EP2/DES4 - 5L
(Late-News Paper)
Invited

High-Performance and Low-Power Full Color Reflective LCD for New Applications

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Keywords: reflective LCD, VA, MRS, IGZO, 1Hz drive

ABSTRACT

We have developed a reflective LCD with full color video image and low power consumption. 22-inch and 11-inch prototype have achieved excellent optical properties and flicker-less 1Hz driving by a new twisted VA-LC mode, reliable materials, an optimal electrode design with micro reflective structure (MRS), and IGZO-TFT technology.

1 INTRODUCTION

Since the reflective display has low power consumption, it is used in electronic book readers, smartwatches, electronic shelf labels, and the like. A practical application as digital signage is also being studied. The electrophoretic electronic paper adopted in many electronic book readers is difficult to multicolor and cannot display moving images. The reflective liquid crystal display (LCD) with the Memory in Pixel (MIP) is applied to the smartwatch. The reflective LCD with MIP can display in multi-color relatively easily, but it is impossible to produce a full color display because the number of colors is limited for multi-color by area gradation display using several sub pixels.

In recent years, various video streaming services utilizing the internet have been used by many people, and large numbers of video files are posted on social media. Thus, it is expected that movie display functions will be required for each reflective display in the future. Under such circumstances, improvement of display reflection performance and reduction of power consumption are urgent issues for mobile terminals including electronic book readers. Therefore, we have developed a novel reflective LCD with low power consumption that can display full color moving images by combining a new reflective LCD mode with IGZO-TFT technology capable of low frequency driving. In this paper, we report the technology of the novel reflective display and prototypes.

2 EXPERIMENT AND RESULT

2.1 Stacking up structure

Fig.1 shows the structure of the reflective LCD. From the observer side, the reflective LCD is composed of a front polarizer, a retardation film, a color filter (CF) substrate, a liquid crystal (LC) layer, and a thin film transistor (TFT) substrate. An alignment layer material formed on the TFT substrate and the CF substrate is treated in an alignment process. Hence, the LC layer has a pre-tilted angle. On the TFT substrate, an electrode with micro reflective structure (MRS) having many concave-convex shapes is formed on the organic insulating layer. Ambient lights incoming at a certain angle are efficiently reflected and scattered by the MRS reflective electrode, so that a bright display can be obtained [1] [2].

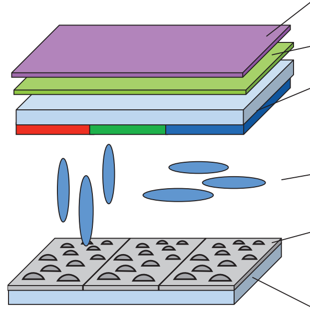

Fig.1 Structure of reflective LCD

2.2 Design of LCD mode

The twisted planar aligned LC mode, which we call High Reflective (HR)-TFT mode, is one of the well-known modes for reflective LCD [3] [4]. The HR-TFT mode is a normally white LC mode. The reflectance of this LC mode in the white state is high, and that in the black state is also high. Hence, the contrast ratio and color reproducibility range (NTSC ratio) are insufficient. In addition, there is room to improve viewing angle characteristics because it is necessary to suppress light leakage in the black state at an oblique viewing angle.

The twist VA mode that we employ is a normally black LC mode. The reflectance in the black state of this LC mode is low, so that contrast ratio is high. We performed a numerical simulation by changing the alignment orientation of LC molecules, the optical axis azimuth angle of the retardation film, and its retardation value. Based on the results, we have designed a structure that can reduce the reflectance in the black state under a wide viewing angle.

We simulated three conditions: (a) HR-TFT, (b) twisted VA mode type1, (c) twisted VA mode type2. Condition (b) is based on the concept of low cost, and condition (c) is based on the concept of emphasizing performance. Fig.2 and Fig.3 show the reflectance viewing angle for the white state and the black state under each condition. Fig.4 shows a contrast ratio for each condition. The calculated values of reflectance in either states and the contrast ratio are normalized values.

