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Improving the electro-optical properties of bistable reflective cholesteric liquid crystal displays

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We have improved the electro-optical properties of a bistable cholesteric liquid crystal display (Ch-LCD) that is driven by a 3+2 dynamic driving scheme (3+2 DDS). The best contrast ratio is achieved at the selection period of 1.2–1.5 ms/line and the temperature range 26–30°C. The suitable preparation period and evolution period for contrast ratio are 40 times and 20 times the selection time, respectively. In the 3+2 DDS, rubbing the homeotropic alignment layer increases reflectivity of the ON state and keeps the reflectivity of the OFF state at the same level, so reflectivity and contrast ratio alike increase as a result. However, in a delayed homeotropic reset driving method, when the homeotropic alignment layer is rubbed, the reflectivity of both the ON and OFF states increases, thus the contrast ratio decreases. The combination of driving method and aligned surface morphology influences the relaxation mechanism in the cholesteric texture. By optimizing panel condition, we have demonstrated an 8.4″ foldable VGA Ch-LCD that exhibits high reflectivity and contrast ratio with an addressing speed of around 1.2 ms/line.

1. Introduction

The bistable cholesteric liquid crystal display (Ch-LCD) has attracted intense interest as a candidate for electronic books, newspapers, and so on, because of its good sunlight readability, low power consumption with image memory, high resolution, high contrast ratio, wide viewing angle, and low cost production [1]. The Ch-LCD has several driving regions such as planar reset, focal-conic reset, and homeotropic reset due to its bistability. In order to enhance the driving speed, the dynamic drive scheme (DDS) was suggested that uses a transient planar state, and achieved an addressing speed of 1 ms/line [2]. According to the DDS switching mechanism the electric field of propagation should be high enough to keep the cholesteric liquid crystal (Ch-LC) homeotropic state in which the Ch-LC directors align perpendicular to the cell surface. After propagation several ms of a selection period is chosen, in which the homeotropic state is maintained if a medium electric field is applied, but evolves to the transient planar state under a sufficiently low electric field. A period of evolution is necessary after the selection to maintain the homeotropic state or to reorient the transient planar state to the focal-conic state. After the sequence of voltage pulses, the homeotropic state relaxes to the planar state (ON) and the focal-conic state maintains its orientation (OFF). The relaxation process of inducing the homeotropic state to the transient planar state in the field is well explained in a conical helix relaxation model. From this model, the helical pitch of the transient planar state is approximated by $P^*=P_0K_{33}/K_{22}$, where P_0 is the intrinsic pitch of the planar state, and K_{22} and K_{33} are the twist and bend elastic constants, respectively [2, 3]. The transition from the homeotropic state to the focal-conic state is much slower than that to the transient planar state because the homeotropic–transient planar transition is a homogeneous relaxation, while the homeotropic–focal-conic transition is a nucleation process.

In order to implement DDS, Huang *et al*. suggested a drive scheme in which row and column driver ICs had outputs of seven and two levels, respectively [2]. However, multi-levels in the driver IC can cause high cost in the display. More recently, Rybalochka *et al*. reported a simple 2+2 DDS for a Ch-LCD in which only two voltage levels were used for the addressing [4]. Although they applied a simple 3×2 pixels display, they did not mention the possibility of grey scale study of a 2+2 DDS. We suggested a relatively simple 3+2 DDS

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and achieved a stable grey scale [5]. The row driver IC had three level outputs of R_H, R_M ($R_H/2$), and R_L. The outputs of the column driver IC were composed of two levels, C_H and C_L. In our system, we applied 32 V for R_H, 16 V for R_M, and 0 V for R_L in which the column voltage was 5.5 V or zero voltage. The liquid crystal was formulated in our laboratory to make it possible for the driving voltage to be lower than 30 V [6]. Also, we could accomplish stable grey scale by using pulse position modulation (PPM) in which the root mean square value of the applied field during the evolution period does not change even under cross-talk pulses.

