67.2: Permanent Bistable Twisted Nematic Displays using Bi-directional Alignment Surface

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Abstract

A new bi-directional alignment surface is developed. Such alignment surface can be used to control the backflow direction of the liquid crystal. Base on this new alignment layer, a bistable twisted nematic LCD which switches between U and T states without surface anchoring energy breaking has been fabricated successfully.

1. Introduction

Bistable twisted nematic (BTN) liquid crystal displays with permanent memory is one of the important zero power displays. It can be stabilized in either the α or α+180° twist states without any biasing voltage applied. Numerous reports [1,2] have already shown their excellent optical performance i.e. very high contrast ratio >50, and very wide viewing angle >160°. Those attractive features make BTN displays an ideal solution for a lot of outdoor applications, i.e. advertisement board, e-paper.

However, those bistable displays are difficult to switch. Dozov et al [3,4] teaches a variant of the BTN display , called BiNem, where the bistable twist states are U state at 0° and T state at 180° respectively. He suggested that inter-switching of U and T states can be achieved by surface anchoring breaking. Such phenomenon is accomplished by high electric field and weak polar anchoring alignment. From the previous studies, weak polar anchoring has to be as weak as <1mJ/cm^2 and very thin cell gaps, i.e. 1.5μm is required. Obviously, the processing windows of manufacturing is small and this has limited its commercialization effort.

In this paper, a new switching mechanism for the BTN without any polar anchoring energy breaking is proposed. The inter-switching of U and T states is based on the different backflow directions of liquid crystal and is controlled by the voltage levels. Such mechanism can be produced by a bi-directional alignment surface. A prototype display by using this new mechanism with cell gap at 2.5μm is successfully fabricated.

2. Bi-directional Alignment Surface

The structure of the proposed liquid crystal display is shown in Figure 1. The upper ITO glass substrate is coated with a polyimide alignment layer JALS-9203 from JSR Corporation. It generates a tilt angle at 8° after mechanical rubbing. A photo-alignment material for liquid crystals from ROLIC Technologies called ROP-103 is applied on the bottom ITO glass substrate.

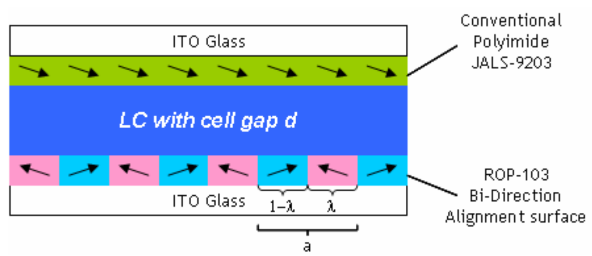

Figure 1. Overview of the proposed cell structure. The arrows show the corresponding tilt directions for the conventional polyimide JALS-9203 (top substrate) and ROP-103 Bi-directional Alignment surface (bottom surface)

The ROP-103 is a linearly photo-polymerizable polymer (LPP) which can be photo-patternable. The photosensitivity of the ROP-103 is at the range of 280nm to 340nm. It can withstand high temperatures, high humidity and eliminate mechanical brushing. No scratches, dust and electrostatic charges as compared to brushing and therefore higher yield and production throughput. By using such features, it is possible to obtain two opposite alignment directions –θ and +θ with the domain size $a(1\text{-}\lambda)$ and $a\lambda$ respectively where $\lambda \approx 0.5$ and $a \approx 2d$. The steps of preparation of the bi-directional alignment surface are shown in Figure 2. During the first step linearly polarized UV (LPUV) exposure, the sample is tilted by α≈45º for defining the direction of the tilt angle θ≈0.5º of the liquid crystal. A mask is needed for the first step LPUV exposure to avoid the unwanted exposure in the area of another tilt direction. At the second step LPUV exposure, the mask is removed since once the polymer is polymerized, the pattern will become stable and not rewriteable anymore. Furthermore, the sample is tilted by -α≈-45º for generating the tilt angle -θ≈-0.5º of the liquid crystal.

