22.2: Photoaligned Transmissive Bistable TN-LCD

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Abstract

Transmissive bistable twisted nematic liquid crystal display has been fabricated using photoalignment. This display can be switched by breaking of the anchoring on one of the substrates. The application of a new photo-alignable polymer SDA-1 was able to achieve the weak polar anchoring condition necessary for switching.

1.   Introduction

Bistable twisted nematic (BTN) liquid crystal displays (LCDs) traditionally have bistable twisted states that differ in twist angle by 2π. [1,2] The bistable twist states are ϕ and $\phi+2\pi$, where ϕ can be varied to optimize the optical properties of the BTN displays. [3] We called these BTN displays 2π-BTN. Unfortunately, the ϕ and $\phi+2\pi$ states are metastable as there is always an intermediate twisted state of $\phi+\pi$ that is more stable. So, the 2π-BTN has not been useful.

Recently, Dozov *et al*. [4,5] demonstrated 0 and π twisted states switching by a combination of strong and weak surface anchoring. We called this type of BTN displays π-BTN. They are truly bistable since there is no stable intermediate twist state which is more stable in between. However, the Dozov's π-BTN is more difficult to make than the ordinary 2π-BTN because asymmetric anchoring is necessary for switching. They need a special alignment layers, such as SiO_x evaporation with high pretilt angles.

In this paper, we report the fabrication of transmissive π-BTN LCD using a photoalaignable polymer SDA-1. We generalized the π-BTN to the case of ϕ and $\phi+\pi$ bistability, where ϕ can be used to optimize the optical properties of the π-BTN. [6] We also investigated the fabrication tolerance of such π-BTN. It will be shown that both the cell gap and the polar anchoring energy of the photo-alignable polymer SDA-1 are the most important factor in obtaining bistability.

2.   Polar Anchoring Energy

The bistability of π-BTN is based on symmetric anchoring of the liquid crystal (LC) cell. One side of the cell has to be strongly anchored while the other side has to be weakly anchored. However, the anchoring energy cannot be too small, otherwise there will be no alignment and no stable twist state at all.

The strong anchoring aligning surface is achieved by the usual rubbed polyimide (PI) layer with low pretilt angle. Such a PI layer provides a strong polar anchoring energy of $1.5 \times 10^{-3} J/m^2$ and a pretilt angle of 5 degree. [7]

In order to achieve weak anchoring surface, we make good use of the recent photoalignment technology. Recently, Skarp *et al*. [8] reported the use of photoaligned layer to achieve weak anchoring. We have also experimented with many different kinds of alignment layers in order to achieve asymmetric anchoring.. Certainly, photoalignment is one of the easiest way to achieve our required asymmetric anchoring in making the π-BTN.

A new polymer, SDA-1, has been developed. [9,10] Its formula is shown in Figure 1.
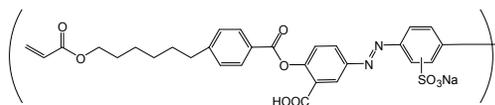
Figure 1. Polymerizable azo dye SDA-1.

The anchoring energy of this polymer can be adjusted from a high value of $8.5 \times 10^{-4} J/m^2$ to smaller values by changing the UV exposure time and polymerization time as shown in Figure 2 and 3.
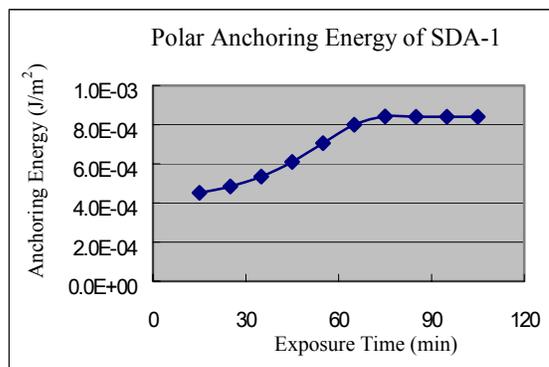
Figure 2. Dependence of Anchoring Energy on Exposure time. (Polymerization time was kept at 60 minutes)

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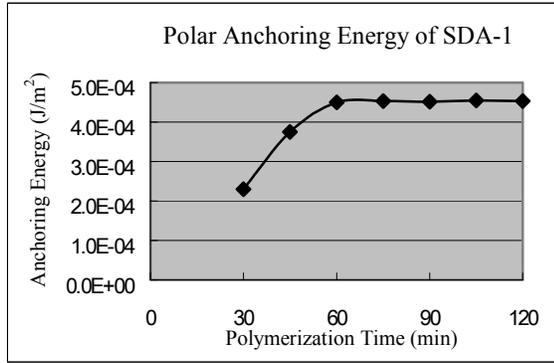
Figure 3. Dependence of Anchoring Energy on Polymerization time. (Exposure time was kept at 15 minutes)

By carefully adjusting the exposure time and polymerization time to 15 minutes and 60 minutes respectively, we achieved an anchoring energy of 4.5×10^{-4} J/m^2 which was suitable for obtaining π-BTN bistability. All the polar anchoring energies were measured using a method we recently developed. [7] It was found that the polar anchoring energy was related to both the UV exposure time and polymerization time. If the exposure time was less than 15 minutes or the polymerization time was less than 30 minutes, the liquid crystal was not properly aligned.

