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High Contrast Ratio FFS-based LCD Switchable to a Stronger Privacy Mode

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Abstract

We have developed an FFS-based LCD that can be switched between two display modes: 1) wide view mode with high contrast ratio and 2) narrow view mode enabling privacy. By combining the new LCD configuration with Switchable Backlight Technology, our 5.3-inch prototype has successfully enabled: 1) enhanced optical properties and 2) privacy mode with the appearance from side viewing direction darker that prevents unauthorized image viewing.

1. Objective and Background

Fringe Field Switching (FFS) based LCD has been widely used for various portable applications such as smartphones, tablet PCs, notebook PCs and automobile displays for the excellent wide viewing angle properties. However, the FFS-based LCD is regarded as unsuitable in terms of privacy protection of personal information displayed on screen. To meet the increasing demand for a display with both a wide viewing angle property and privacy protection, Viewing Angle Adjustable (VAA) techniques based on FFS LCDs have been developed. Previously, a VAA FFS LCD that used a double LC panel system have been proposed but the viewing angle adjustable technology increases manufacturing cost and display thickness. Another reported approach used a single LC panel with a flat transparent electrode on the counter-side substrate, which allows a vertical electric field to be applied in order to obtain the narrow viewing angle mode [1,2]. Also disclosed is a VAA LCD technology wherein each pixel is comprised of three colors' sub-pixels (RGB) and a white sub-pixel in a single panel [3]. However, these LCDs have a critical drawback on the compatibility between the wide view mode and privacy mode.

By combining a new structure of counter-side electrode with Switchable Backlight Technology we propose a novel FFS-based LCD that is switchable between two display modes with high compatibility: 1) wide view mode with high contrast ratio and 2) narrow view mode enabling stronger privacy.

2. Configuration and Operation principle

On-axis contrast ratio-enhanced LCD Configuration:

Figure 1 shows the configurations of a conventional VAA LCD (hereafter "conventional LCD") and a new VAA LCD (hereafter "new LCD"). As shown in Fig. 1 (a), the conventional LCD consists of a TFT substrate and a counter-side substrate. The TFT substrate has first and second pixel electrodes and an insulator between them. The counter-side substrate has a black-matrix (BM), a CF layer, a first overcoat (OC) layer, a flat transparent electrode, and a second OC layer in this order. The LC material has a positive dielectric anisotropy (i.e. positive type LC). Alignment films on each substrate promoted horizontal alignment of the LC (i.e. planar LC alignment). Thus, the LC injected was homogeneously aligned by anti-parallel rubbing treatment on the alignment films. Meanwhile, our new LCD shown in Fig. 1 (b) has a much simpler configuration than the conventional LCD. The counter-side substrate includes a metallic BM electrode, CF layer and thin over coat layer in this order. The metallic BM electrode functions as a third electrode for switching to the narrow view mode. Except for adopting the metallic BM electrode, the structure of TFT-side substrate, LC material and alignment film are the same as the conventional LCD counterpart. The new LCD has a simplified configuration that has greatly contributed to enhancing the optical properties, especially in the wide view mode and to alleviating color mixture due to the parallax from the oblique viewing direction.

Operation principle of wide/narrow view modes:

Figure 2 shows the operation principle of wide/narrow view modes in conventional LCD and new LCD configurations. The operation principle of conventional LCD is shown in Fig. 2(a-1) and (a-2). The wide view mode in the conventional LCD suffers from unwanted vertical electric field when an AC voltage is applied to the first pixel electrode on the TFT-side substrate. Accordingly, brightness (transmission) of the LCD is lowered because the LC retardation is reduced due to

