Application of Large Active-Matrix Reflective Cholesteric Liquid-Crystal Technology in Outdoor Public Information Displays

Heng-Yi Tseng*, Yi-Han Tseng*, Yi-Jyun Ke*, Meng-Chiou Huang*, Yi-Ling Lin*, Ming-Chun Li*, Jen-Chieh Hsieh*, Wei-Kai Huang*

***Technology Group, AUO Corporation, Science Park, Hsin-Chu 300094, Taiwan, R.O.C.**

Abstract

The utilization of large-sized active matrix reflective cholesteric liquid crystal (ChLC) technology in outdoor public information displays (PID) has gained significant attention. This technology leverages the unique optical properties of ChLC to enhance visibility and reduce power consumption. ChLC technology operates without the necessity of backlight, relying instead on ambient light for image presentation. Its bistable characteristics ensure that energy is only consumed during image updates, thus providing significant energy efficiency. In applications for outdoor PID, the incorporation of wide-temperature materials, combined with active matrix, has successfully led to the development of the world's largest 32-inch full-color ChLC reflective display. Active matrix ChLC displays can achieve large sizes, rapid page transitions, ultra-low power consumption, and high picture quality, making them one of the most promising technologies currently available.

Author Keywords

Cholesteric Liquid Crystal (ChLC); Reflective Display; Active Matrix; Outdoor Signage

1. Introduction

The transmission of information has become exceptionally important in this age, with countless messages exchanged daily among individuals. Consequently, various types of displays have been developed to meet user demands. Outdoor public information displays (PID) have been extensively utilized across different sectors, the need for displays is not confined to indoor use. PID suitable for outdoor environments should incorporate several key features: 1. Large size (greater than 24 inches), as developing larger screens is a primary objective due to extended viewing distances. 2. Readability in bright outdoor conditions is essential; typical transmissive displays that use backlight or emissive technologies can suffer from reduced visibility in direct sunlight, complicating information recognition. 3. The display must exhibit ultra-low power consumption; energy-efficient displays are capable of utilizing solar power or batteries, which reduces the expenses associated with setting up electrical grids. 4. A wide temperature operating range is necessary; outdoor displays must possess this capability due to their functioning in environments that often experience extreme heat or cold.

Figure 1 presents the outdoor performance of AUO's 24.5-inch passive matrix cholesteric liquid crystal display (ChLCD) [1], also demonstrated at the SID 2024 exhibition. This ChLCD is ideally suited for outdoor PID applications due to its large size, readability in sunlight, ultra-low power consumption, and capability to operate across a wide temperature range.

Figure 1. AUO's 24.5-inch passive matrix ChLCD.

Current mainstream display technologies depend on continuous power supplies to generate light through backlight modules or emissive materials. However, transmissive displays not only face continuous power consumption but also struggle to maintain high-quality performance in bright environments, presenting significant challenges for outdoor PID applications. Reflective displays, by utilizing ambient light as their primary light source, address the power consumption problems associated with backlights and deliver exceptional picture quality in outdoor environments. Cholesteric liquid crystal (ChLC) technology is ideally positioned as a new alternative for energy-efficient displays because of its bistable and Bragg reflection properties [2-3]. As the demand for wide temperature ranges in outdoor usage continues to grow, ChLC materials that function effectively in temperatures from -30°C to +85°C have been adopted. These materials maintain their reflectance and reflection wavelengths, which are not significantly impacted by temperature fluctuations, rendering them highly appropriate for outdoor PID applications.

ChLC are created by introducing appropriate chiral dopants into nematic liquid crystals, resulting in a periodic helical arrangement of the liquid crystal molecules. This helical structure possesses Bragg reflection characteristics, allowing for the selective reflection of specific wavelengths of light within its photonic bandgap [4-5]. As a result, colors can be displayed without relying on backlights or color filters. The molecular arrangement of ChLC is typically classified as planar texture, focal conic (FC) texture, or homeotropic texture, as shown in Figure 2. (a) The planar texture is one of the stable states of ChLC, wherein the liquid crystal molecules are arranged in a periodic helical structure with the helical axes uniformly oriented perpendicular to the substrate, allowing for Bragg reflection. The bandwidth of the Bragg reflection in the planar texture can be controlled through the differences in the liquid crystal's birefringence, which ensures excellent color purity. Due to its stability, the planar