3.   Optimization Design of Transmissive π-BTN

To optimize the transmittance of both twist states, Mueller Matrix calculus with Strokes vectors approach is applied. [11] π-BTN has a twist state condition $\phi_2 = \phi_1 + \pi$. The first five optimized optical modes for transmissive π-BTN are shown in Table 1. We choose α=45˚ as the angle of the linearly polarized input light and γ as the angle of the linearly polarized output light.

Optical Mode	dΔn (μm)	ϕ_1	ϕ_2	γ
A	0.266	-22.5	157.5	-67.5
B	0.546	22.5	202.5	67.5
C	0.799	67.5	247.5	22.5
D	1.045	112.5	292.5	-22.5
E	1.288	157.5	337.5	-67.5

Table 1. The first five optimized optical modes for transmissive π-BTN.

4.   Experimental Results

To confirm the theoretical results, a transmissive π-BTN cell with 1.5μm cell gap and φ = -22.5 was fabricated as shown in Figure 4. To realize bistable switching, one substrate was coated with photosensitive polymer SDA-1 to achieve anchor breaking. The other substrate was coated with ordinary polyimide with pretilt around 5 degrees.
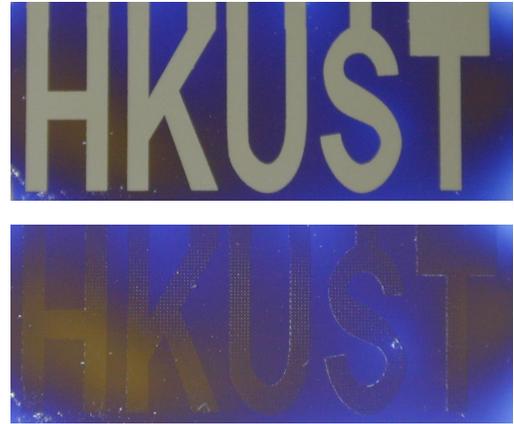
Figure 4. Bistable pattern showing permanent bistability. Top: φ = –22.5, bright state; Bottom: φ =157.5, dark state

4.1   d/p Ratio

The LC used for fabricating the π-BTN was ZLI5700-100 with a birefringence Δn of 0.1581. For fabricating the demonstration cell, we chose the optical mode A. The ideal d/p ratio, from a heuristic point of view, should be given by

$$\frac{d}{p} = \frac{-22.5 + 90}{360} = 0.1875 \tag{1}$$

However, as the high twist state usually has a higher elastic energy, the LC has to be doped in a way that the high twist state is more favored. So, a larger d/p ratio should be used in order to balance the elastic energy of the two twist states. Therefore, the d/p ratio was adjusted to be about 0.3 in order to achieve bistability.

4.2   Optical Properties

Figure 5 shows the measured as well as the simulated transmission spectra of the on and off states. It can be easily seen that the agreement is generally good except that the measured spectra have lower transmission. This is probably because of the use of imperfect polarizers. There are also interference fringes in the measured spectrum, which is evidently due to finite reflection of the indium tin oxide (ITO) glass.
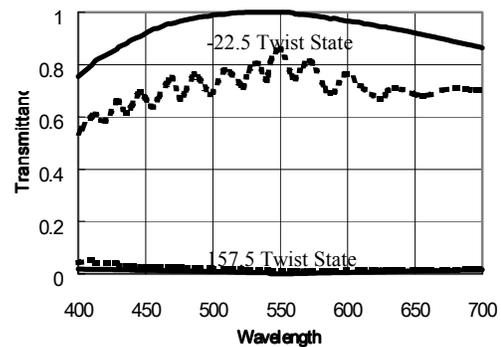
Figure 5. Transmission spectra of the two stable twist states. Solid lines: theory; Dotted lines: experimental data

