Gray Level Inversion Improvement for Viewing Angle Controllable LCD

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ABSTRACT

We proposed a novel method to solve gray level inversion of viewing angle controllable LCDs. By narrowing the overlap area between pixel and bias electrode, brightness at white state increases obviously at large view in privacy mode. Experiment proved that gray level inversion in privacy mode can be effectively improved.

1. INTRODUCTION

Nowadays, with the development of the liquid crystal display (LCD) technology, the viewing angle of the display has been widened from about 120° to over 160° to accommodate the viewer's movement for a better viewing experience. However, on many occasions, when the device needs to display personal privacy or trade secrets, the information needs to be effectively protected against embarrassing or business losses caused by the information disclosure. To satisfy this requirement, we need viewing angle controllable (VAC) LCDs to realize the switching between wide viewing angle mode (WVA) and narrow viewing angle mode (NVA) [1-3]. Recently, many research institutes have been committed to the development of VAC technology using a single cell [4-5]. Compared with the dual cell, it has the advantages of low cost, low power consumption, simple process, lighter and thinner, etc. The VAC-FFS-TFT-LCD display device can realize the WVA and NVA mode switching by setting a bias voltage on the color filter side. In the WVA mode, the CF side does not apply a bias voltage to achieve a normal FFS mode having a wide viewing angle. In the NVA mode, with bias voltage applying on the CF side, the liquid crystal molecules are lifted up to form a light leakage at large viewing angle, resulting in a lower contrast at oblique direction to achieve NVA mode. However, in the NVA mode, when the brightness of the dark state is higher than the white state at large viewing angle, the gray scale inversion problem occurs, which affects the privacy protection.

In this paper, we discussed an improved structure that can solve the gray level inversion problem. By reducing the proportion of the top pixel electrode in the AA area of the sub-pixel, the brightness of the white state at large viewing angle increases in the NVA mode, and the gray scale inversion is improved.

2. STRUCTURE and OPERATION PRINCIPLAE

Figure.1 shows a proposed cell structure of VAC-FFS LCD which is composed of a color filter layer, a thin film transistor layer and a positive nematic liquid crystal layer sandwiched between them.

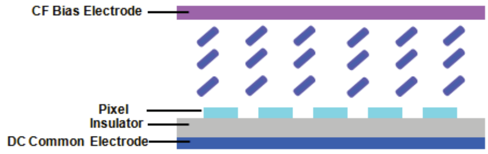
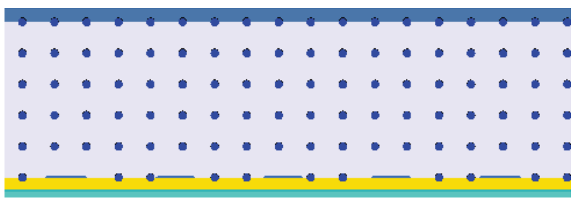


Fig. 1 Schematic diagram of the proposed VAC FFS LCD

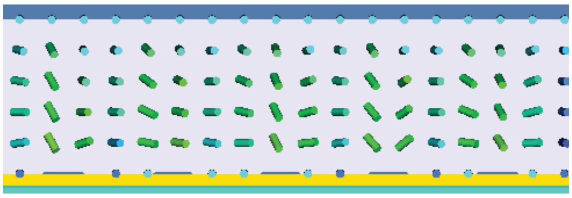
In the device, the bias electrode is setting on top substrate, the pixel electrodes patterned in a slit form and common electrode are setting on bottom substrate, and there is an insulator layer between them. In the FFS device, where the LC layer exists under crossed polarizer, the cell transmittance can be described by:

$$Tr = \frac{1}{2}\sin^2(2\varphi)\sin^2\left(\frac{\pi n_{eff} d}{\lambda}\right) \quad (1)$$