ISSN 0097-996X/25/5602-1267-$1.00 © 2025

texture is commonly used as the bright state in ChLCD. (b) When a small pulse voltage is applied, the planar texture transitions to the FC texture. In FC state, the helical axes of ChLC molecules become randomly arranged, causing periodicity to vanish and dramatically reducing reflectance, which is typically characteristic of the dark state in ChLCD. The random arrangement in FC texture results in the scattering of incident light, creating an increased haze. (c) When the applied electric field exceeds a certain threshold, the originally periodic arrangement of liquid crystal molecules is unwound by the electric field, aligning the molecules parallel to the electric field. This configuration is referred as homeotropic texture, which appears transparent. In ChLCD, bright and dark states are generated through planar and FC, respectively. The bright state results from applying voltage to switch the ChLC into homeotropic texture, followed by releasing the voltage to realign the molecules into planar state. By manipulating the amplitude and duration of pulse voltage, the ratio of planar and FC textures can be controlled, thus enabling reflectance adjustments for grayscale. ChLC can maintain stable configurations in both planar and FC textures without the necessity for an external field.

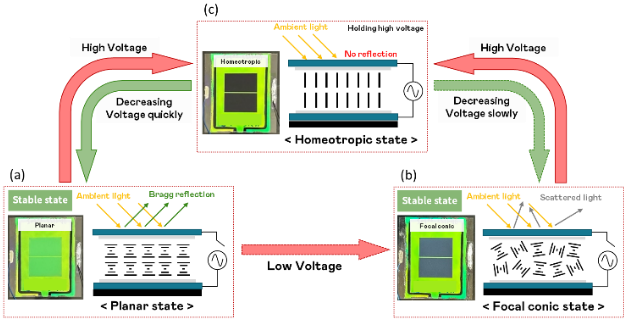

Figure 2. The molecular arrangement of ChLC (a) planar texture, (b) focal conic (FC) texture and (c) homeotropic texture.

2. Comparison of Passive and Active Matrix Cholesteric Liquid Crystal Reflective Displays

In response to the demand for larger display sizes, a 32-inch active matrix ChLCD has been developed. Due to the increased dimensions, challenges related to enhance RC loading are encountered. Active matrix technology was employed to reduce RC loading, thereby improving the uniformity of voltage distribution affected by this issue. The dimensions of ChLCD are constrained by the RC loading; an increase in RC loading results in a reduction of display size. Passive matrix architectures are widely employed in ChLCD, consisting of vertically and horizontally arranged upper and lower electrodes. These electrodes are typically made of indium tin oxide (ITO), as illustrated in Figure 3(a). Despite a simpler manufacturing process, the relatively high resistance of ITO and the total capacitance contributed by all pixels in the driving path lead to elevated RC loading. Furthermore, ChLC materials possess a capacitance significantly greater than standard liquid crystal materials, making it challenging to achieve larger sizes with passive matrix. Our evaluation suggests that passive matrix ChLCD have a size limit of 30 inches and are thus unsuitable for PID applications. The data lines of active matrix ChLCD are made of metal and exhibit very low resistance. During operation, the capacitance is determined by the data line and one pixel, as shown in Figure 3(b). The RC loading of active matrix ChLCD is only one-fiftieth that of passive matrix ChLCD, making them more suitable for achieving larger sizes, with maximum dimensions exceeding 75 inches.

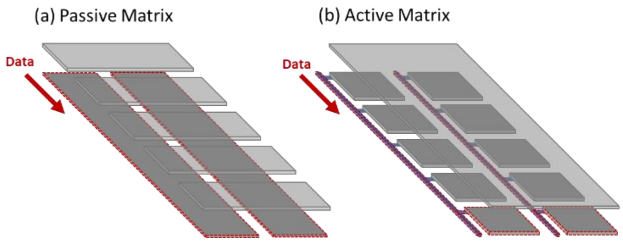

Figure 3. The capacitance evaluation for (a) passive matrix and (b) active matrix.

Figure 4 presents the driving waveform of ChLCD, divided into four phases: Reset phase, Wait phase, Scan phase, and End phase. During the Reset phase, all liquid crystal molecules align parallel to the electric field, resulting in a homeotropic texture due to applied a high voltage. The voltage is then rapidly decreased to 0V, transitioning the ChLC from the homeotropic to the planar texture, which results in a bright state during the Wait phase. In the Scan phase, varying voltages are applied within fixed operation time, or consistent voltages are applied over varying durations to tailor the desired reflectance. When the applied voltage is lower (or the operation time shorter), the ChLC remains in the planar texture due to an absence of electric field changes, resulting in a brighter image. Conversely, when the voltage is higher (or the operation time longer), more regions of the ChLC switch to the FC texture, causing a darker image. Finally, upon entering the End phase, the ChLC exhibits its bistable characteristics.

