Development of Ultra-High Contrast Dual-Cell LCDs with Moiré Reduction Structures

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Keywords: Liquid crystal display, Dual-Cell, High contrast, Moiré reduction structure

ABSTRACT

We have investigated ultra-high contrast display using dual-cell liquid crystal display (LCD) technology. Dual-cell LCDs have issues such as moiré and color unevenness. Thus, we have developed a dual-cell LCD that solved these issues by arranging a light-shielding pattern in the diagonal direction of the subpixel pitch in a dimming cell.

1 Introduction

In recent years, display devices such as TVs, laptops, and mobile phones have been required to have high contrast ratios such as organic light-emitting diodes (OLEDs), μ-light-emitting diode (LED) displays, and liquid crystal displays (LCDs) with mini-LED local dimming backlight [1]. Moreover, for displays used in fields such as medical diagnostics, broadcasting, and automotive, high reliability as well as a high contrast ratio are required. LCDs are more suitable for these applications than OLEDs and μ-LED displays because they can achieve high reliability. In addition, LCDs have excellent brightness and the resolution characteristics. However, LCDs with mini-LED local dimming backlight have an issue with the display quality accuracy due to the halo effect caused by backlight leakage in low gray levels [2-3]. Therefore, we have developed the dual-cell LCD, which can control the dimming area for each pixel. The dual-cell LCD is an ultra-high contrast LCD technology in which two liquid crystal cells are stacked.

2 Experiment

2.1 Structure of the dual-cell LCD

Our dual-cell LCD has a structure in which a display cell is stacked on a dimming cell. Figure 1 shows a cross-section structure of the developed dual-cell LCD. A color or monochrome cell is used as the display cell, and a monochrome cell is used as the dimming cell. The display and dimming cells are applied in in-plane switching mode. A thin optical clear adhesive film is used to glue the two cells. Four polarizer films are used in the panels. The absorption axes of the two central polarizer films are placed in parallel. Two polarizer films on the panel's outside are placed orthogonally with the absorption axes of the central polarizer films. The central polarizer films are can also be changed from two to one. In this case, the transmittance of the panel increases, but the contrast ratio of the panel decreases to less than half compared with a four-polarizer film composition. The configuration of the polarizer films needs to be examined according to the applications.

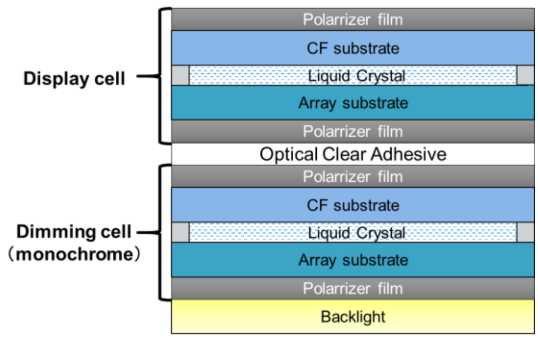
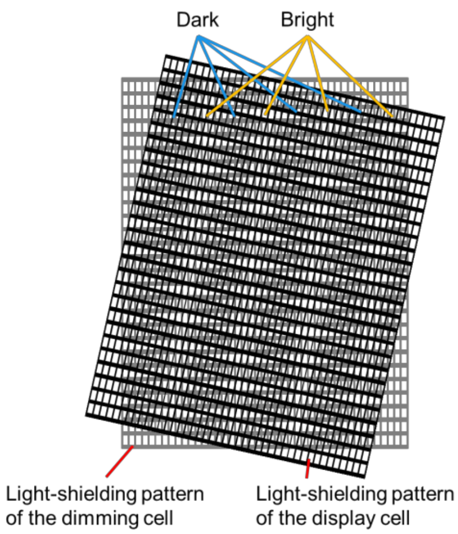


Figure 1. Cross-sectional structure of the dual-cell LCD.

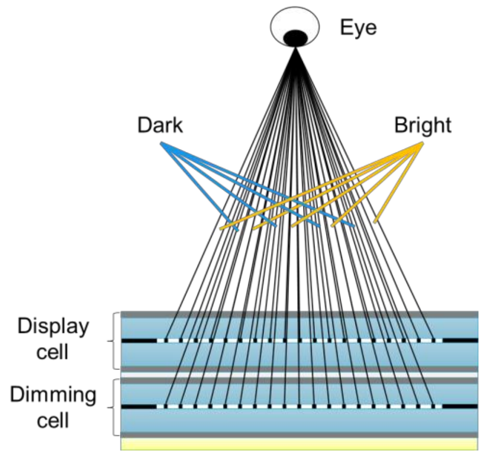
2.2 Moiré phenomenon

Moiré is one of the issues affecting dual-cell LCDs [4]. Two factors are assumed to cause moiré in dual-cell LCDs. One is misalignment; another is parallax. Figure 2 (a) shows a moiré phenomenon caused by the misalignment of the azimuth angle between the display and the dimming cell. Here, the moiré phenomenon occurred because of periodic bright and dark areas generated by misalignment of the light-shielding patterns such as the black matrix and metal lines in the display and the dimming cell. Accordingly, a dual-cell LCD must have a high-accuracy alignment smaller than pixel size.