In this paper, we describe the optimization of a 3+2 dynamic driving scheme to find driving conditions and treatment on alignment layers to obtain better electro-optical properties of the panel. We have examined the dependence of the physical properties on driving methodology.

2. Experimental

Using a Ch-LC mixture formulated in our laboratory, we have prepared panels, 640 × 480 pixels as VGA, of 4 µm cell gap in a manufacturing pilot line. We measured the electro-optical properties of the panel at 25°C, utilizing the LCD 5000 (Otsuca, Japan) calibrated with $BaSO_4$ and a photo-measurement apparatus assembled in our laboratory. All programmed waveforms used in the computer were saved in an arbitrary waveform generator, Wavetek 39A. The signals from the generator supplied by the power amplifier, NF Electronics 4005, were sent to the LCD 5000 and a photo-measurement apparatus. They were then detected by the instruments and analysed by oscilloscope, HP 54510B, and a computer. All waveforms were programmed by Boland C^{++}.

3. Results and discussion

3.1. *Optimization of a 3+2 dynamic drive scheme*

From the transient planar study of homeotropic to transient planar, the transition time can be indirectly measured by a capacitance test. According to our previous result, the transition time for a cholesteric cell was around 1.0–1.5 ms at room temperature [5]. Capacitances varied with temperature. We applied this result to our panel and verified that it was well fitted to the homeotropic to transient planar transition at room temperature. Around 1.0–1.5 ms was the best selection time for a 3+2 DDS. One major problem of DDS is temperature dependence. We measured the contrast ratio and the selection time with temperatures as shown in figure 1. Optimum selection time with the appropriate temperature and contrast ratio is necessary for optimum performance of a Ch-LCD. We selected a time interval of 0.8–2.2 ms and a temperature range of 20–30°C. Improved contrast ratio requires different ranges of temperature setting, according to the selection time. When the selection time is 1 ms, the temperature should be over 29°C; with a selection time of 1.5 ms, the temperature range is 23–29°C. In the case of a selection time of 2 ms an operating temperature of 27°C or less is suitable. When the temperature increases, a higher driving speed is possible. However, from this temperature dependence study, we find that 1 ms driving of a Ch-LCD by DDS is not easy, due to the capacitance effect of the Ch-LC during the actual driving, even though a transient planar state occurs during such a short time range. The transient planar state is so sensitive to temperature that a circuit for temperature compensation would be necessary for commercial use.

The waveform of the dynamic driving scheme shown in figure 2 was used for optimization of a 3+2 DDS. The optimization of the preparation and evolution periods was studied after fixing the selection time. These periods should be as short as possible in order to decrease the total driving time and minimize the reset time. In general, the higher the voltage preparation, the shorter the required preparation period. In this system the maximum voltage was fixed at 32 V due to the use of STN IC and two selection times (T_s, 1.1 and 1.5 ms) were selected. Preparation time (T_p) and evolution time (T_e) were described by the ratio of T_s in order to compensate the entire composite waveform easily by adjusting frequency of the driver IC. The effect of T_p with T_s was measured when T_e was set at 40 times T_s by the contrast ratio of the panel, as shown in figure 3. When the T_p is 20 times T_s, the contrast ratio is, respectively, 5.3 and 6.3 for the two T_s values. When the T_p is 40 times T_s, the contrast ratio is, respectively, 8.5 and 8.2 for the two T_s values. We find that the suitable time for the preparation period is 40 times the selection period.