Where φ is the angle between LC director and the transmission axis of the bottom polarizer , and Δn_{eff} is the effective birefringence of the LC layer, and λ is the incident wavelength. According to the equation (1), when the CF bias voltage is 0V, the device is normal WVA mode, as shown in Figure.2(a), the signal is not applied to the pixel electrode, $\varphi = 0°$ and $\Delta n_{eff} \approx 0$, the amount of light leakage in each direction are rarely(Figure.4(a)), here is the dark state; When the signal is applied to the pixel electrode, the LCs rotate as shown in Figure 2(b) , when $\varphi = 45°$ and $\Delta n_{eff} d/\lambda \approx 1/2$, the transmittance reaches maximal, here is the white state. The device shows wide-viewing angle;



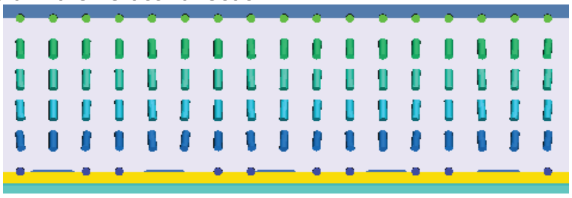
(a) Dark State



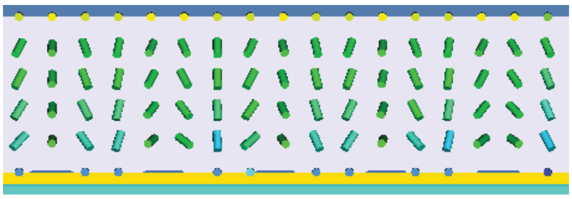
(b) White State

Fig. 2 Orientation of LC molecules in WVA mode: (a) Dark state (b) White state

As shown in Figure.3(a), when a bias voltage is applied to the CF bias electrode, and the signal is not applied to the pixel electrode, the LCs tilt due to the strong vertical electric field, and $\Delta n_{eff} > 0$ in oblique directions, resulting in light leakage at large viewing angles(Figure.4(b)). When the signal is applied to the pixel electrode in white state, the contrast of the device decreases at large viewing angles, this is the NVA mode. According to the above mechanism, we can achieve the purpose of wide and narrow viewing angle switching by controlling the electric field in the vertical direction.

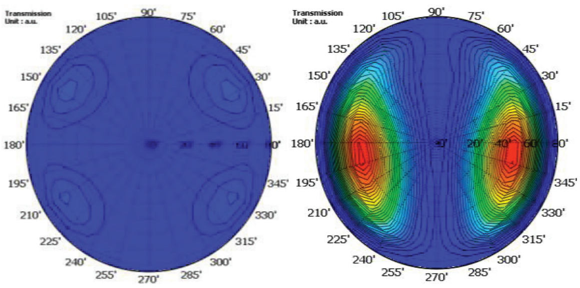


(a) Dark State



(b) White State

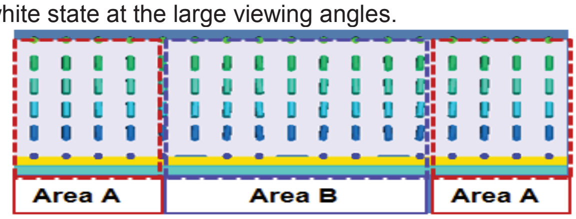
Fig. 3 Orientation of LC molecules in NVA mode: (a) Dark state (b) White state



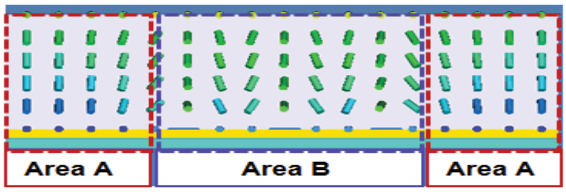
(a)WVA mode (b)NVA mode

Fig. 4 Iso-luminance curves in dark state at an incident wavelength of 380–780 nm ： (a) WVA mode (b) NVA mode

As shown in figure.3, in the NVA mode, when the pixel electrode and CF bias electrode have the same polarity, the electric field in the vertical direction is weakened in the white state, resulting in the brightness of the white state at large viewing angles being smaller than the dark state, so that the gray scale inversion occurs. We proposed an improved structure, as shown in Figure 5, the AA area is divided into A area and B area. When the B area is increased, some amount of LCs is not affected by the fringe electric field, only affected by the vertical electric field. In this state, the liquid crystals always keep a high tilt angle state, thereby improving the brightness of the white state at the large viewing angles.