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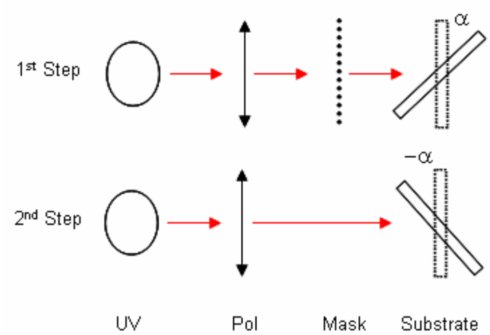

Figure 2. The preparation procedures for the bi-directional alignment surface.

Such alignment configuration results in obtaining splay configurations and ordinary homogenous configurations array within the liquid crystal bulk. The detailed simulated liquid crystal configuration is illustrated in Figure 3.

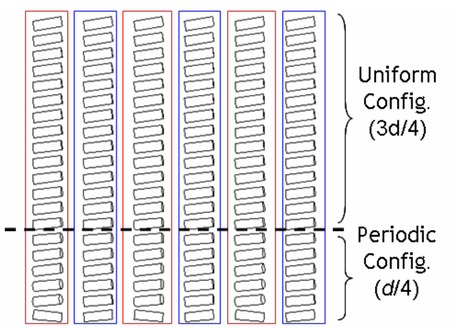

Figure 3. The liquid crystal configuration inside the liquid crystal bulk, splay configurations (red box) and homogenous configurations (blue box).

It is found that the periodic configuration is about d/4 of the cell gap d from the bottom bi-directional alignment surface. Such periodic configuration is the core controlling unit for our proposed switching mechanism.

3. Simulation Results of Backflow Directions

It is well-known that, backflow effect can be controlled by voltage. Normally, higher backflow effect, higher voltage is required. On the other hand, the backflow direction is governed by the boundary alignment direction. According to the continuum theory of Ericksen [5] and Leslie [6], the equations of motion for nematic liquid crystals are

$$\rho \dot{\upsilon}_i = F_i + \sigma_{ji,j} \tag{1}$$

$$\rho_1 \ddot{n}_i = G_i + g_i + \pi_{ji,j} \tag{2}$$

where i and j denote x, y, or z components, the subscript j preceded by a comma denotes differentiation with respect to the j-th coordinate, and summation over repeated indices must be carried out. Equations (1) – (2) express the balance of forces acting on the director, and the incompressibility of the liquid, respectively. Here ρ is the fluid density, υ_i is the fluid velocity, F_i is the body force (for example, due to gravitation), σ_{ji} is the i-th component of the surface force acting at the x_j plane, ρ_1 is the moment of inertia per unit volume associated with the director, n_i is the (dimensionless) unit vector denoting the average molecular orientation (director), G_i is the external body torque, g_i is the internal body torque, and π_{ji} is the i-th component of the surface torque across the x_j plane. Equations (1) – (2) can be solved by numerical method [7] and related to the Leslie viscosity coefficients, α_i, where i = 1, 2, 3, 4, 5 and 6.

According to our configurations, there are two opposite backflow directions induced by splay and ordinary homogenous configurations near the bottom of the bi-directional alignment surface. Their strength can be modulated by the voltage applied. Figure 4 and 5 show the corresponding numerical simulation results of U to T and T to U transactions respectively. If we applied a high voltage, i.e. 25V across the 3μm cell, the backflow induced by splay configurations will overcome its opponent homogenous configuration (red box), and the bulk liquid crystal system is driven to 180° twisted state as shown in Figure 4.

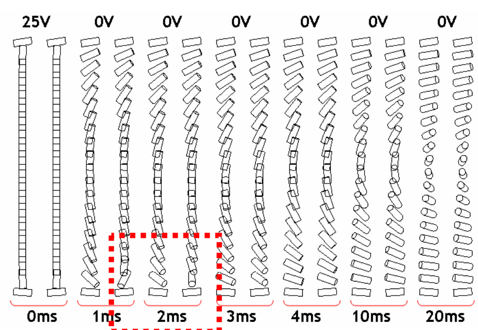

Figure 4. U to T transaction (0ms to 20ms).

