Viewing Angle Controllable LCDs with RGBW CF

Mengqing Zhu, Shaonan Zhang, Jun Jiang, Smart Chung, Wei Quan, Jiajun Shen

R&D Center, InfoVision Optoelectronics (Kunshan) Co., Ltd, No.1, Longteng Road, Kunshan, Jiangsu 215301, China
Institute of Jiangsu (IVO) Flat-Panel-Display Technologies, Jiangsu, China

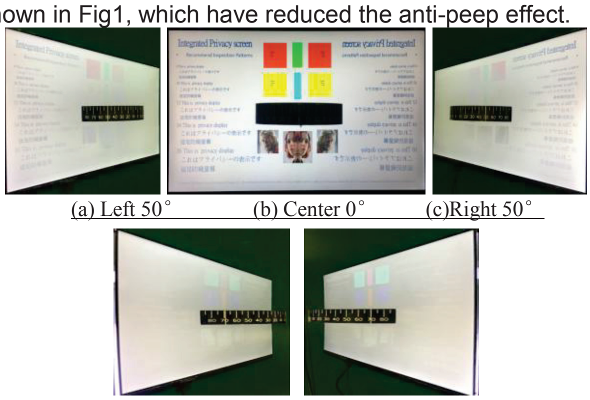
Keywords: Viewing Angle Controllable, RGBW CF, Contrast ratio,

ABSTRACT

This paper researched a viewing angle controllable FFS-LCD with RGBW CF, the measurement results show good anti-peep effect and low contrast ratio. Compared with conventional device and by analyzed the root causes of light leakage, we propose some methods to improve contrast ratio.

1. INTRODUCTION

Fringe Field Switching Liquid Crystal Display (FFS-LCD) has become one of mainstream panel display because of its high resolution, light weight, energy saving, high contrast and no radiation [1]. With the popularity of personal display and people's attention to protect personal privacy, there is a strong market demand for Viewing Angle Controllable Liquid Crystal Display (VAC-LCD) [2]. Many investigations were proposed on VAC-LCD, one is highly initial aligned pre-tilt angle about 50° ~90° at top plate while the bottom substrate aligned pre-tilt angle of 2° with negative liquid crystal [3~4]. Another technique is no need for larger pre-tilt angle with positive liquid crystal [5], it can switch between WVA (Wide Viewing Angle) mode and NVA (Narrow Viewing Angle) mode by controlling the third electrode voltage on RGB side. In NVA mode, both sides have gray scale inversion at large viewing angle, as shown in Fig1, which have reduced the anti-peep effect.



(a) Left 50° (b) Center 0° (c)Right 50°

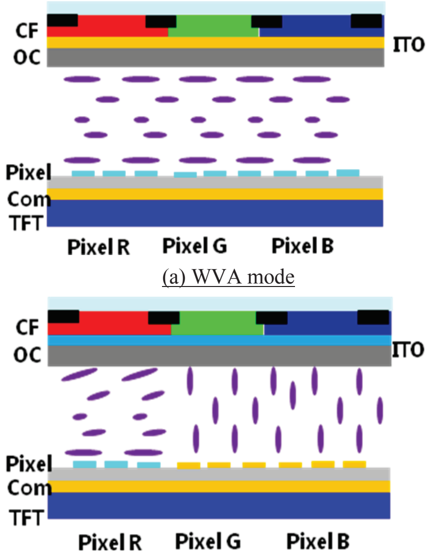
(d) Left 70° (e)Right 70°

Fig1. Prototype of conventional device with 13.3inch VAC-LCD

In this paper, we proposed a VAC-LCD with RGBW CF, which has no gray scale inversion.

2. OPERATION PRINCIPLE

The structure of the conventional VAC-LCD by controlling the third electrode voltage on CF side, the wide viewing angle (WVA) and narrow viewing angle (NVA) switch as shown in Fig2. In WVA mode, the third electrode applied with a voltage of 0V, in NVA mode, the third electrode applies an alternating voltage to form a vertical electric field.



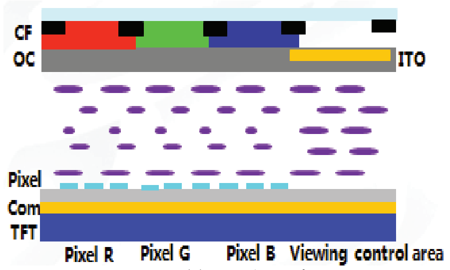
(a) WVA mode

(b) NVA mode

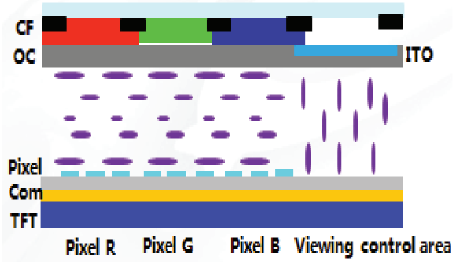
Fig2. Schematic of the conventional VAC FFS LCD

Gray scale inversion occurs because liquid crystal molecules are in a standing state by a vertical electric field in NVA mode, and these pixels leak lights when the observers viewed obliquely. For example, when a red pattern is displayed, only the pixel R is rotated horizontally, the observers will see a cyan display at large viewing angle because the pixel G and pixel B are leaking lights.