The moiré phenomenon is caused by not only misalignment but also parallax. Figure 2 (b) shows a moiré phenomenon caused by parallax. This type of moiré is caused by a slight difference in the pitch in a perspective view of light-shielding patterns in the display and the dimming cell due to parallax. Because parallax cannot be eliminated, we investigated structures that reduce moiré caused by the parallax.



(a)



(b)

Figure 2. Principle of moiré phenomenon caused by (a) misalignment and (b) parallax.

2.3 Simulation of moiré

The light-shielding pattern for reducing the moiré of the dual-cell LCD was examined using a moiré simulator. The moiré simulator reproduced moiré by changing the pitch in a perspective view of light-shielding patterns in the dimming cell based on the parallax calculation for each viewing angle. The simulation model's pixel number was set to 50 × 50 pixels for simplification. Figure 3 shows a comparison of simulation and experimental results for moiré when the same light-shielding patterns are stacked as an example. We had confirmed that the moiré level of the experimental result was reproduced in the simulation.

2.4 Unitization of the pixel for dimming cell

The dual-cell LCD can cause moiré due to the dimming

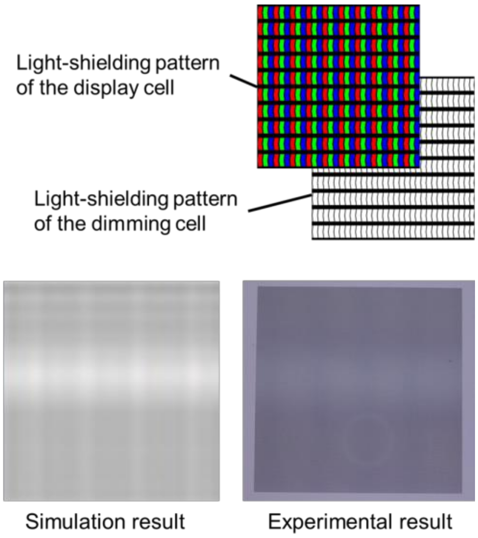


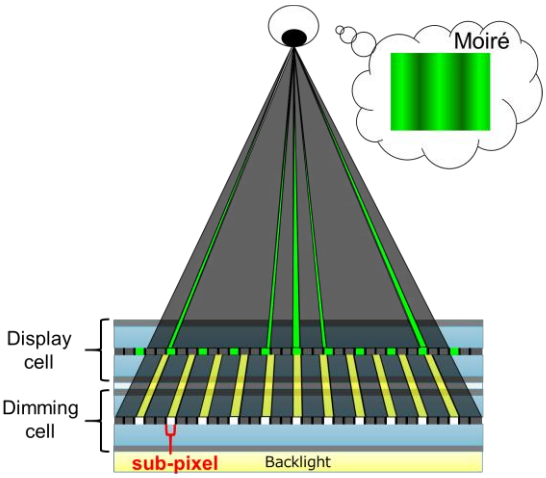
Figure 3. Comparison of simulation and experimental results for moiré.

cell's lighting areas. Figure 4 (a) shows a monochromatic representation of the dual-cell LCD when dimming in each sub-pixel unit. A subpixel unit refers to a red, green, or blue pixel unit. For example, if the display cell illuminates green pixels, the dimming cell illuminates a pixel at the same position as shown in Figure 4(a). In this case, the pixel illuminated by the dimming cell at the same position of the red and blue pixels in a light-off state operates as the light-shielding pattern. As a result, moiré is worsened because of the expansion of periodic dark areas as the width of the light-shielding pattern increases. Therefore, the display of the dimming cell is controlled by three subpixels acting as a one-unit pixel, as shown in Figure 4 (b).

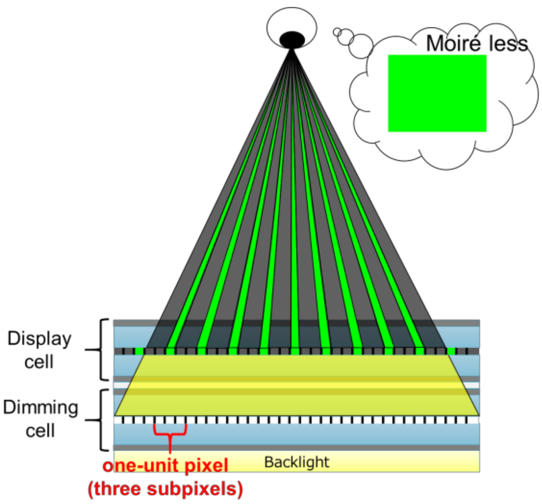
3 Results and discussion

3.1 Results of moiré simulation

Generally, interference between parallel patterns can be suppressed by rotating one of them in an oblique direction. Therefore, the light-shielding pattern of the dimming cell is preferably a zigzag pattern. Figures 5 (a) and (b) show simulation models of light-shielding patterns. The vertical signal electrode is called the source line, and the horizontal scanning electrode is called the gate line. The light-shielding pattern of the source line of the dimming cell is a zigzag pattern that is bent at the same pitch as the pixels. On the other hand, if the gate line is bent to match the subpixel pitch, the pitch of the zigzag pattern must be extremely narrow in comparison with the source line. In this case, moiré worsens because the bending angle of the gate line is nearly parallel to the source line of the display cell. Therefore, gate lines are designed with a narrow width