If the evolution voltage is too high or too low, ON–OFF switching cannot be obtained. In this system R_H and R_M levels were applied repeatedly to have optimum root mean square value of 24 V during driving [5]. From the evolution study, when T_p is 60 times T_s and T_e is over 10 times T_s, the contrast ratio is 8.1 and 7.6 for the two T_s, as shown in figure 4. When T_e is 20 times T_s, the contrast ratio for both T_s values is over 8.1. For the evolution period, around 20 times the selection period is suitable for a 3+2 DDS in the Ch-LCD. The short evolution period gives incomplete transition from the transient planar state to the focal-conic state. An increase of T_e by more than 60 times T_s results in a decrease of contrast ratio, because the longer evolution

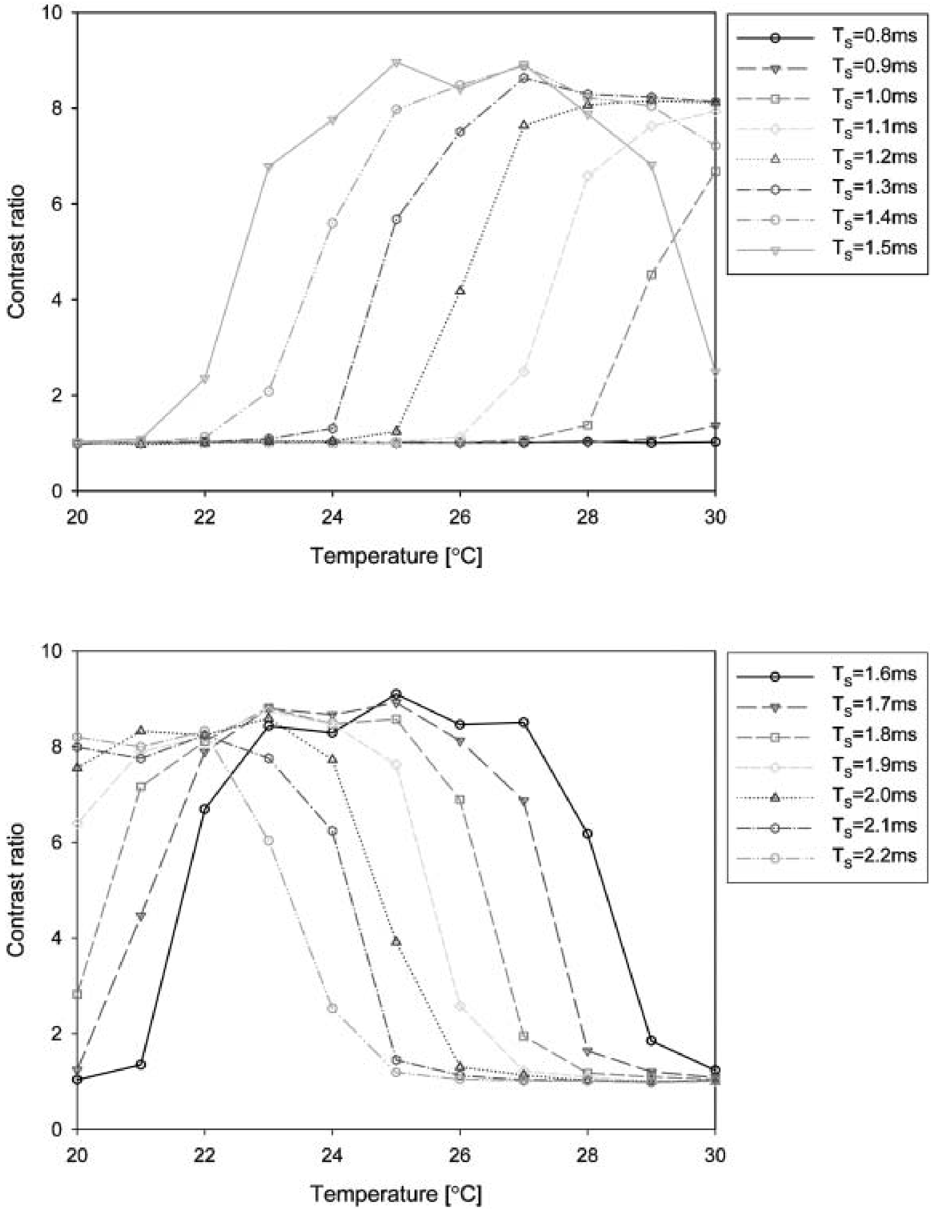

Figure 1. The effect of driving temperature and selection time on a 3+2 DDS in a Ch-LCD.

