

04 FEB 1999

BISTABLE TWISTED NEMATIC LCD

The invention relates to bistable twisted nematic LCDs, and particularly to optimization of operating modes thereof.

Bistability of liquid crystal twist cell was first discovered by Berreman. It was not until 1995 that the first prototype Bistable Twisted Nematic (BTN) cell was demonstrated (Tanaka et. al.). The demonstrated cell was based on a π (180-degree) twist configuration. The cell gave high contrast ratio, fast response, wide viewing angle, and a high cross-talk immunity. Since then, different cell configurations have been proposed. Among them, BTN cells with 90° and 270° initial twists were proposed by Xie et al. Despite the poorer optical performance of those proposed non- 180° twist cells, they have other advantages such as larger operating retardation value. All the proposed cell configurations adopt twist angles that are multiples of 90° . The reason is that based on the assumption of linear crossed polarizers, the transmission is theoretically optimized at twist angles of 90° multiple. However, it is obvious that the dark state breed-through is also important in determining the optical performance of a BTN cell. In fact, in the design of a display, instead of the bright state transmission, the contrast ratio is a more important factor to be optimized. Besides, to obtain an achromatic display, it is imperative that we take the whole visible spectrum into consideration. We observe that the performance of BTN cells can be further enhanced if the assumption of cross polarizers is removed.

Using two definitions of contrast ratios (one favours cells with high transmission while the other favours cells with low breed-through) as objective functions, optimized cell configurations covering two ranges

of twist angles are proposed. The lower-twisted group offers higher retardation that relaxes the small cell gap requirement. Adopting larger cell gaps eases the manufacturing process and results in a better cell gap control. Hence, the ratio of cell gap to helical pitch (d/p), which determines the stability of the BTN select states, can be better controlled. The higher-twisted group outperforms the existing BTN configurations with less dark state breed-through. Cells with the proposed configurations are fabricated. They show excellent optical performance, with high contrast, wide viewing angle, and achromatic appearance.

It is an object of the invention to seek to provide a BTN cell of enhanced performance.

According to the invention there is provided a bistable twisted nematic LCD cell, comprising front and rear polarizers and a liquid crystal layer having an initial twist angle, wherein the cell does not have a configuration with a twist angle of 180 degrees and an angle between the polarizers of 90 degrees.

The LCD cell may have an initial twist angle which is not a multiple of 90 degrees, and/or may have an angle between the polarizers which is not 90 degrees.

Characteristics of BTN LCD operation and a liquid crystal cell embodying the invention are hereinafter described, by way of example, with reference to the accompanying drawings.

Fig. 1 shows schematically LC Director configurations for different states;

Fig. 2 shows schematically a BTN cell configuration;

Figs. 3 to 10 show graphically wavelength-transmission plots of bright and dark metastable states;

Figs. 11 to 28 show graphically further wavelength-transmission plots of bright and dark metastable states;

Figs. 29 and 30 show graphically wavelength-transmission plots of known BTN LCD cells; and

Fig. 31 shows an exploded perspective view of a liquid crystal cell according to the invention.

The structure of a BTN cell is similar to that of a conventional Twisted Nematic (TN) or Super Twisted Nematic (STN) cell, except that the substrates are rubbed in favour of the two selected states instead of the initial twist state (Fig. 1a). If $\varnothing$ is the twist angle (in degrees) of the initial state, by applying a suitable waveform, it is possible to switch the cell to two metastable twist states, namely, $\varnothing - 180^\circ$ and $\varnothing + 180^\circ$ states. From various studies on BTN, it is known that the d/p ratio (d is the cell gap and p is the helical pitch) is critical in achieving practical memory retention times of the selected metastable states.

Practical memory retention times can be achieved when:

$$\frac{0.8\phi}{360} \leq d/p \leq \frac{1.4\phi}{360}$$

If a sufficiently high voltage is applied to a BTN cell, Frederick's transition occurs that results in vertical alignment of mid-plane liquid crystal molecules (i.e., reset state, Fig. 1b). Depending on the voltage level applied after the reset state, it is possible to relax the cell to either one of the two metastable states. If the voltage level is below a threshold, the $\emptyset + 180^\circ$ twist state (Fig. 1c) is obtained. On the other hand, if the voltage level is above some saturation value, the $\emptyset - 180^\circ$ twist state (Fig. 1d) is obtained. The two metastable states correspond respectively to the optical bright and dark states of the display. By optimizing the cell parameters, BTN of excellent optical performance can be obtained.