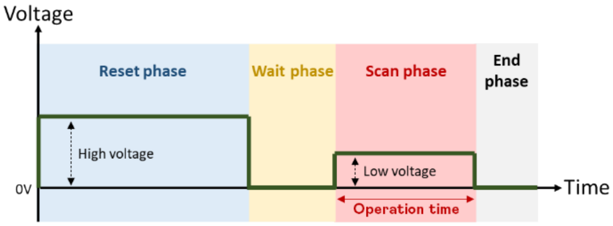

Figure 4. The driving waveform of ChLCD.

Figure 5 presents the reflectance changes as a function of applying a fixed voltage for different operation times during the Scan phase. When the voltage is applied for a short operation time, the ChLC remains in the planar texture, representing the bright state, with no significant voltage change detected. As the operation time increases, the reflectance in the dark state decreases, indicating the ChLC switch to the FC texture. Varying operation times yield different levels of reflectance. At 16 ms of operation time, the reflectance of dark state is 5.4; increasing the operation time to 1024 ms results in a reflectance drop to 2.54, achieving over a twofold improvement in contrast ratio. When the operation time exceeds 500 ms, the reflectance gradually approaches its minimum, with reflectance of dark state nearing saturation. These findings suggest that achieving optimal contrast ratio in ChLCDs requires sufficient operation time; however, extended durations may adversely affect the page refresh time. Thus, balancing contrast ratio and page refresh time is essential.

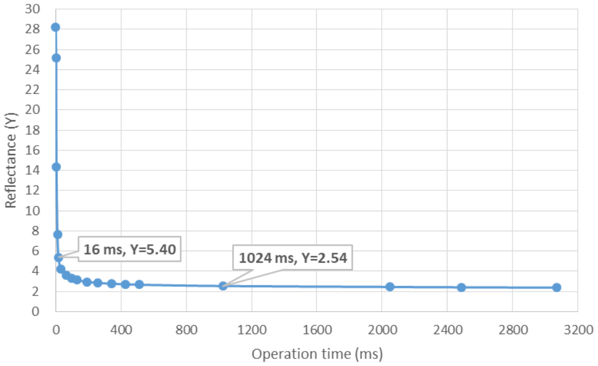

Figure 5. The relationship between reflectance changes due to a fixed voltage for varying operation time during the Scan phase.

Passive matrix ChLCD pixels are composed of upper and lower electrodes oriented horizontally and vertically. By sequentially applying voltage to the pixels, each pixel can be rapidly turned on and off in succession to display an image. The driving waveform of passive matrix ChLCD as shown in Figure 6. In a passive matrix, horizontal lines are referred to as Scan Lines; the next line's signal is executed only after the previous line's signal has been completed. Vertical lines are known as Data Lines; which utilize the voltage received from the Scan Lines to determine if voltage should be applied to the respective pixels. Passive matrix must consider the interference caused by previous signals on subsequent signals. Once scanning begins, it is necessary to wait for the completion of the prior drive before proceeding to the next, resulting in extended refresh times for passive matrix. The page refresh time of passive matrix ChLCD is determined by multiplying the pixel operation time and the number of scan lines. A shorter pixel operation time results in faster page refresh but yields lower contrast ratio, while a longer pixel operation time leads to slower page refresh and higher contrast ratio. Considering the page refresh time, the pixel operation time for passive matrix ChLCD typically ranges from 5 ms to 20 ms.

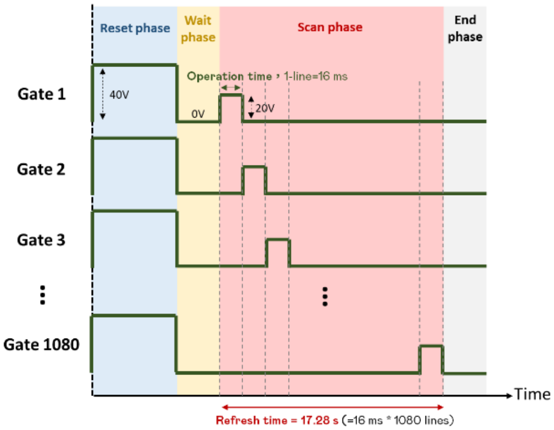

Figure 6. The driving waveform of passive matrix ChLCD.