As shown in Fig.2, the high reflectance range of the white state in either twisted VA mode types is narrower than that in the HR-TFT mode. However, either twisted VA modes have the same level of reflectance as the HR-TFT mode in most of ranges. The difference between two twisted VA mode types is small. In either twisted VA mode types, the reflectance of the black state in the direct and oblique viewing angles is lower than that in HR-TFT mode, as shown in Fig.3. The reflectance in the black state of twist VA mode type1 is partially higher than that of HR-TFT mode, but it is lower in the range of about two-thirds of the total viewing angle (Fig.3). In the twisted VA mode type2, the reflectance in the black state in the range of polar angle 40 ° to 80 ° is extremely low compared with the other conditions (Fig.3). As shown in Fig.4, either twisted VA mode types greatly improve the viewing angle range with a high contrast ratio. The contrast ratio of the twisted VA mode type2 is higher than that of the twisted VA mode type1 in the range up to the polar angle 60 ° which is commonly used (Fig.4). From the above results, we have selected the twisted VA mode type2 of the condition (c) as the optimal configuration.

2.3 Reflection Characteristics in Prototype

When preparing a prototype based on the configuration designed by the simulation, we used not only the aluminum normally used in HR-TFT mode, but also silver alloy as an alternative reflective material for the electrode. Further, the twisted VA mode is normally black, and it is possible to increase the aperture ratio by deleting the black matrix (BM) on the CF substrate. Therefore, the BM has been removed in the prototype.

Fig.5 shows the pixel observation results for the black state of prototypes. In the HR-TFT mode, the reflectance in the black state increases and the contrast ratio decreases due to the light leakage around the wiring [Fig.5(a)]. On the other hand, in the twist VA mode, high contrast ratio can be achieved without BM since the light leakage around the wiring is suppressed [Fig.5(b)].

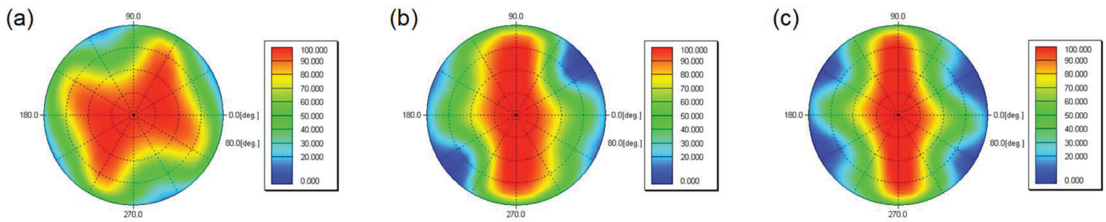

Fig. 2 Simulation results of reflectance in white state; (a) HR-TFT, (b) twisted VA mode type1, (c) twisted VA mode type2

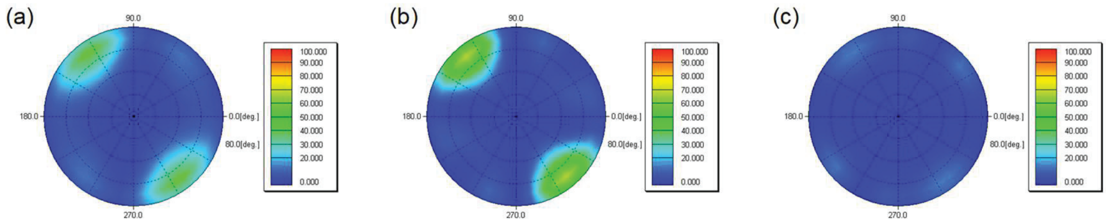

Fig. 3 Simulation results of reflectance in black state; (a) HR-TFT, (b) twisted VA mode type1, (c) twisted VA mode type2

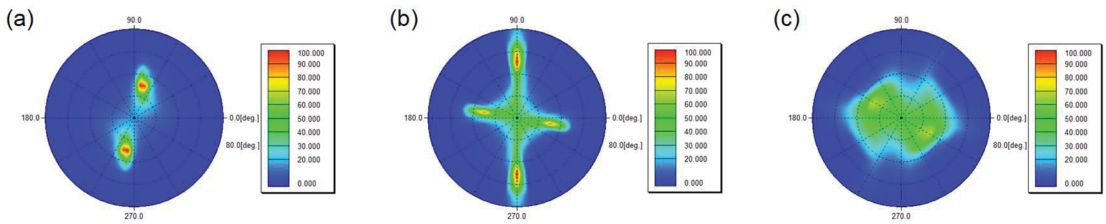

Fig. 4 Simulation results of contrast ratio; (a) HR-TFT, (b) twisted VA mode type1, (c) twisted VA mode type2