Figure 2 shows a BTN cell configuration. Four parameters, the initial state twist angle $\emptyset$ (in degrees), the front polarizer angle α (in degrees), the rear polarizer angle β (in degrees), and the cell retardation $d\Delta n$ (in micrometers) are to be optimized to achieve high contrast, wide viewing angle, and achromatic appearance of the display. Hereinafter a cell configuration is abbreviated and denoted by $\emptyset, \alpha, \beta, d\Delta n$ (in micrometers). To achieve high contrast of the display, two definitions of contrast ratios are adopted. The first favours the bright state and the second favours the dark state.

The bright state can be termed CR_1 , and the dark state CR_2 .

Making use of the two objective functions CR_1 , and CR_2 simultaneously, a cell configuration may be assessed by both its bright and dark states. At different initial state twist angles, the polarizer angles and the cell retardation are varied to achieve optimal configurations with high CR_1 and CR_2 . Two ranges of initial twist angles within which optimal configurations are located are used. The lower-twisted group offers higher retardation values, hence less stringent cell gap control requirement. Configurations with good optical performance can be found when the twist angle is located in the range $30^\circ - 80^\circ$, with front polarizer in the range $30^\circ - 60^\circ$, rear polarizer angle in the range $85^\circ - 119^\circ$ and retardation in the range $0.33\mu m - 0.44\mu m$. The four representative candidates for the group are as follows (Table 1):

Twist ϕ	Front Polarizer Angle α	Rear Polarizer Angle β	Retardation $d \Delta n$
40 ± 10	40 ± 10	95 ± 10	0.38 ± 0.05
50 ± 10	42 ± 10	99 ± 10	0.39 ± 0.05
60 ± 10	46 ± 10	104 ± 10	0.39 ± 0.05
70 ± 10	50 ± 10	109 ± 10	0.39 ± 0.05

Table 1 Lower-twisted optimized configurations

It is observed that for lower-twisted configurations with good optical performance, the two polarizers make an angle of approximately $45^\circ - 69^\circ$ with one another.

By rotating the two polarizers together by 90° , the optical performance at normal viewing direction is not changed while the transmission and chromatics at oblique viewing directions are changed to some extent.

The corresponding optimized configurations are shown in Table 2.

Accordingly, optimized configurations are found when the front polarizer angle is in the range $-60^\circ - -30^\circ$, with rear polarizer angle in the range $5^\circ - 29^\circ$. For configurations with good optical performance, the two polarizers make an angle of approximately $45^\circ - 69^\circ$ with one another.

Figures 3 - 10 show the corresponding wavelength-transmission plots of the bright and dark metastable states.

Twist ϕ	Front Polarizer Angle α	Rear Polarizer Angle β	Retardation $d\Delta n$
40 ± 10	-50 ± 10	5 ± 10	0.38 ± 0.05
50 ± 10	-48 ± 10	9 ± 10	0.39 ± 0.05
60 ± 10	-44 ± 10	14 ± 10	0.39 ± 0.05
70 ± 10	-40 ± 10	19 ± 10	0.39 ± 0.05

Table 2.

Lower-twisted optimised configurations with polarizers rotated by 90° .

On the other hand, the higher-twisted group offers excellent optical performance with high CR_1 and CR_2 , which outperforms the existing BTN configurations. Configurations with good optical performance can be found when the twist angle is located in the range $120^\circ - 220^\circ$, with front polarizer angle in the range $19^\circ - 76^\circ$, rear polarizer angle in the range $94^\circ - 154^\circ$, and retardation in the range $0.22 - 0.35$. The nine representative candidates for the group are as follows (Table 3)

Twist φ	Front Polarizer Angle α	Rear Polarizer Angle β	Retardation $d\Delta n$
130 ± 10	29 ± 10	104 ± 10	0.28 ± 0.05
140 ± 10	30 ± 10	106 ± 10	0.28 ± 0.05
150 ± 10	36 ± 10	113 ± 10	0.27 ± 0.05
160 ± 10	40 ± 10	118 ± 10	0.27 ± 0.05
170 ± 10	47 ± 10	126 ± 10	0.27 ± 0.05
180 ± 10	50 ± 10	130 ± 10	0.27 ± 0.05
190 ± 10	56 ± 10	135 ± 10	0.27 ± 0.05
200 ± 10	60 ± 10	140 ± 10	0.28 ± 0.05
210 ± 10	66 ± 10	144 ± 10	0.30 ± 0.05

Table 3 Higher-twisted optimized configurations

It is observed that for higher-twisted configurations with good optical performance, the two polarizers make an angle of approximately 65° — 90° with one another. Similar to the lower-twisted case, by rotating the two polarizers together by 90° , the optical performance at normal viewing direction is not changed while the transmission and chromatics at oblique viewing directions are changed to some extent. Accordingly, optimized configurations are found when the front polarizer angles is in the range -71° — -14° , with rear polarizer angle in the range 4° — 64° . For configurations with good optical performance, the two polarizers make an angle of approximately 65° — 90° with one another. The corresponding optimized configurations are shown in Table 4.