time leads to a slow transition time, and destabilizes the transient planar and focal-conic states. The reflectivity also reduces due to the embedment of the focal-conic texture into the planar texture. The fluctuation of the evolution voltage is much more sensitive to DDS than that of the preparation voltage. The preparation voltage has only a lower limit for the homeotropic state. If the lowest preparation voltage is above the lower limit for the homeotropic state, a random fluctuation has no effect. The evolution voltage should be maintained in a limited region between lower and upper limits for a high contrast ratio. The Ch-LC can realign to the homeotropic state at a higher evolution voltage, whereas it relaxes to the planar state at a lower voltage, regardless of selection voltage. Thus the selection of the evolution voltage is critical for obtaining the desired contrast ratio in a 3+2 DDS.

3.2. *Rubbing effect of the homeotropic alignment layer on the dynamic driving scheme*

The surface treatment or polymer treatment of a Ch-LCD has the effect of stabilizing the planar or focal-conic texture at zero field. The choice of alignment layer

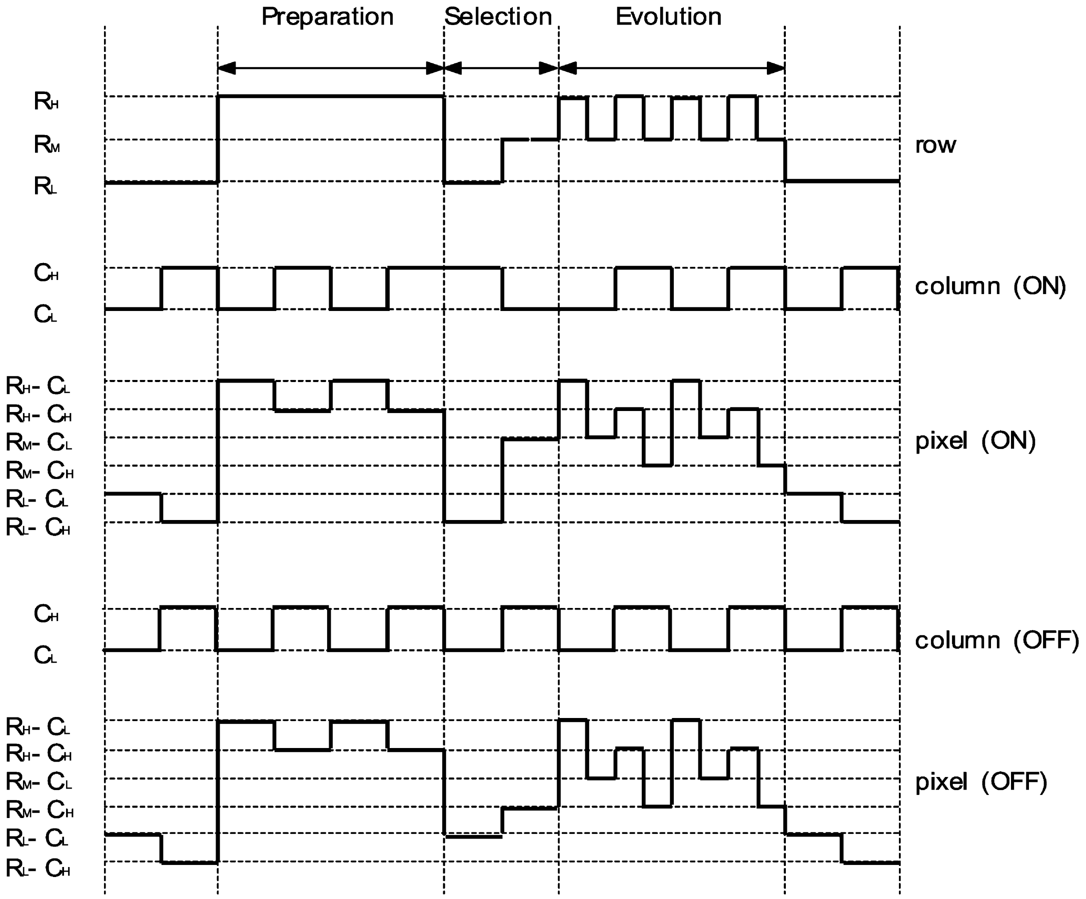

Figure 2. Waveform of the driving scheme for a 3+2 DDS.