Table1 Comparison results for reflectance characteristics

	HR-TFT with aluminum electrode	New Twisted VA with aluminum electrode	New Twisted VA with silver alloy electrode
Reflectance for black state	0.73%	0.32%	0.41%
Reflectance for white state	7.70%	7.50%	9.42%
Contrast ratio	11 : 1	23 : 1	23 : 1

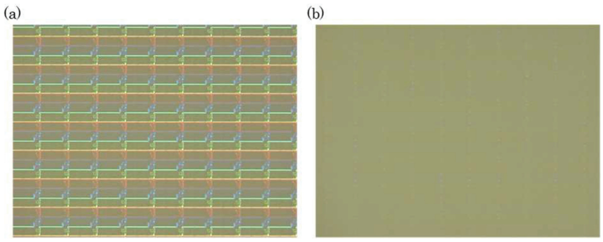

Fig. 5 Pixel observation results of black state; (a) HR-TFT, (b) twisted VA mode

The comparison results of the reflectance characteristics of prototypes are summarized in Table1. When compared with those of the aluminum reflective electrode configuration, the reflectance in the white state of the new twisted VA mode is equivalent to that of the HR-TFT mode. In the twisted VA mode, the contrast ratio is high because the reflectance in the black state is as low as one half or less of that in the HR-TFT mode. In addition, by changing the reflective electrode from aluminum to silver alloy, the reflectance can be improved from 7.50% to 9.42%.

In Fig.6, we show the contrast ratio viewing angle. The incident angle is -30°, and the receiving angle is from 0 ° to 60°. The azimuth angle is 315° that is the same as the azimuth angle in the simulation result of Fig.4. The measurement point of specular reflection angle was not able to measure well since the effect of the surface reflection of the polarizer is large. However, the twisted VA mode has higher contrast ratio than HR-TFT mode at most other receiving angles (Fig.6). And we have confirmed that the contrast ratio of the twisted VA mode is high at azimuth angles other than 315 °.

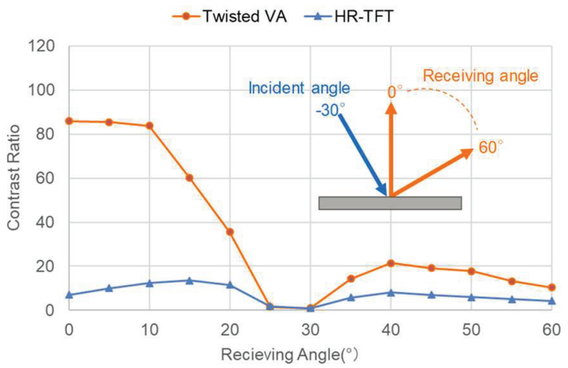

Fig.6 Measurement result of the contrast ratio viewing angle of prototypes

2.4. Realization of low power consumption

We adopted oxide semiconductor Indium Gallium Zinc Oxide (IGZO) as TFT element. The IGZO-TFT has low off-leakage current of the I-V characteristic, and thus both low-frequency driving and 16,770,000 colors (8-bit RGB colors) are possible [5]. Taking advantage of the features of this IGZO-TFT, the prototype switches the driving frequency to 60Hz when displaying moving images and 1Hz when displaying still images. As shown in Fig.7(b), a voltage is applied to the TFT elements of each pixel for one frame in 60 frames at 1Hz drive. In the remaining 59 frames, the driver IC and the driving circuit of LC panel are almost off. Hence, it is possible to drastically reduce the power consumption using 1Hz pause drive.