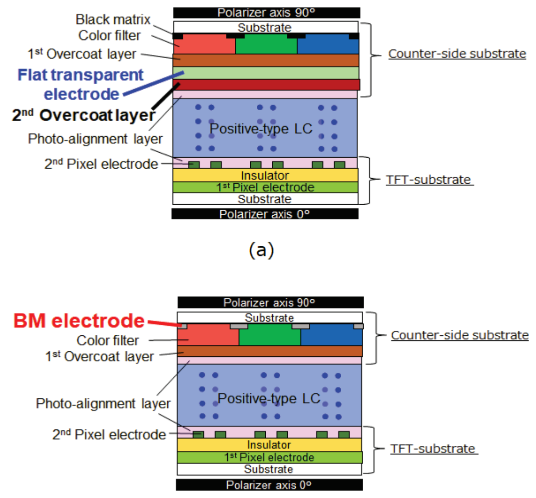


Figure 1. Configuration of (a) Conventional LCD and (b) New LCD

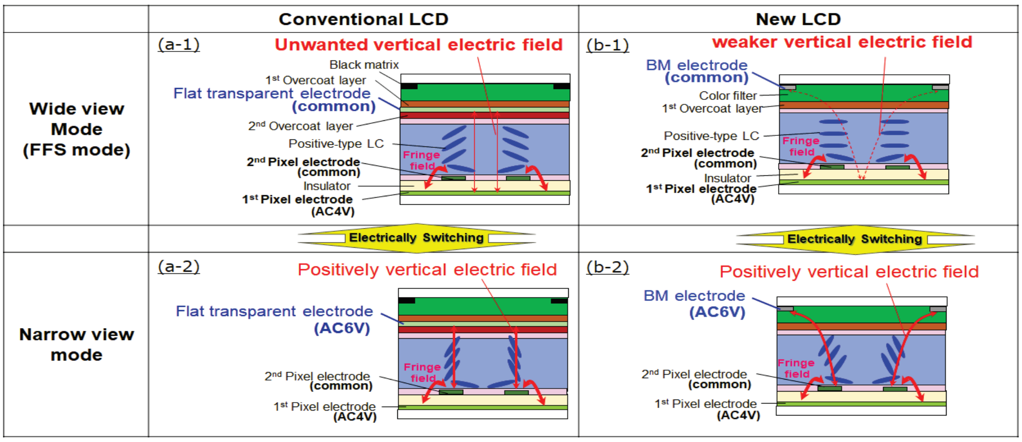


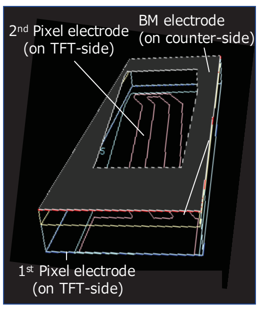
Figure 2. Conventional LCD (a-1) Wide view mode, (a-2) Narrow view mode and New LCD (b-1) Wide view mode, (b-2) Narrow view mode

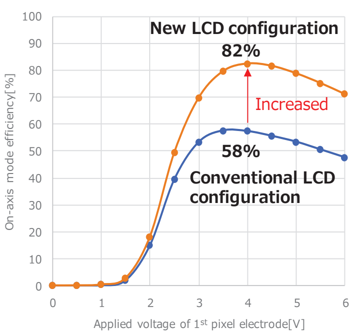
the vertical electric field. Consequently, conventional LCD has lower brightness (transmission) compared to a normal FFS LCD (i.e. FFS LCD without VAA). In the narrow view mode, a good privacy performance from the side direction is achieved owing to the vertical electric field. The operation principle of the new LCD is shown in Fig. 2(b-1) and (b-2). The wide view mode of the new LCD is expected to have similar optical performance as a normal FFS LCD because the unwanted vertical electric field is minimized by electric-shielding from the dielectric layers (CF/OC) placed on the metallic BM electrode. Also, the narrow view mode of the new LCD is expected to have almost the same privacy performance as the conventional LCD.

3. Results

Optical properties (Simulated results):

Figure 3(a) shows the simulated model of our new LCD configuration. Fig. 3(b) shows the comparison of Voltage-Transmission (V-T) curves calculated from the conventional LCD and new LCD models in wide view mode (AC voltage applied to metallic BM: 0V (=common potential)). A maximum of *the LC mode efficiency (defined as the ratio of transmission of LC electrically-driven in cross Nicoll-placed polarizers to that of the layer placed in parallel Nicoll-placed polarizers)* of the conventional LCD was approximately 58% (Luminance~ 300cd/m2), while



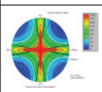
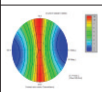
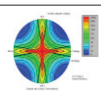
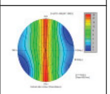


(a) (b)