Twist φ	Front Polarizer Angle α	Rear Polarizer Angle β	Retardation $d\Delta n$
130 $\pm$ 10	-61 $\pm$ 10	14 $\pm$ 10	0.28 $\pm$ 0.05
140 $\pm$ 10	-60 $\pm$ 10	16 $\pm$ 10	0.28 $\pm$ 0.05
150 $\pm$ 10	-54 $\pm$ 10	23 $\pm$ 10	0.27 $\pm$ 0.05
160 $\pm$ 10	-50 $\pm$ 10	28 $\pm$ 10	0.27 $\pm$ 0.05
170 $\pm$ 10	-43 $\pm$ 10	36 $\pm$ 10	0.27 $\pm$ 0.05
180 $\pm$ 10	-40 $\pm$ 10	40 $\pm$ 10	0.27 $\pm$ 0.05
190 $\pm$ 10	-34 $\pm$ 10	45 $\pm$ 10	0.27 $\pm$ 0.05
200 $\pm$ 10	-30 $\pm$ 10	50 $\pm$ 10	0.28 $\pm$ 0.05
210 $\pm$ 10	-24 $\pm$ 10	54 $\pm$ 10	0.30 $\pm$ 0.05

Table 4 Higher-twisted optimized configurations with polarizers rotated by 90°

Figures 11-28 show the corresponding wavelength-transmission plots of the bright and dark metastable states. For comparison, Figures 29-30 show the wavelength-transmission plots for the originally proposed 180, -45, 45, 0.27 configuration.

Table 5 summarizes the optimum configurations with the contrast ratios CR_1 and CR_2 . It is observed that all the proposed higher-twisted configurations have better dark state performance (higher CR_2) than that of the originally proposed π -twist configuration with crossed polarizers ($CR_1=33.65$ and $CR_2=25.31$).

Twist	Front Polarizer Angle	Rear Polarizer Angle	Retardation	Contrast Ratio CR_1	Contrast Ratio CR_2
40	40	95	0.38	16.52	53.90
50	42	99	0.39	25.23	68.63
60	46	104	0.39	29.41	68.02
70	50	109	0.39	18.06	64.29
130	29	104	0.28	34.67	31.29
140	30	106	0.28	32.54	54.41
150	36	113	0.27	36.49	115.14
160	40	118	0.27	34.64	303.36
170	47	126	0.27	32.55	510.94
180	50	130	0.27	35.93	235.37
190	56	135	0.27	35.66	108.43
200	60	140	0.28	36.98	56.14
210	66	144	0.30	39.71	31.84

Table 5 Optimized cell configurations

Thus, using two definitions of contrast ratios (one favours cells with high transmission while the other favours cells with low breed-through) as objective functions, optimized cell configurations covering two ranges of twist angles are obtained. The lower-twisted group offers higher retardation that relaxes the small cell gap requirement. Adopting larger cell gaps eases the manufacturing process and results in a better cell gap control. Hence, the ratio of cell gap to helical pitch (d/p), which determines the stability of the BTN select states, can be better controlled in a BTN LCD according to the invention. The higher-twisted group outperforms the existing BTN configurations with less dark state breed-through. Cells with the proposed configurations show excellent optical performance, with high contrast, wide viewing angle, and achromatic appearance.

The cell 1 illustrated in Fig. 31 has a front (as viewed) polariser 2, a front (as viewed) substrate 3, a liquid crystal layer 4 between the front substrate and a rear (as viewed) substrate 5, and a rear (as viewed) polariser 6.

The front buffing direction is indicated at 7 and the rear buffing direction at 8, to provide the required rubbed alignment.

The substrates 3 and 5 may be of any suitable material such as plastic and include a transparent thin film coated on both sides of the inner faces of the substrates to provide electrical voltage to switch the electrical layers to other bistable states. The thin film may be of indium tin oxide (ITO) or other suitable material.

An initial twist angle is indicated at 9 and the front and rear polariser angles are indicated at 10 and 11 respectively,

The direction of view is shown at 'V'.

