic constant, K_{33} is the bend elastic constant and d is the thickness of the LCD. For the symmetric boundary condition, if the splay and bend cells have the same elastic energy. The following equation can be derived

$$(K_{33}-K_{11})\sin 2\alpha+(\pi-4\alpha)(K_{33}+K_{11})=0 \tag{3}$$

By solving this equation, we can obtain a pretilt angle that bistability will occur. Usually, the pretilt angle lies between 45° and 58° for all values of K_{33}/K_{11}.

The large pretilt angle that is required for bend-splay bistability can be obtained in several ways, such as polyimide rubbing [2,3], photoalignment [4,5] and SiO_2 evaporation can be used to produce large pretilt angles [1]. In our present demonstrated BBS LCD, newly invented nano-structured alignment surfaces are used [7]. Unlike the previous demonstration using SiO_2 evaporation, this

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new alignment method is compatible with conventional manufacturing techniques for mass production.

The method to achieve precisely controlled high pretilt angles is by the use of nano-domains of vertical and horizontal alignment. These nano-domains and nano-structures are achieved by controlled phase separation in a homogeneous solution of the two types of alignment materials. Experimentally, horizontal and vertical polyimides are dissolved in special solvents that allow them to mix together. The mixture is then applied to form a liquid layer on the glass substrate. Controlled drying and curing will then generate the nano-texture necessary for generating the high pretilt angles. This process is very repeatable and reliable. It is also very robust and thermally stable.

The basic cell structure of our dual frequency bistable bend splay liquid crystal display is shown in Figure 1. Only two ordinary ITO electrodes are used. The cell is filled with a commercial dual frequency liquid crystal from Merck.

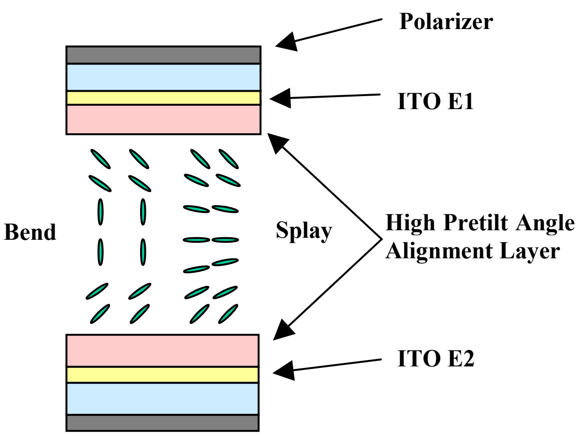

Figure 1. The basic cell structure.

3. Driving Methods

The driving method is based on the dual frequency effect of liquid crystal [6]. When the driving frequency is lower than cross over frequency, the dielectric anisotropy of the liquid crystal is positive, and vice versa. Actually most LC exhibit this effect. However the cross over frequency is usually quite high, at hundreds of kHz. We performed a measurement of the dielectric anisotropy of several LC. The relationship between dielectric anisotropy and frequency for the LC we used is shown in Fig. 2. The cross over frequency is about 20 kHz. This is an acceptable value for the construction of driver circuits.

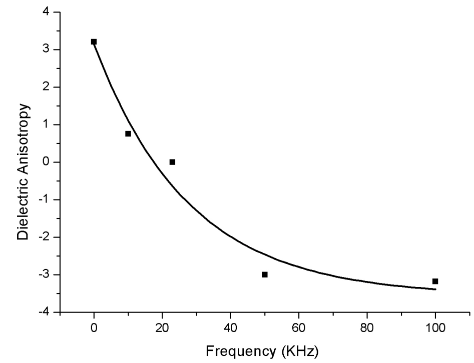

Figure 2. Relationships between dielectric anisotropy and frequency.

The mechanism of driving is straightforward. Fig. 3 shows the schematics. When a low frequency driving waveform is applied, the LC will exhibit positive dielectric anisotropy. The LC molecule will therefore align parallel to the electric field. Thus the LC alignment configuration will become a bend state. When a high frequency waveform is applied, the LC at the middle of the cell will exhibit negative dielectric anisotropy and will tend to align themselves to the electric field perpendicularly. Thus the splay configuration can be obtained.

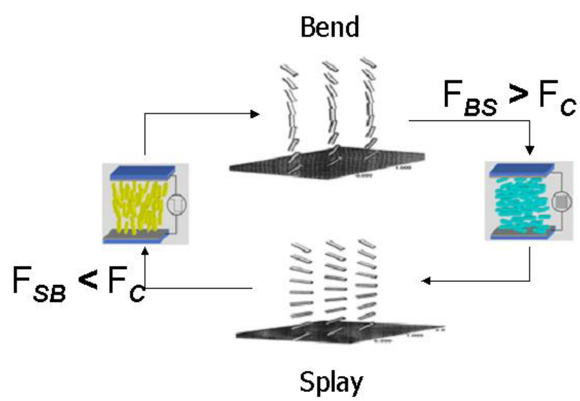

Figure 3. Driving method for bend transition.