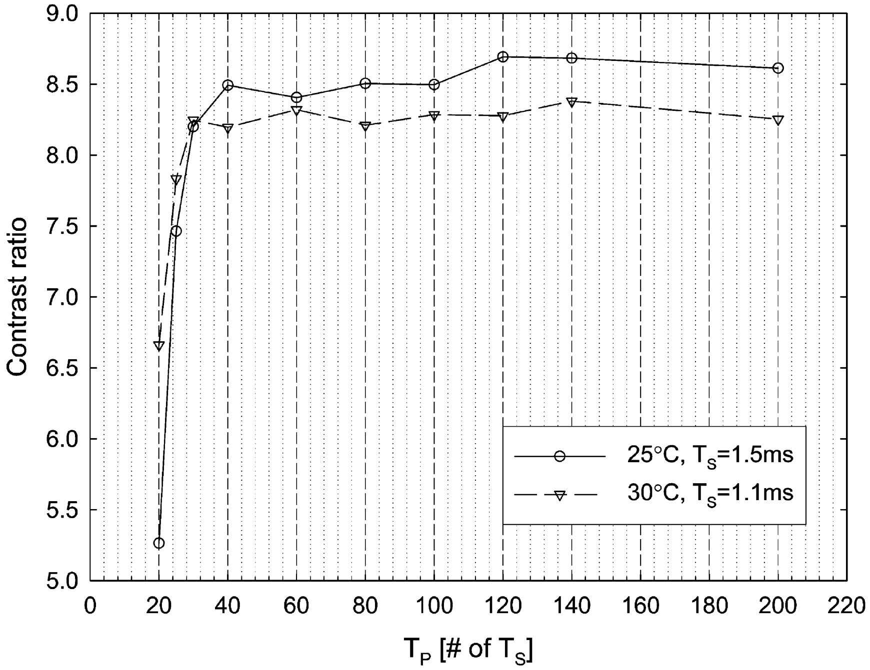

Figure 3. The effect of preparation and selection times on a 3+2 DDS in a Ch-LCD.

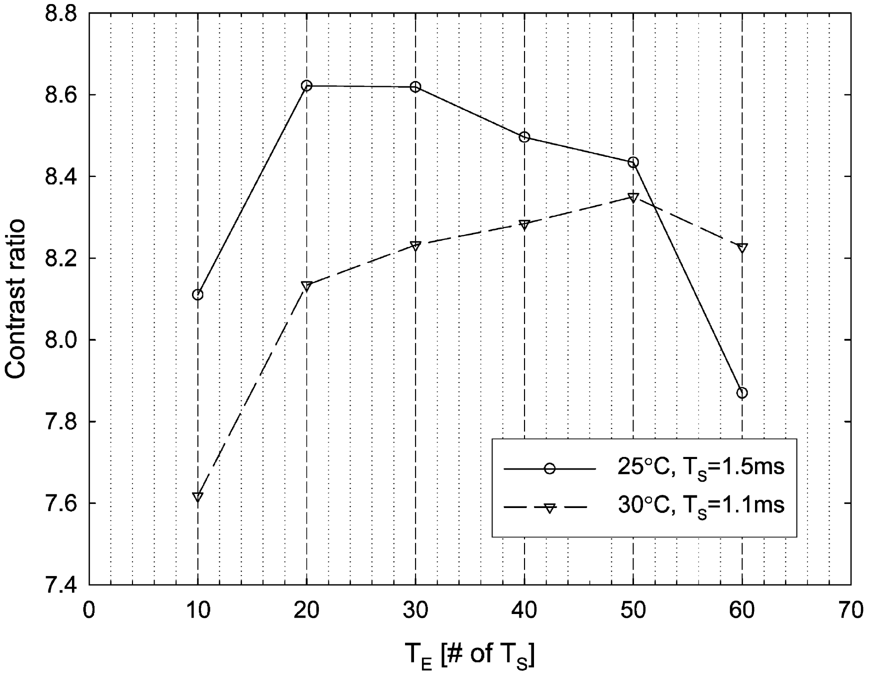

Figure 4. The effect of evolution and selection times on a 3+2 DDS in a Ch-LCD.