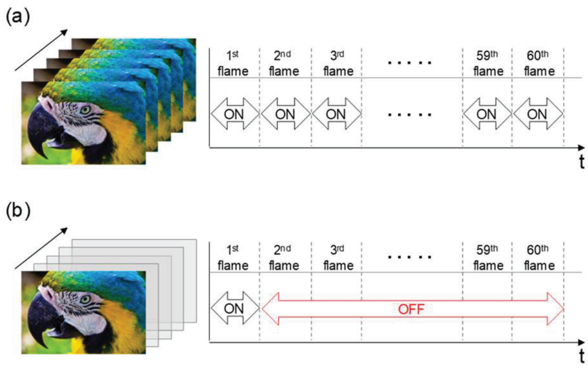

Fig.7 Driving image; (a) 60Hz drive, (b) 1Hz drive

In general, when the LCD is driven at the low-frequency, the display quality is often reduced significantly by flicker. There are two typical causes of flicker generation. One is temporary luminance change (reflectance change) due to a decrease in the voltage holding ratio (VHR) of the LC panel. The other is a change in the optimal counter voltage due to the residual DC (r-DC) component caused by impurity ions in the LC layer being biased to the single-sided substrate. We have solved these problems by newly developing highly reliable materials (LC, alignment film, sealing material) and a method of optimizing reflective electrode design focusing on work function. As a result, a flicker-less 1Hz drive has been achieved. Fig.8 shows the flicker measurement result at 1Hz drive in grayscale. Normally, the intense flicker is likely to occur in gray scale, but luminance changes about 0.1cd / m^2 of Fig.8 is not visible, and the flicker value of JEITA method is -71.9dB.

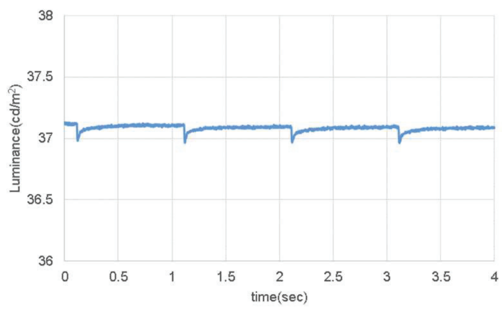

Fig.8 Result of 1 Hz flicker measurement in grayscale

Fig.9 shows the estimated power consumption of the 22-inch prototype when the tentative circuit for technical inspection is replaced with a circuit for mass production. As a backlight is not required, the power consumption even at 60Hz drive is 3970mW, which is less than one tenth of that of the 22-inch transmissive LCD. And the power consumption at 1Hz drive is 556mW, which is one-seventh of 60Hz drive.

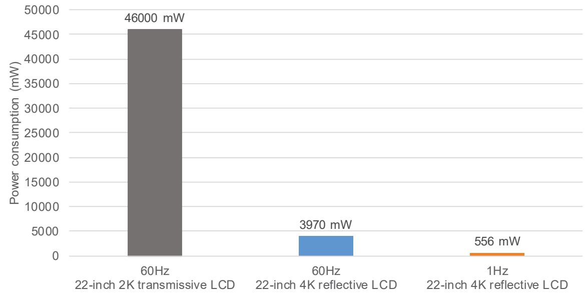

Fig.9 Estimated power consumption at each driving frequency

3 PROTOTYPE SPECIFICATON

Table2 shows the specification of prototypes. The LCD mode is the new twisted VA mode using a negative type LC material and a vertical alignment layer, and the reflective electrode is made of the silver alloy. Number of pixels for the 22-inch is 3840 × RGB × 1920, and that for the 12-inch is 1280 × RGB × 1920. The resolution is 200ppi, the number of colors is 16.77 million, the reflectance is 9.42%, the contrast ratio is 23 : 1, and the NTSC ratio is 19%. The estimated power consumption at 60Hz is 3970mW for the 22-inch and 1400mW for the 12-inch, and 556mW and 283mW at 1Hz, respectively. Fig.10 is a photograph of prototypes.

Table2 Specification of prototypes

Panel size	22-inch	12-inch
Number of pixels	3,840 × RGB × 1,920	1280 × RGB × 1,920
Resolution	200ppi	
Number of colors	16.77M (Full color)	
Reflectance	9.42%	
Contrast ratio	23 : 1	
Color gamut	NTSC 19%	
Power consumption (driving frequency)	3970mW / 556mW (60Hz / 1Hz)	1400mW / 283mW (60Hz / 1Hz)

Fig.10 22-inch and 12-inch prototype

4 SUMMERY

By combining the new twisted VA mode and the silver alloy MRS reflective electrode, we have achieved high reflectance, high contrast ratio and high NTSC ratio. Moreover, by employing IGZO-TFT technology and optimally designing members such as reflective electrode structure and LC material, alignment film material, the flicker-less 1Hz drive has been realized. Consequently, we have developed the reflective LCD that is able to display full-color moving images and has low power consumption.

In recent years, various video streaming services utilizing the internet have been used by many people, and video files are frequently posted on social media. Thus, it is expected that movie display functions will be required for electronic book readers and digital signage in the future. Since the newly developed reflective LCD is capable of full color video display and low power consumption, we expect to contribute greatly to performance improvements for either applications. In addition, we believe that the novel reflective LCD will allow the creation of new applications.

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