Figure 3. (a) Structure of New LCD used in optical simulations and (b) Simulated Voltage-Transmission (V-T) curves for wide view mode

that of the new LCD was higher at approximately 82% (Luminance ~450cd/m2). Table 1 below shows the simulated optical properties of the conventional and new LCDs. Simulation results of the wide mode show that the new LCD has a higher contrast ratio (1090 versus 760) and a higher mode efficiency (82 versus 58) than the conventional LCD. In addition, simulation results of the narrow view mode show that the new LCD has a higher

Table 1. Simulated Optical properties

	Conventional LCD		New LCD	
	Wide view mode	Narrow view mode	Wide view mode	Narrow view mode
On-axis CR	760	13	1090	40
On-axis mode efficiency [%] (∝ Transmission)	58	39	82	67
Viewing angle properties regarding contrast ratio				
Applied voltage of counter-side electrode [V]	0	4	0	5.5

contrast ratio (40 versus 13) than the conventional LCD.

Experimental optical properties:

Figure 4 shows the experimental relation between on-axis contrast ratio and an AC voltage applied to the counter-side electrode of conventional LCDs and new LCD. Applying AC0V(COM) to the BM electrode corresponds to the wide view mode, in which on-axis CR of our new LCD is drastically enhanced to 927 compared to that of the conventional LCDs; CR of conventional LCD(1) with second overcoat (OC) layer ~623 whereas CR of conventional LCD(2) without second OC layer ~277.

Applying AC4~6V to the BM electrode enables the narrow view mode. In the narrow view mode, the on-axis CR of the new LCD is 358, which is higher than the conventional LCD(1) with second overcoat (OC) layer (CR=133) and significantly higher than the conventional LCD(2) without second OC layer (CR=35). Experiments proved that the new LCD design enables relatively high CR ratio in both the wide view mode and narrow view mode. Also, we experimentally confirmed that our new LCD has a higher mode efficiency than the conventional

LCD, with efficiency improvement ranging from 1.1 to 1.2 times that of the conventional type.

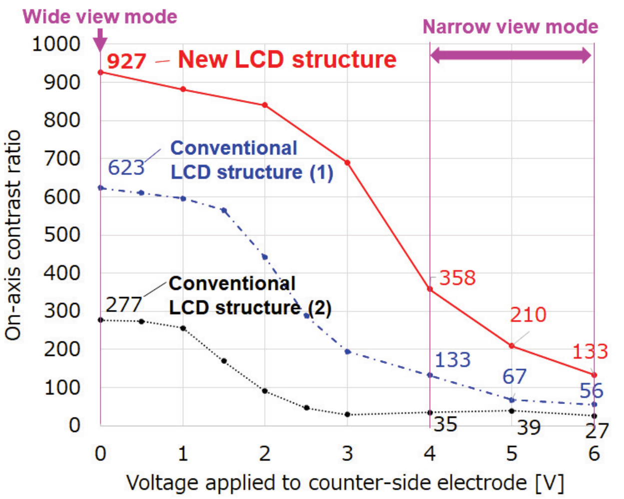


Figure 4. On-axis contrast ratio determined by experiments as a function of voltage applied to counter-side substrate electrode

Switchable Backlight Technology:

Although an LCD privacy effect from the side direction is enhanced by applying a voltage to the BM counter-electrode, the displayed image on the new LCD screen is objectionably bright due to the off-axis light leakage, consequently, the privacy performance (i.e. privacy strength and quality) was still not satisfactory. In order to improve the privacy performance at the side view direction, Switchable Backlight Technology was used to further improve privacy strength and quality. Fig. 5 shows a Switchable Backlight (BL) Technology; (a) Schematic diagram, (b) BL-Public mode, (c) BL-Privacy mode.

In Fig. 5(a), the switchable Backlight consists of a public light guide, a louver film, a LED1 and a normal BL. The public light guide is PMMA substrate including micro particle which causes dispersion of incident beam with wide viewing angle. And the normal BL consists of a Brightness Enhancement Film (BEF), a normal light guide, a reflector and a LED2. The combination of the normal BL and the louver film exhibits the narrow viewing angle since micro particles in the public light guide do not cause dispersion of incident light due to the short light path.