is very important and the rubbing method is another factor to be considered in the domain texture. A homogeneous alignment layer provides a higher reflective panel because the layer stabilizes the planar structure of the cholesteric mixture, while a homeotropic alignment layer provides a higher contrast ratio due to stabilizing the focal-conic texture. An alignment layer without rubbing gives better viewing angles with a relatively low reflectivity due to the decreasing of planar domain size.

A cholesteric liquid crystal has a tendency to align with the rubbing state and this causes a more planar-preferred structure with a higher reflectivity performance [6]. When both sides of the alignment layers in the cell are rubbed, there is a mirror-like appearance from the viewing side. This is due to the almost perfect planar texture with very large domain sizes. When one side of the alignment layer is rubbed, the reflectivity greatly increases. However, the contrast ratio decreases due to the interference of the focal-conic structure. This is attributed to the domain texture, a balance between domain size and domain distribution, and helical axes. We have shown photographs of the surface texture in Ch-LCD panels with rubbing and without rubbing elsewhere [6].

We applied rubbing to the panel under the former driving method, delayed homeotropic reset (DH-reset) [7] and examined the effect of rubbing the alignment layer, as shown in figure 5, when T_p was set 100 times T_s and T_e was set 40 times T_s. The reflectivity of the unrubbed homeotropic layer is 0.14 and 0.05 in the ON and OFF states, respectively. In the OFF state, the reflectivity of the rubbed homeotropic alignment layer is higher than that of the unrubbed layer, so the contrast ratio decreases because the dark level is too high. The reflectivity of the unrubbed homogeneous layer is 0.14 and 0.06 in the ON and OFF state, respectively. A positive rubbing effect is not expected since the dark level is too high in the DH-reset driving method.

We obtained different results when rubbing was applied to a 3+2 DDS driving method in a panel, as shown in figure 6, when T_p was set 100 times T_s and T_e was set 40 times T_s. The reflectivity of an unrubbed homeotropic alignment layer was 0.13 and 0.03 in the ON and OFF state, respectively. When rubbing was applied to the dynamic driving panel, the reflectivity of the ON state increases; however, the reflectivity of the OFF state remains the same, as shown in figure 6. The dark level remains constant regardless of the rubbing condition. Therefore, both the reflectivity and contrast ratio increase in a 3+2 DDS for the Ch-LCD. In general, rubbing has a more stabilizing effect on the planar state than on the focal-conic state. The driving of a 3+2 DDS uses a short time of about 1 ms for relaxation of the homeotropic to the transient planer state, thus rubbing does not affect the stability of the focal-conic state. In the case of a DH-reset Helfrich type