4. Results

To confirm the theoretical results, a transmissive BBS with 1.5µm cell gap was fabricated. The optical birefringence is 0.23. The switched display is shown in Fig. 4. It shows permanent bistability with no decay of transmittance for a long period of time. The top five pictures show the various viewing angle of this display. The bottom two pictures demonstrate the on (bend) and off (splay) states of this display.

Figure 4. Bistable pattern shows permanent bistability and excellent viewing angles.

From Figure 4, we find that the viewing angle of the cell is quite good and the Bend and Splay can be swatch back and forth.

The dual-Frequency BBS cell behaves as a typical ECB cell. Thus the optical performance can be optimized easily. The bend and splay state director alignment can be calculated easily. By setting the polarizer and analyzer to +45 degrees and –45 degrees respectively, the transmission is given by:

$$T = \frac{1}{2}\sin^2\left(\frac{\Gamma}{2}\right) \qquad (4)$$

where Γ is the retardation of the LC cell and given by:

$$\Gamma = \frac{2\pi}{\lambda}\int_0^d \left(n_e(\theta,\lambda) - n_o(\lambda)\right)dz \qquad (5)$$

The simulation transmission spectra and the experimental results are shown in Fig. 5. It can be seen that the agreement is very good. The measured contrast ratio of the cell is 42. It can be further improved to 200 theoretically [8] by adding suitable half wave plate between the polarizer and the cell.

5. Passive matrix driving

For Passive Matrix driving, we can use a simple scheme as shown in Fig. 6. For simplicity let us use a 2x2 pixels display as an example. There are two rows R1 and R2 and two columns C1 and C2. Different from normal STN passive matrix driving method, we suggest that divide the row scan selection pulse into two phases. The first phase is the reset phase; one of row electrodes will apply high frequency high voltage reset pulse. Therefore the whole selected row will be reset to splay state at the shortest time. For the second phase, the data-write phase, same row electrode will apply low frequency selection pulse. And only those column-selected pixels will switch to bend state. The other pixels will remain at splay state.

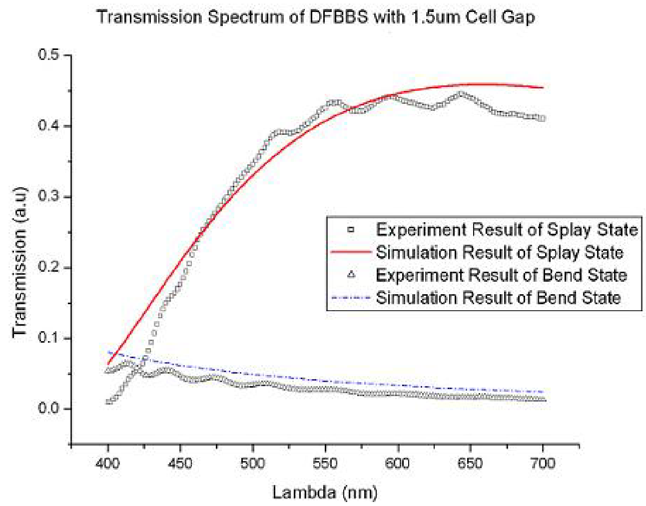

Figure 5. Transmission spectrum of bend and splay state. The maximum contrast is 42 at 638nm.

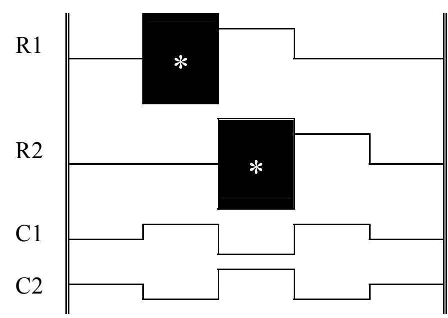

Figure 6. Driving waveform of the 2x2 pixels. R1 and R2 is the row scan waveform, C1 and C2 is the column waveform. Waveform with asterisk is high frequency waveform.

In Figure 6, firstly, R1 applies a high frequency high voltage waveform, therefore the two pixels P1 and P2 will switch to the splay state. After that, R1 applies a low frequency waveform. According to the resultant waveform of R1 - C1 and R1 - C2, only P1 experience high enough voltage to switch back to bend state but P2 remains in the splay state. The driving is repeated at R2 again, and only P4 will be switched back to bend state this time. Moreover, it can be noticed that the reset phase of R2 overlaps with the data-write phase of R1. Such a pipeline scheme is able to reduce the driving time of each frame. Fig. 7 demonstrates the state of pixels (P1, P2, P3 and P4) after one frame of passive matrix driving shown in Fig. 6.

	C1	C2
R1	P1 (B)	P2 (S)
R2	P3 (S)	P4 (B)

Figure 7. The final states of the 2x2 matrix display (P1, P2, P3 and P4) using the driving waveforms of Fig. 6. B –Bend State, S – Splay State

6. Conclusions

In this paper, a bistable bend splay display using dual frequency liquid crystal is demonstrated. Switching can take place with only 2 electrodes. It solves the complexity issue of the previous three-terminal device. Such a display has excellent viewing angles and contrast ratios. It operates in a lower voltage than the other bistable displays based on the twisted nematic effects. It should also exhibit fast switching. It is estimated that the row switching pulse can be below 1ms. Thus a high information content matrix display is possible.

7. Acknowledgements

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