To summarise:

- (1) Bistable Twisted Nematic LCD operating modes with non-90° multiple twist have been produced. The configurations are optimized such that they offer excellent optical performance of the display, with high contrast, wide viewing angle, and achromatic appearance.
- (2) In the proposed configurations, the two polarizers make an angle differing from 90°. The polarizer angles are determined such that the two contrast ratios CR_1 and CR_2 are optimized. On the other hand, existing configurations adopt crossed polarizers which maximize the transmission for the 180° twist configuration.
- (3) Applying 1 and 2 above, the optimized configurations are divided into two groups. The lower-twisted group offers higher retardation that relaxes the small cell gap requirement. Adopting larger cell gaps eases the manufacturing process and results in a better cell gap control. Hence, the ratio of cell gap to helical pitch (d/p), which determines the stability of the BTN select states, can be better controlled.
- (4) Applying 1, 2 and 3 above, configurations with good optical performance can be found when the twist angle is located in the range 30° – 80°, with front polarizer in the range 30° – 60°, rear polarizer angle in the range 85° – 119°, and retardation in the range $0.33\mu m - 0.44\mu m$.

- (5) Good optical performance is maintained when the polarizer angles for the configurations stated in 4 above are rotated together by 90° , with front polarizer angle located in the range $-60^\circ - -30^\circ$ and rear polarizer angle located in the range $-5^\circ - 29^\circ$.
- (6) For lower-twisted configurations with good optical performance as stated in 4 and 5 above, the two polarizers make an angle of approximately $45^\circ - 69^\circ$ with one another.
- (7) Applying 1, 2 and 3 above, among the representative lower-twisted configurations (Tables 1 and 2), the $50^\circ - 60^\circ$ twist configurations give the best contrast ratios with $CR_1 > 25$ and $CR_2 > 65$.
- (8) Applying 1 and 2 above, the higher-twisted group outperforms the existing BTN configurations with less dark state bleed-through, hence higher contrast. The configurations result in BTN cells with wide viewing angle and achromatic appearance.
- (9) Applying 1, 2 and 8 above, configurations with good optical performance can be found when the twist angle is located in the range $120^\circ - 220^\circ$, with front polarizer in the range $19^\circ - 76^\circ$, rear polarizer angle in the range $94^\circ - 154^\circ$, and retardation in the range $0.22\mu m - 0.35\mu m$.
- (10) Good optical performance is maintained when the polarizer angles for the configurations stated in 9 above are rotated together by 90° , with the front polarizer angle located in the range $-71^\circ - -14^\circ$ and the rear polarizer angle located in the range $4^\circ - 64^\circ$.
- (11) For higher-twisted configurations with good optical performance as stated in 9 and 10 above, the two polarizers make an angle of approximately $65^\circ - 90^\circ$ with one another.

- (12) Applying 1, 2 and 8 above, among the representative higher-twisted configurations (Tables 3 and 4), the $150^\circ - 190^\circ$ twist configurations give the best contrast ratios with $CR_1 > 32$ and $CR_2 > 100$.



CLAIMS

1. A Bistable Twisted Nematic LCD cell, comprising front and rear polarizers and a liquid crystal layer having an initial twist angle, wherein the cell does not have a configuration with a twist angle of 180 degrees and an angle between the polarizers of 90 degrees.
2. A LCD cell according to claim 1, wherein the initial twist angle is not a multiple of 90 degrees.
3. A LCD cell according to claim 1 or 2, wherein the angle between the polarizers is not 90 degrees.
4. A LCD cell according to any preceding claim, the initial twist angle in the range 30 to 80 degrees, and retardation in the range 0.33 to 0.44 micrometres.
5. A LCD cell according to claim 4, the front polarizer angle in the range 30 to 60 degrees, the rear polarizer angle in the range 85 to 119 degrees.
6. A LCD cell according to claim 4, the front polarizer angle in the range -60 to -30 degrees, the rear polarizer in the range -5 to 29 degrees.
7. A LCD cell according to any of claims 4 to 6, the angle between the polarizers in the range 45 to 69 degrees.



8. A LCD cell according to any of claims 4 to 7, the initial twist angle in the range 50 to 60 degrees.

9. A LCD cell according to claim 1, the initial twist angle in the range 120 to 220 degrees, and retardation in the range 0.22 to 0.35 micrometres.

10. A LCD cell according to claim 9, the front polarizer angle in the range 19 to 76 degrees, the rear polarizer in the range 94 to 154 degrees.

11. A LCD cell according to claim 9, the front polarizer angle in the range -71 to -14 degrees, the rear polarizer in the range 4 to -64 degrees.

12. A LCD cell according to any of claims 9 to 11, the angle between the polarizers in the range 65 to 90 degrees.

13. A LCD cell according to any of claims 9 to 12, the initial twist angle in the range 150 to 190 degrees.