With reference to Fig. 5(b), when both LED1 and LED2 are simultaneously turned on, the switchable BL functions as a BL-Public mode (wide viewing mode by Backlight). As for Fig. 5(c), in when LED1 is tuned off and LED2 is turned on, the switchable BLs functions as a BL-Privacy mode (narrow viewing mode by Backlight). Therefore, the combination of our LCD configuration with BM electrode and Switchable Backlight Technology is suitable for the development of a new LCD that can be switched between a wide view mode and a stronger privacy mode.

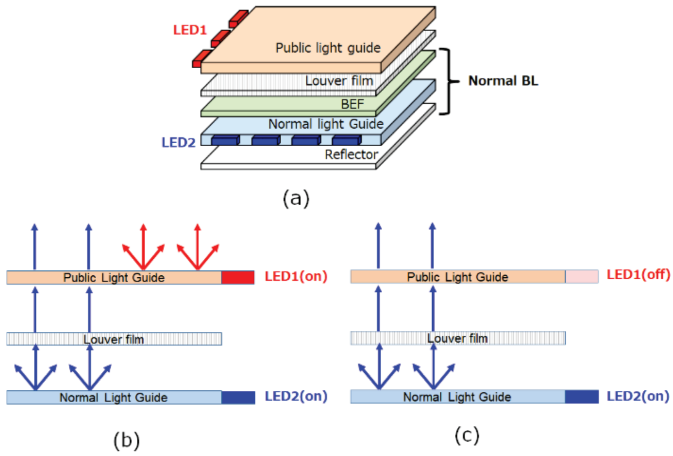


Figure 5. Switchable Backlight technology; (a)Schematic diagram, (b) BL-Public mode, (c) BL-Privacy mode

5.3-inch Prototype of new switchable LCD:

We have developed a new 5.3-inch high CR FFS-based LCD prototype that can be switched to a stronger privacy mode (Fig. 6). Table 2 shows the specifications of the new 5.3 inch prototype LCD. The on-axis contrast ratio of the New LCD is 900 in the wide view mode and ~200 in the narrow view mode. The new LCD has superior CR to the conventional LCD in both the wide view mode and narrow view mode. In addition, when BL-privacy mode in Switchable Backlight Technology is applied to the narrow view mode, a stronger privacy effect is observed. Therefore, in the wide view mode the new LCD has the same optical performance (contrast ratio, viewing angle) as a normal FFS mode (no privacy function) but the new LCD has a stronger privacy mode that prevents unauthorized image viewing with the appearance from side viewing direction darker.

Figure 6. 5.3 inch Prototype of new switchable LCD;
(a) Wide View mode (BL: public, LC: public),
(b) Normal Privacy mode (BL: public, LC: privacy),
and (c) Stronger Privacy mode (BL: privacy, LC: privacy)

Table 2. Specification of 5.3 inch Prototype

Panel Size		5.3 inch		
Number of Pixels		1920×1080		
Resolution		400ppi		
mode		**Wide View** (BL:public, LC:public)	**Narrow View (Normal Privacy)** (BL:public, LC:privacy)	**Stronger Privacy** (BL:privacy, LC:privacy)
Display Luminance		450cd/m2	350cd/m2	350cd/m2
On-axis CR		900:1	200:1	200:1
Privacy performance	@front-view	Visible	Visible	Visible
	@side-view	Visible	Almost-Non-Visible (Bright)	Non-Visible (Dark)
Applied voltage of BM electrode		0V	AC5.5V	AC5.5V

4. Conclusion

By combining a new structure of counter-side BM electrode with Switchable Backlight Technology, we developed a novel FFS-based LCD that is switchable between two display modes with high compatibility: 1) wide view mode with high contrast ratio and 2) stronger privacy mode. By adopting a metallic BM electrode as the counter-side electrode for applying a voltage, CR of our new LCD in the front viewing direction was enhanced to a sufficient level of 927 in the wide view mode (1.5 times more than a conventional type LCD with a privacy function). The CR of our LCD in the front viewing direction was enhanced to 200 in the narrow view mode, which is twice as high as a conventional type LCD with a privacy function. By applying BL-Privacy mode in Switchable Backlight Technology, privacy strength is further enhanced to prevent unauthorized image viewing with the appearance from side viewing direction darker.

The additional manufacturing cost of the new LCD is almost negligible. We believe that our new FFS-based LCD will open a new era of smartphones, notebook PCs and automobile displays.

5. References

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