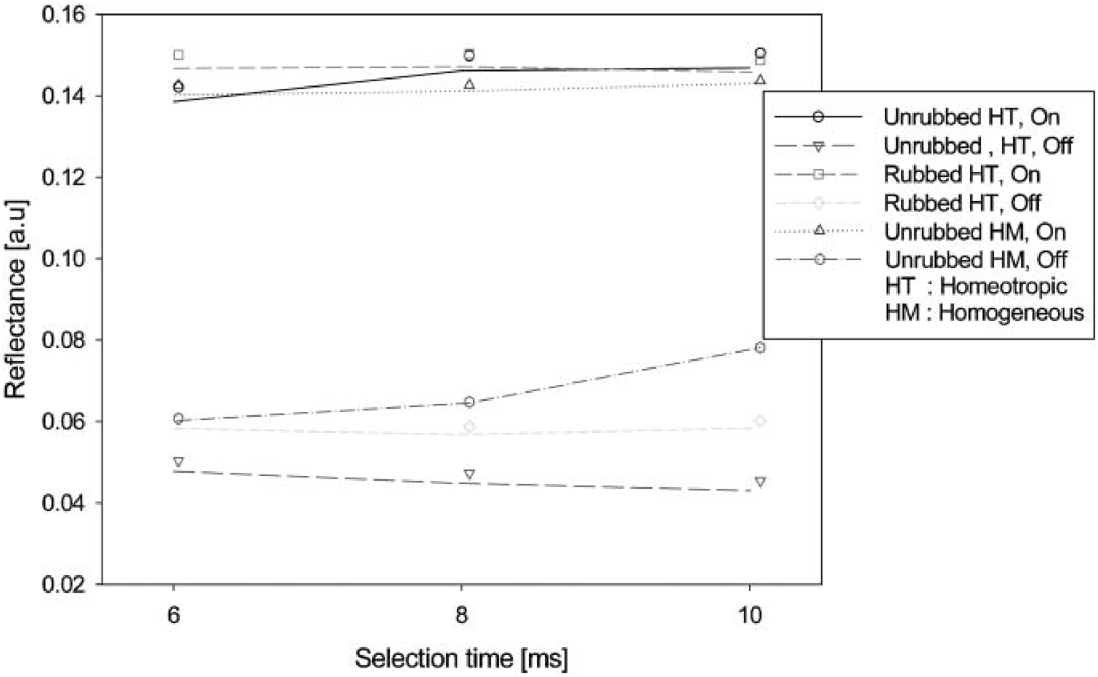

Figure 5. The rubbing effect of DH-reset driving on a Ch-LCD.

instability of a liquid crystal in the planar state or the planar relaxation state converts to the focal-conic state for dark level. The planar state stabilized by rubbing is harder to change to the focal-conic state than for the unrubbed case. Therefore the contrast ratio decreases due to the poor dark level. Meanwhile, rubbing in the 3+2 DDS has less effect on the transient planar state, so it can easily change to the focal-conic state. Therefore, as the change in dark level is minimized, the contrast ratio increases.