(a) Dark State

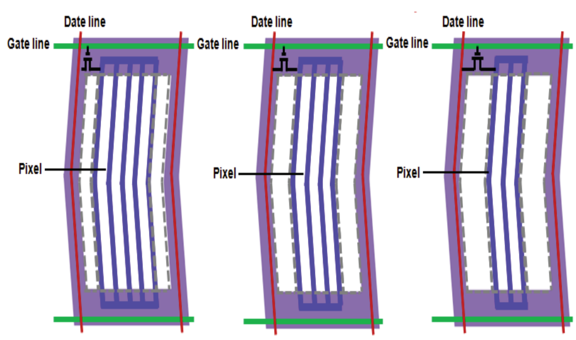


(b) White State

Fig. 5 Orientation of LC molecules in NVA mode: (a) Dark state (b) White state

3. RESULTS and DISCUSSION

In terms of the concept mentioned above, we used TechWiz LCD to simulate three structures to confirm the viewing angle controllable function of our proposed LCD. As shown in Figure 6, the only difference is the number of slits: 5slits, 4slits and 3slits, respectively. The designed retardation for the FFS cell is 0.335μm with d = 3.3μm and a surface tilt angle of 2° both of the ceiling and floor side. The dielectric anisotropy of the LC is 9.5 with elastic constants k11 = 11.5 pN, k22 = 5.75 pN and k33 = 13.8 pN. The thickness of the pixel electrode and DC common electrode are 0.06μm, and the width of the pixel electrode and the distance between them are 2.5μm and 5.5μm, respectively.

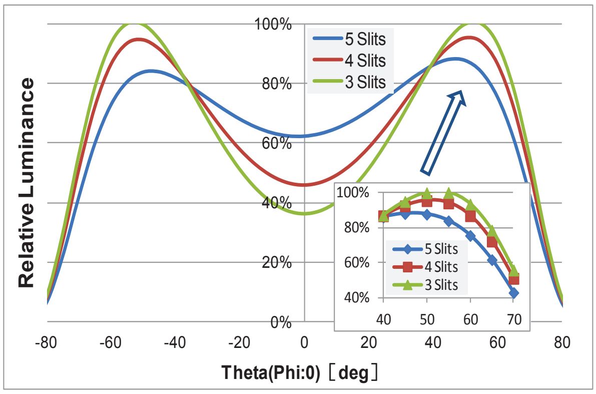


(a)5Slit (b)4Slit (c)3Slit

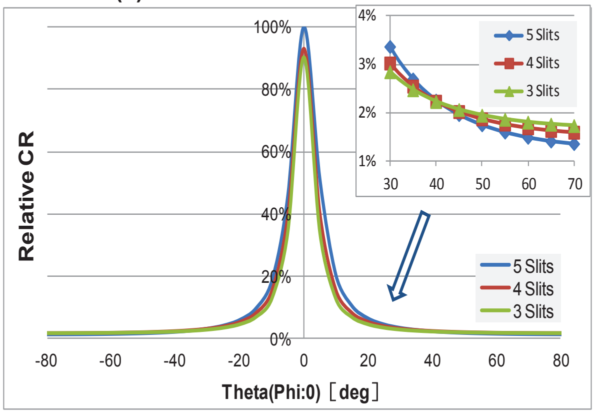
Fig. 6 Proposal structure：(a) 5 Slits (b) 4 Slits(c) 3

Slits

Figure.7 shows the brightness in white state and the contrast at large viewing angles of the three structures, and when the polar angle of the horizontal direction ＞ 40° , the brightness and contrast can be improved to some extent.