On the other hand, if a low voltage is applied such as 15V, the backflow induced by splay configuration is weaker than those induced by homogenous configurations (blue box). The homogenous configurations induced backflow will dominate the liquid crystal relaxation. The bulk liquid crystal system therefore, switches to U states finally as shown in Figure 5.

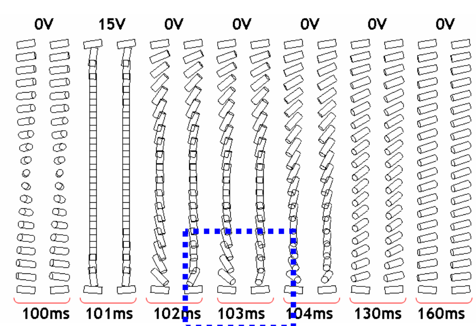

Figure 5. T to U transaction (100ms to 160ms).

Figure 6 shows the corresponding optical response of the proposed cell structure. The simulation parameters of the liquid crystal system are summarized at Table 1.

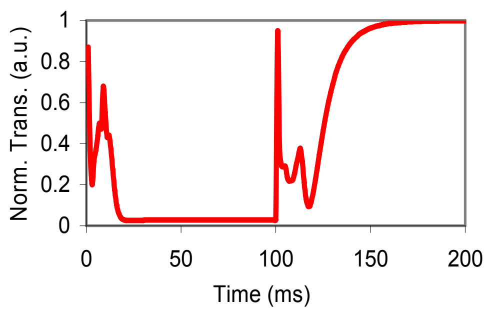

Figure 6. Optical response of the corresponding driving waveform proposed in Figure 4 and 5.

Table 1. Simulation Parameters

Cell gap	3μm
Upper alignment pretilt angle	8°
Lower alignment pretilt angle	±0.5°
α_1	$6.5x10^{-3}$
α_2	$-79.5x10^{-3}$
α_3	$-1.2x10^{-3}$
α_4	$83.2x10^{-3}$
α_5	$46.3x10^{-3}$
α_6	$-34.4x10^{-3}$

4. Passive Driving Scheme

Figure 7 shows the transmission voltage curve of the proposed BTN display. The liquid crystal used here is MLC-6204-000 with Δn=0.1478. It can be seen that when the applied voltage below 20V, the cell will switch to the untwisted U state and appear bright. However, for voltage larger than 20V, the backflow induced by splay configurations become dominate. Hence, the cell starts to switch to the twisted T state and appear dark. For voltage levels below 10V, which is the Freedericksz transition threshold voltage, the cell will be unchanged.

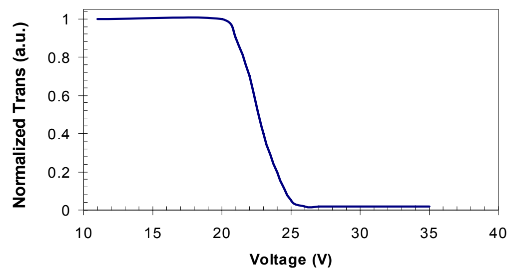

Figure 7. Transmission voltage curve of the proposed driving scheme.

In the present example, a display with resolution of 2x2 is assumed, as shown in Figure 8. It consists of two rows R1 and R2 and two columns C1 and C2. The pixels are labeled as P1, P2, P3 and P4. The timeslots are labeled as S1, S2, S3 and S4.

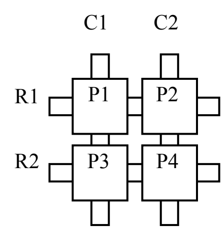

Figure 8. A sample 2x2 display for illustrating the passive driving scheme.