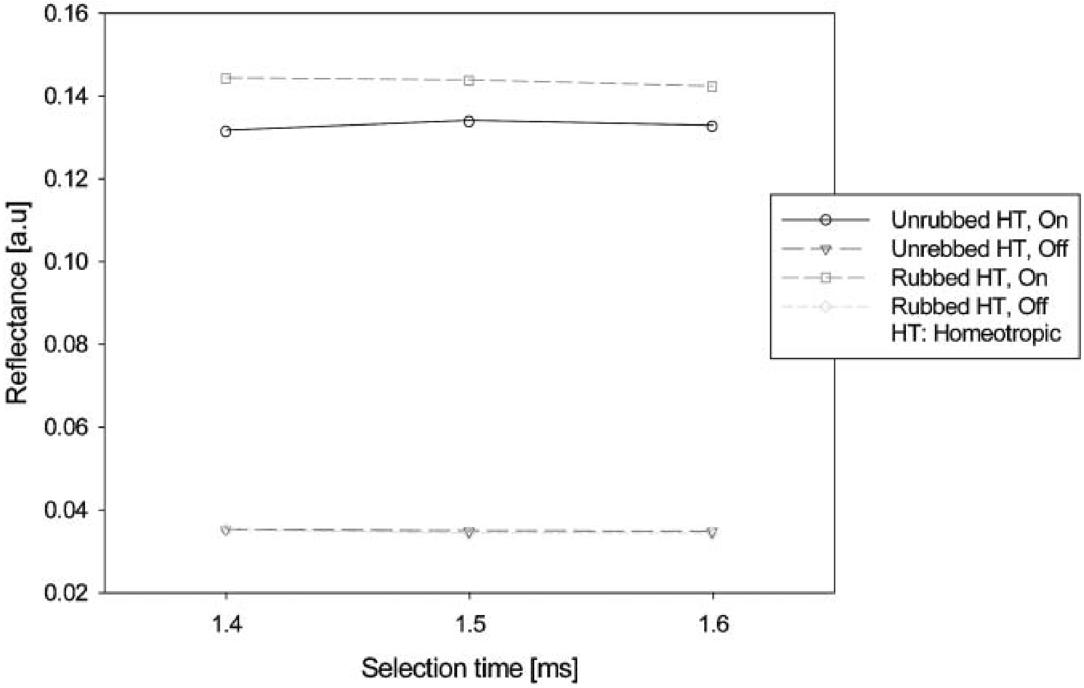

Figure 6. The rubbing effect of a 3+2 DDS on a Ch-LCD.

It has been reported that cell surface anchoring does not affect the transition from homeotropic to transient planar because the transition is a bulk phenomenon [8]. However, we find that the mechanism of this phenomenon is affected by the driving methodology, and the combination of driving method and aligned surface morphology influences the relaxation mechanism in the cholesteric texture. Rubbing conditions such as strength and speed, are not so critical for control of the optical properties of the panel in certain ranges. We find that high reflectivity and contrast ratio are obtained by rubbing for the 3+2 DDS in a Ch-LCD in which the homeotropic alignment layer is used as surface treatment layer. The driving scheme and the mechanism of relaxation of the Ch-LC is very important for improving Ch-LCD panel properties. The bistability of a Ch-LCD is maintained after the rubbing process in any driving scheme. We have achieved high reflectivity and contrast ratio by optimizing driving and panel conditions for the 3+2 DDS and demonstrated an 8.4″ foldable VGA Ch-LCD ($640 \times 480 \times 2$) with an addressing speed of about 1.2 ms/line and grey levels of 8.

4. Conclusion

We have developed a novel 3+2 dynamic driving scheme (3+2 DDS) for a Ch-LCD whereby the best contrast ratio is achieved at a selection period of 1.2–1.5 ms/line in a temperature range of 26–30°C. We find the suitable preparation and evolution periods are 40 times and 20 times the selection time, respectively. We achieve high reflectivity and contrast ratio by rubbing on the homeotropic alignment layer in 3+2 DDS for a Ch-LCD. Rubbing in a 3+2 DDS has less effect on the transient planar state, which can change easily to the focal-conic state. In delayed homeotropic reset driving, the reflectivity is high, but the contrast ratio decreases because the transient planar state stabilized by rubbing is difficult to change to the focal-conic state.

References

[1] S.T. Wu, D.-K. Yang. *Reflective Liquid Crystal Displays*. John Wiley, p. 197 (2001).

[2] X.-Y. Huang, D.-K. Yang, J.W. Doane, *Appl. Phys. Lett.*, **67**, 1211 (1995); X.-Y. Huang, D.-K. Yang, J.W. Doane. *J SID*, **5**, 179 (1997).

[3] P. Watson, V. Sergan, J.E. Anderson, J. Ruth, P.J. Bos, *SID 98 Dig.*, 905 (1998); D.-K. Yang, Z.-J. Lu. *SID 95 Dig.*, 351 (1995).

[4] A. Rybalochka, V. Sorokin, S. Valyukh, A. Sorokin, *SID 00 Dig.*, 818 (2000); A. Rybalochka, V. Sorokin, S. Valyukh, A. Sorokin. *SID 01 Dig.*, 882 (2001).

[5] N.-S. Lee, W.-S. Choi. *Displays*, **25**, 201 (2004).

[6] W.-S. Choi, M.-K. Kim. *Displays*, **25**, 195 (2004).

[7] N.-S. Lee, Y.-G. Mo, S.-H. Jeong, K.-S. Sung, W.-S. Choi. *KLCC*, **4**, 21 (2001).

[8] P.-K. Yang, Z.J. Lu. *SID 95 Dig.*, 351 (1995).