In active matrix ChLCD, each pixel is equipped with a thin-film transistor (TFT). The gate of each TFT is connected to horizontal scan lines, the drain is connected to vertical data lines, and the source is linked to the ITO electrode. An active matrix ChLCD sequentially activates one horizontal scan line at a time, turning on the TFT while the corresponding vertical data line delivers the appropriate drive signal, charging the electrodes to the required voltage. The TFT is then turned off, preserving the charge on the liquid crystal capacitor until the next signal is written. At the same time, the next horizontal scan line is activated with its corresponding drive signal, allowing for the sequential writing of data for the entire display. Figure 7 presents the driving waveform for the active matrix ChLCD. Given the voltage-holding property of the TFT, the driving process remains unaffected by subsequent signals. This property ensures that the page refresh time for active matrix ChLCD is nearly identical to the pixel operation time. The longer pixel operation time allows the ChLC fully switch into FC texture, achieving the lowest reflectance in the dark state; thus, the active matrix ChLCD can attain the highest contrast ratio without sacrificing page refresh time.

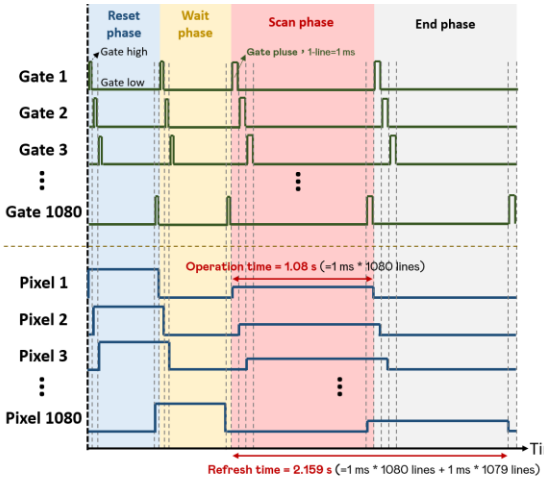

Figure 7. The driving waveform of Active matrix ChLCD.

Table 1 compares a FHD ChLCD under passive and active matrix. The passive matrix ChLCD, with a pixel operation time of 16 ms, results in a page refresh time of approximately 17 seconds. Due to the short pixel operation time, the ChLC cannot fully transition to FC texture, resulting in a contrast ratio of only 5. Conversely, the active matrix ChLCD, with a pixel operation time of 1080 ms, achieves a page refresh time of about 2 seconds. Because the pixel operation time exceeds 500 ms, the dark state attains the lowest reflectance, allowing for a contrast ratio exceeding 10. The active matrix ChLCD's characteristic that the page refresh time is almost equal to the pixel operation time makes it particularly suitable for applications in extremely low-temperature environments. At lower temperatures, the viscosity of the ChLC material increases, causing its response time to slow significantly, necessitating an extension of the pixel operation time. For instance, in a low-temperature scenario, the page refresh times for passive and active matrix FHD ChLCDs are 400 seconds and 12 seconds, respectively.

Table 1. Comparison of ChLCD under passive and active matrix configurations

Tech.	Passive Matrix ChLCD	Active Matrix ChLCD
Resolution	1920 X 1080	
Page Refresh Time	17.28 sec	2.16 sec
Pixel Operation Time	16 ms	1080 ms
CR	5	>10

3. 32-inch Active Matrix ChLC Reflective Display

Outdoor PID has gained widespread usage, moving beyond traditional indoor applications. ChLC technology, with its reflective and bistable characteristics, offers excellent readability in sunlight and ultra-low energy consumption, making it highly suitable for outdoor PID applications. Compared to passive matrix systems, active matrix configurations provide several advantages: 1. Large size capability; in ChLC technology, the RC loading of active matrix is only one-fiftieth that of passive matrix. 2. Faster page refresh speed; active matrix drive each pixel independently through TFT, whereas passive matrix must consider interference from previous signal. 3. Higher contrast ratio; active matrix can achieve longer operation time with shorter page refresh time, yielding a dark state with lower reflectance. Therefore, active matrix ChLCD represent the most suitable display technology for outdoor PID applications.