4.3 Bistable Switching

Figure 6 shows the bistable switching of our fabricated cell. It can be seen that both the on and off states show true stability with no decay of transmittance for a long time. We have also checked that the bistability lasts for more than half year.
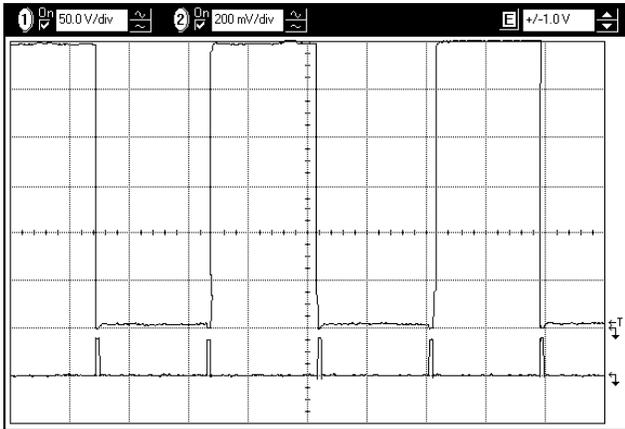
Figure 6. Switching behavior of the π-BTN. Top: Optical response; Bottom: Switching pulse train.

Switching of π-BTN is effected in the same manner as in a conventional 2π-BTN. The driving electrical pulse consists of a reset pulse followed by a selection pulse. The amplitude of the selection pulse determines the final twist state of the device, according to the backflow dynamics. [5] The reset and selection pulses are both 0.2ms in Figure 6. Switching can be achieved with pulses as short as 0.1ms. The measured contrast ratio from Figure 1 is above 80. The switching time of the twist states is about 1ms. It is very fast and is a direct result of the small cell gap used.

5. Excellent Viewing Angles

The viewing angle of π-BTN was very large. It can achieve excellent contrast ratio in both vertical and horizontal directions. Figure 7 and 8 shows the viewing cone of the bright state and dark state respectively.
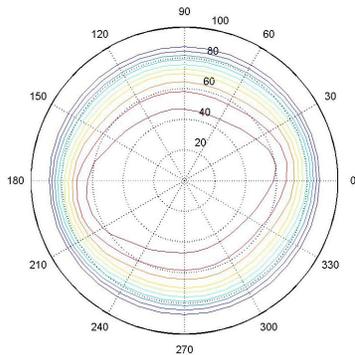
Figure 7. Viewing cone of the π-BTN; Bright State.
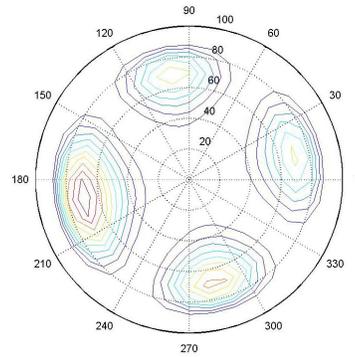
Figure 8. Viewing cone of the π-BTN; Dark State.

The viewing cone of the bright state is uniform. However, due to the light leakage of the two polarizers, there are four regions with a higher transmittance in the dark state. By rotating one polarizer of 90 degrees, the bright state change to dark state, and the polar plot of the new dark state is shown in Figure 9. It can be seen that the light leakage happens again. It proves that the leakage is due to the polarizers but not the design of the LC cell.
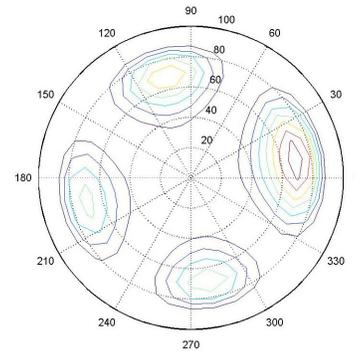
Figure 9. Viewing cone of new Dark State with ratating one polarizer of 90 degrees.

The viewing cone of contrast ratio is shown in Figure 10. The contrast ratio is above 1000 at the center of the polar plot.
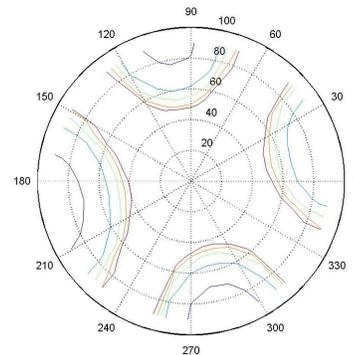
Figure 10. Viewing cone of Contrast Ratio.

6.   Conclusion

In summary, we have demonstrated that the photoalignment material SDA-1 is useful in obtaining bistable switching in π-BTN. This new photo-alignable polymer SDA-1 can achieve different polar anchoring energy by carefully adjusting the UV exposure time and polymerization time. The variable polar anchoring energy of SDA-1 was valuable to the future development of LCDs.

This display has optimized optical properties and can be switched at a relatively low voltage of 30V with a pulse width of less than 0.25ms. Both theoretical and experimental results show that this display has excellent contrast ratio and wide viewing angles.

7.   References

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