Figure 9 shows an example of the passive driving pulse of this BTN display. In the first timeslot S1, an in phase low voltage is applied to both R1, C1 and C2, in order to set the entire row P1 and P2 to U states. At the same time, an out phase low voltage is applied to R2 to eliminate the crosstalk effect on P3 and P4. X is an unknown state, which can be either U or T state. In the second timeslot S2, similar to timeslot S1, entire R2 has been set to U states. Now, the entire display is in U states and should appear white. During the timeslot S3, an out phase high voltage is applied to R1 and C1 respectively. Pixel P1 will experience high enough voltage to switch to T state. While a out phase low voltage is applied to C2, pixel P2 will experience a lower voltage level compare to P1, hence it will remain in U state. An out phase voltage is also applied to R2, the voltage levels should be carefully adjusted to eliminate the crosstalk effect, in order to keep P3 and P4 in U states. At the timeslot S4, again, similar to S3, an out phase high voltage is applied to R2 and C2 respectively, such that P4 will switch to T state because of the high voltage levels and P3 will remain at U state. In the meantime, a voltage is applied to R1 in order to keep P1 and P2 unaffected. Figure 10 shows the resultant pixels appearance after the driving scheme is applied.

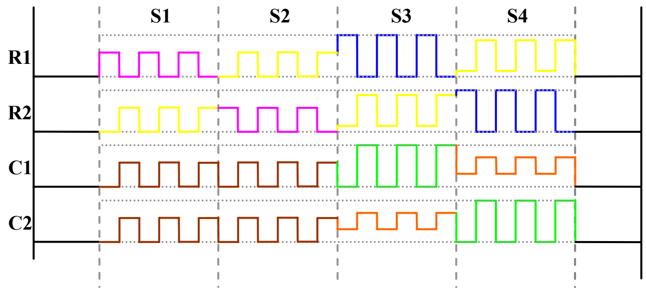

Figure 9. Example of passive driving scheme.

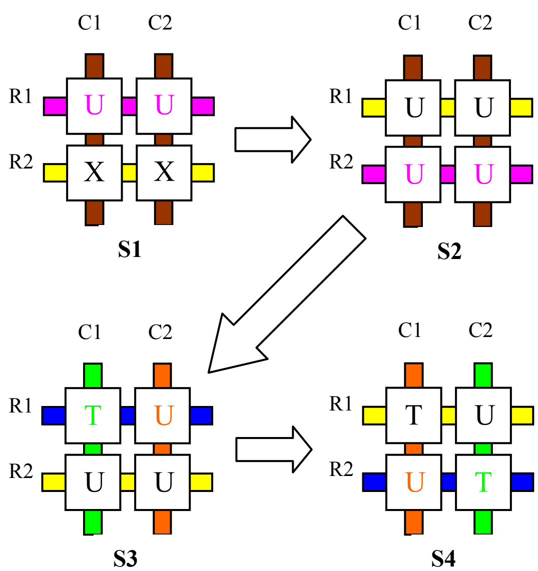

Figure 10. Resultant pixels appearance after the driving scheme applied.

5. Experimental Results

In order to verify the simulation results, a 64x64 passively addressing device using our proposed structure is fabricated successfully. The prototype is shown in Figure 11. The cell gap of the prototype is 2.5μm and is filled by commercial liquid crystal MLC-6204-000 with Δn=0.1478 from Merck. The polarizer and analyzer can be further optimized at 22.5° and -67.5° respectively [8] to give perfect optical properties. It shows permanent bistability with no decay of transmittance for a long period of time.

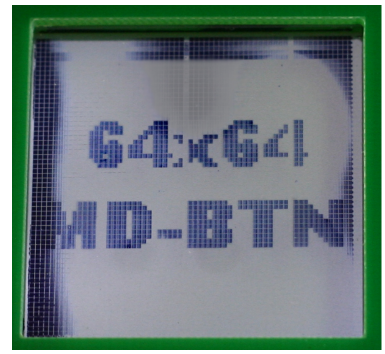

Figure 11. A 64x64 prototype .display using proposed cell structure.

6. Conclusion

In this paper, a new switching mechanism for bistable nematic twisted displays is proposed. By using the bi-directional alignment surface, which is fabricated by a photo-polymerizable polymer, different backflow directions can be controlled by changing the voltage levels. Such switching avoids any anchoring breaking, hence large cell gap can be made possible. All materials involved are commercially available. Furthermore, since the switching depends on the voltage level, it is completely compatible with ordinary low cost STN drivers.

7. Acknowledgement

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8. References

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