Figure 8 presents the 32-inch active matrix ChLC reflective display developed by AUO, currently the largest ChLC reflective display in the world, with related specifications shown in Table 2. This active matrix ChLC exhibits excellent optical quality, with a bright state reflectance exceeding 28% and a contrast ratio above 8.5 in normal mode. Due to its bistable characteristics, power consumption occurs only during image transitions, resulting in extremely low power consumption of approximately 0.06 watts (assuming screen transitions every five minutes) and a refresh time less than 3 seconds. Contrast ratio can be adjusted by applying different waveforms to this active matrix ChLCD. In high picture quality (PQ) mode, the contrast ratio can reach as high as 15, although this increases power consumption. In high speed mode, page refresh time can be reduced to under 0.8 seconds by compromising color depth.

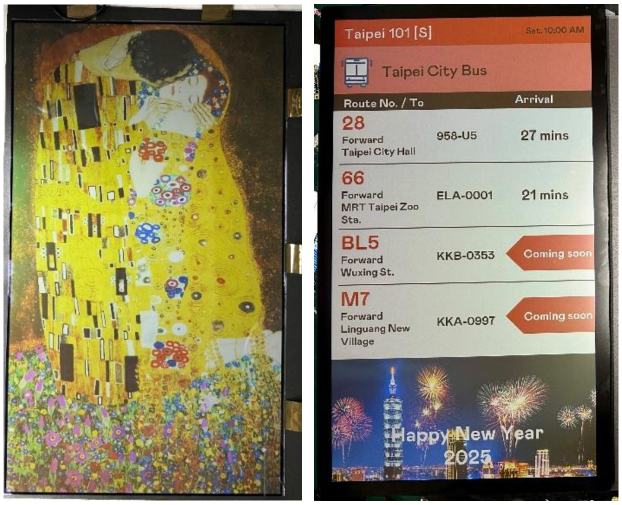

Figure 8. AUO's 32-inch active matrix color ChLC reflective display.

Table 2. Specifications of the 32-inch active matrix ChLC reflective display.

Tech.	32" Active Matrix ChLCD		
Mode	Normal	High PQ	High Speed
Resolution	1920 X 1080		
Operation temp.	-30~85℃	-30~85℃	-30~85℃
Reflectance	28%	28%	28%
NTSC	22%	32%	22%
Contrast Ratio	8.5	15	8.5
Page refresh time (at 25℃)	< 3 sec	< 3 sec	< 0.8 sec
No. of Colors	16.7M	16.7M	32.7K
Power Consumption *(screen transition every 5 minutes)*	0.06 W	< 6 W	0.04 W

4. Conclusion

The world's largest cholesteric liquid crystal (ChLC) reflective display has been developed using active matrix technology. This active matrix ChLC display achieves a reflectance greater than 28% and a contrast ratio exceeding 8.5, while supporting more than 16.7 million colors under the NTSC standard of 22%, ensuring excellent visibility in bright outdoor conditions. The combination the bistability of ChLC and the advantages of active matrix allows for a page refresh time of under 3 seconds and a power consumption just 0.06 watts. Depending on usage scenarios, options are available for either enhanced picture quality or faster page refresh speeds. These features make AUO's 32-inch active matrix ChLCD ideal for outdoor PID applications. Ongoing development of active matrix ChLC technology aims to yield high-quality ChLC reflective displays exceeding 65 inches.

5. References

1. Tseng H, Tien K, Tseng Y, Ke Y, Liao C, Su J. 49-2: Invited Paper: High Performance Cholesteric Liquid Crystal Technology Development. SID Symposium Digest of Technical Papers. 2024 Jun;55(1):662–5.
2. Yang DK, Doane JW, Z. Yaniv, Glasser J. Cholesteric reflective display: Drive scheme and contrast. Applied Physics Letters. 1994 Apr 11;64(15):1905–7.
3. John, Lu Z, J. William Doane. Characterization of reflective cholesteric liquid-crystal displays. Journal of Applied Physics. 1995 Nov 1;78(9):5253–65.
4. John, Fritz WJ, Lu ZJ, Yang DK. Bragg reflection from cholesteric liquid crystals. Physical review E, Statistical physics, plasmas, fluids, and related interdisciplinary topics. 1995 Feb 1;51(2):1191–8.
5. Tamaoki N. Cholesteric Liquid Crystals for Color Information Technology. Advanced Materials. 2001 Aug;13(15):1135–47.