We proposed the viewing angle controllable structure is a bottom substrate which provides the first and the second electrode on pixel RGB, and a top substrate which is provided with the third electrode at viewing control area. By controlling the third electrode voltage on W (White) color resist side, the panel can switch between the WVA mode and the NVA mode. The schematic is shown as Fig3.



(a) WVA mode



(b) NVA mode

Fig3. Schematic of the proposed VAC FFS LCD with RGBW CF

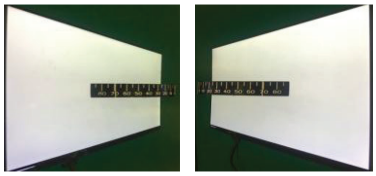
For WVA mode, the first and second electrode, which named common electrode and pixel electrode respectively, forming a strong edge field effect is same as the conventional FFS display, the third electrode applied with a voltage of 0V only at W side. As for the NVA mode, the first and second electrode applies the same voltage as WVA mode, the third electrode applies an alternating voltage to form a vertical electric field. The liquid crystal under the W has a large pre-tilt angle, and the liquid crystal molecules have a phase delay in the off-axis direction, resulting in the increasing of light leakage at the dark-state. Just only viewing control areas are light leakage, so there won't be grayscale inversion.

3. EXPERIMENT RESLUTS AND DISSCUTION

In this research we have a 13.3 inch VAC-LCD sample, which has 1920 RGB * 1080 resolution, active area with 293.76 mm length and 165.24 mm width. The materials of first, second and third electrode are indium tin oxide, the thickness of the first and second electrode are both 600A and the third electrode is 400A, the width and pitch of the pixel electrode are 3.5um, 7um respectively, the thickness of the pixel electrode and the common electrode passivation layer is 2500A. The twisted nematic LC material (Merck, $\triangle\varepsilon$ =6.8, $\triangle$n=0.1116 at 589 nm, Tni= 100 deg C, r1=100 mPa*s, K11 = 15 PN and K33 = 15.75 PN) is used. The ratio of viewing control area to the display area is 1:1 on CF. The transmittances of the single polarizer is greater than 41.5%, pairs of parallel and crossed polarizer were assumed to be 35% and 0.0090%, respectively.

Fig4 show the 13.3 inch VAC-LCD prototype, when we form a vertical electric field by applying an AC signal about 5 V to the third electrode, the tilt angle of the LC molecule makes a narrow viewing angle, within 50 degrees viewing angle, it has no color fades, and the content is invisible. There will be no grayscale inversion as the viewing angle increases.

(a)Left 50° (b) Center 0° (c)Right 50°



(d) Left 70° (e)Right 70°

Fig4. Prototype 13.3inch VAC-LCD of proposed device

According to results of the actual optical measurement, contrast ratio of WVA and NVA mode in horizontal direction is shown as Fig5 and Fig6.The contrast ratio of both devices are above 10:1 at 85° in WVA mode, conventional device is above 3:1 at 50° while proposed device at 35° in NVA mode. Compared with conventional device, the device we proposed has lower contrast ratio, and the viewing angle is narrower.

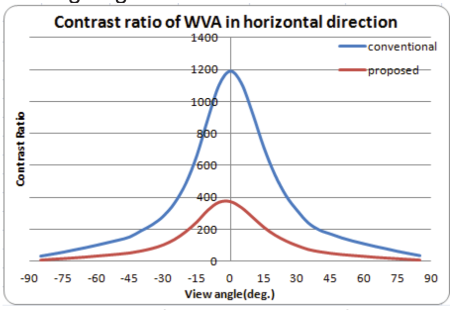


Fig5. Contrast ratio of both devices of WVA mode in horizontal direction

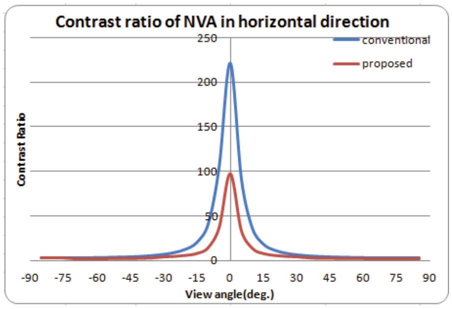


Fig6. Contrast ratio of both devices of NVA mode in horizontal direction

In WVA mode, the conventional device has a high contrast ration of 1193, and the RGBW device contrast ratio is 373, which is 31.3% of the conventional device. As we know, the contrast ratio is defined as white brightness divide dark brightness, the pixel ITO is only in RGB pixel, and half of the RGBW device area is W pixel without pixel ITO. Therefore, the brightness of white state is only 47.9% of the conventional device. The dark brightness of RGBW device is 153.1% of the conventional device. One reason is that the W color resist material has a high transmittance, and the other reason is that the different thickness between RGB color resist and W color resist, that causes the W edge stage to be too large, resulting in serious light leakage. Fig7 is the SEM of RGBW CF, the average thickness of RGB color resist is 5.11um, and the thickness of W color resist is only 4.72um, there is still a 0.39um gap after UV OC layer.