(a)



(b)

Figure 4. Monochromatic representation of the developed dual-cell LCD when (a) dimming in each sub-pixel unit or (b) three subpixels as one-unit pixel.

without using the zigzag pattern. In addition, the display of the dimming cell is controlled with three subpixels acting as a one-unit pixel. Thus, the light-shielding pattern has also simulated the case of reducing the number of source lines as shown in Figure 5(b). Figures 6 (a) and (b) show moiré simulation results when the light-shielding patterns of Figures 5 (a) and (b) are used. From simulation results, applying the zigzag pattern significantly reduced vertical and horizontal moiré compared to the simulation result of Figure 3. However, when the number of light-shielding patterns in the source line was reduced (Figure 5(b)), color unevenness occurred, as shown in Figure 6 (B). Figure 7 shows a mechanism of color unevenness. When the number of source lines was reduced, the pitch of the light-shielding pattern in the dimming cell is not matched to the subpixels of the display cell. If these pitch discrepancies occur, the red, green and blue (RGB) aperture ratio will change in the plane. As a result, the RGB balance of each pixel changes and the displayed color also changes depending on the position. Therefore, the pitch of the light-shielding pattern in the dimming cell was matched with the subpixels pitch.

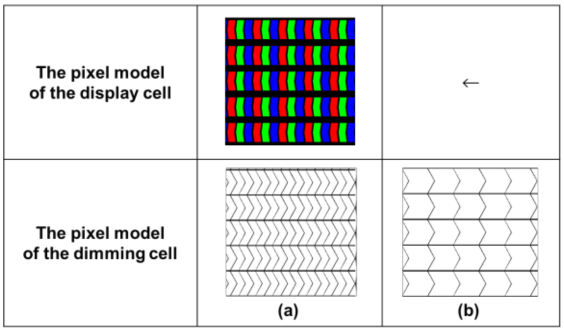
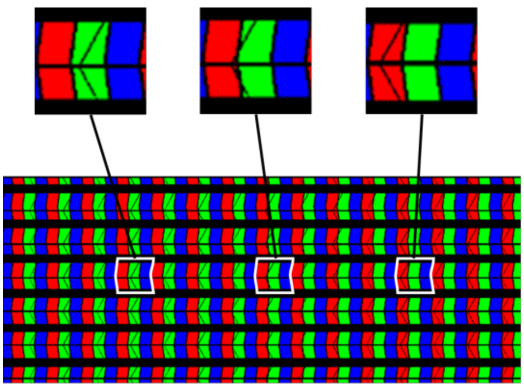


Figure 5. Simulation models of light-shielding patterns.

(a)

(b)

Figure 6. Results of moiré simulation.



Enlarged image of the moiré simulation results (b)

Figure 7. Mechanism of color unevenness.

3.2 Pixel structure of the dimming cell

Figure 8 shows an improved pixel structure of the dimming cell to reduce moiré and color unevenness. The pixels are not divided into subpixel units to increase the transmittance of the dimming cell. The source lines are designed in a zigzag pattern to reduce moiré. In addition, a dummy light-shielding pattern was placed on the pixel as a measure against color unevenness. Indium-tin oxide pixel electrodes were placed to cover source lines not matched with the bending angle of the zigzag pattern.

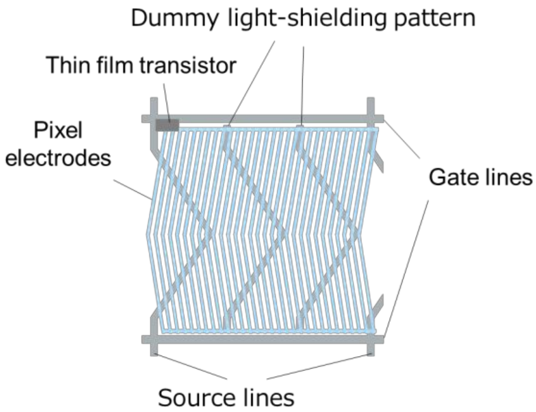


Figure 8. Improved pixel structures of the dimming cell.

4 Conclusions

Moiré is one of the issues affecting dual-cell LCDs caused by two factors. One is misalignment; another is parallax. We proposed a moiré reduction structure for dual-cell LCDs based on simulations and experimental results. A pixel structure with a zigzag pattern and a subpixel pitch reduces not only moiré but also color unevenness. In the future, we will use this pixel structure to fabricate the prototype of a monochrome dual-cell medical diagnostic display with a contrast ratio greater than 500,000: 1, a brightness of 1,000 cd/m^2, and an almost invisible moiré.

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