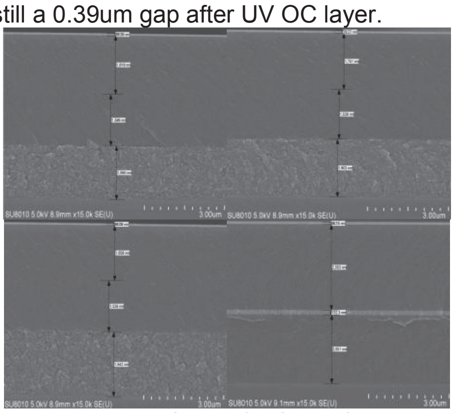


Fig7. The SEM of RGBW CF

In NVA mode, the contrast ratio of the conventional device is 323, and the RGBW device is only 202, which is 62.5% of conventional device. The brightness of the white state is 44%, which is the same reason as WVA mode. A vertical electric field is applied only to the W pixel in NVA mode, since there is a 1.35um gap before ITO at W color resist, the ITO electric is not perpendicular, and there will be an oblique electric field. The dark state leaks lights, whose brightness is 70.4%.

Through the above analysis, the main reason for the lower CR is that coating white color resistance resulting in a large gap of W color resist. In order to improve the flatness on CF, we propose two methods. One is pattern white but it need to increase a W photo mask and use white color resist with higher contrast ratio. In this way the exposure of W is same as RGB, the thickness will be similar, an d the flatness of the whole surface after UV OC will be better. The other one is to form white color resist by using UV OC with half tone mask, so that the thickness of the W resist will be same as the RGB.

Table 1 shows the measured optical data of 13.3 inch VAC-LCD panel. The difference of brightness and contrast ratio between conventional device and proposed device is caused by the reasons that mentioned previously. The proposed device has omnidirectional viewing angle and fast response time in WVA mode, and has a smaller viewing angle in NVA mode, which means a better anti-peep effect. Response time is extended but it is still within acceptable limits. In addition, the NTSC of RGBW is slightly smaller, which is a normal fluctuation range. We know that although the W color resist is increasing, NTSC will not be affected.

Table1. A specification of prototype 13.3 inch VAC-LCD

13.3inch VAC-LCD					
		conventional		proposed	
display mode		WVA mode	NVA mode	WVA mode	NVA mode
Luminance		681cd/cm²	323cd/cm²	326cd/cm²	202cd/cm²
Contrast ratio		1193:1	222:1	373:1	98:1
Viewing angle	CR > 10	±85deg	±20deg	±85deg	±10deg
	CR > 3	±85deg	±50deg	±85deg	±35deg
Response time		23ms	8ms	24ms	19ms
NTSC		72	63	70	61

We also studied the color difference between two devices. As shown in Fig8, red and yellow triangles stand for the conventional and proposed devices color chromaticity respectively in WVA mode.

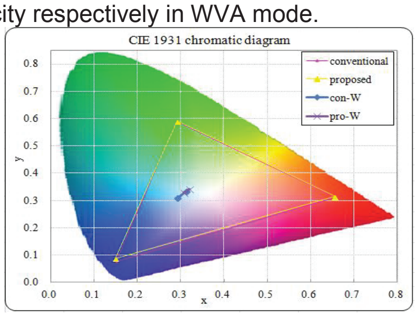


Fig8. Color Chromaticity of the both devices VAC-LCD

4. CONCLUSION

In conclusion, we have shown a prototype 13.3 inch VAC-LCD with RGBW CF, this VAC-LCD can switch between narrow viewing angle display mode and wide viewing angle mode freely through CF ITO under W color resist side, which has no grayscale inversion in NVA mode. The actual optical properties show that the wide viewing mode can display as same as normal do, while the narrow viewing mode can reduce viewing angle to 35 degrees in horizontal direction.

5. ACKNOWLEDGEMENT

The authors would like to appreciate team members of Project 13.3 inch for providing supports.

REFERENCES

[1] Liu C. T. , Revolution of the TFT LCD technology. J. Journal of Display Technology, Vol. 3, No. 4, pp. 342-350, (2007).

[2] ZHU Mengqing. , New viewing angle controllable with FFS-LCD, Chinese Journal of Liquid Crystals and Display, Vol. 33, No. 3, pp. 182-187, (2018) .

[3] Limei Jiang., Viewing angle controllable LCDs with hybrid aligned nematic LC, International Display Workshops, pp.225-227, (2016)..

[4] XU Yaqin. , A New viewing angle controllable LCD, CHINA FPD CONFERENCE, pp.35-640,(2016).

[5] Mengqing Zhu. , The Optical Properties of Viewing Angle Controllable LCD, International Display Workshops, pp.219-221,(2017).