(a) The luminance at white state



(b) Contrast Ratio

Fig. 7 Optical difference of the proposed VAC structure

In order to verify the improvement effects of the proposed structures, we have fabricated a prototype 13.3inches FHD (1920RGB*1080) LCD whose structure corresponds to that mentioned above.

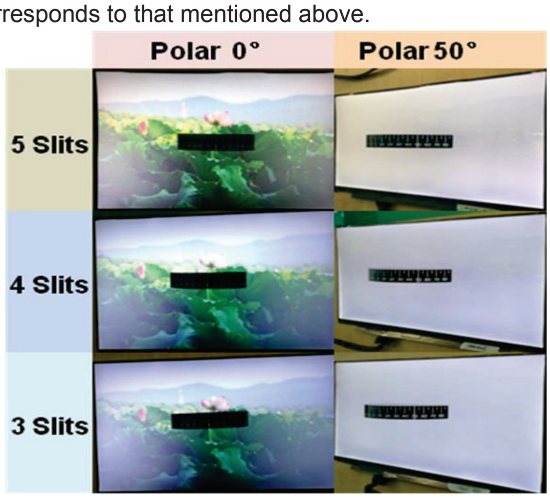
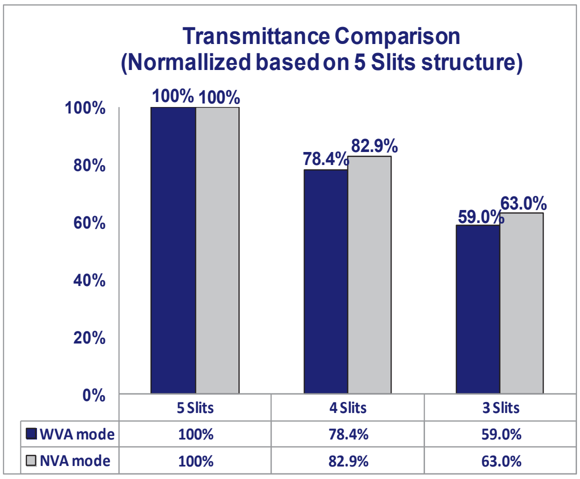


Fig. 8 NVA Performance comparison of the prototype 13.3inches LCD device



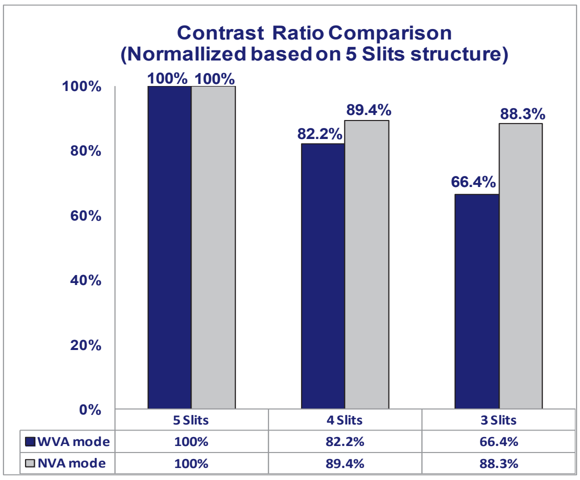


Fig. 9 Optical comparison of the prototype 13.3inches LCD device：

(a) Transmittance (b) Contrast Ratio

As shown in Figure.8, the privacy protection at large viewing angles would be improved when reducing the number of slits. As shown in Figure.9, we measured the transmittance and contrast ratio in the WVA mode NVA mode. With reducing the numbers of slits, transmittance and contrast ratio will decrease to some extent: the numbers of slits are reduced from 5Slits to 3Slits, WVA mode transmittance is reduced by 41%, and NVA mode is reduced by 37%

4. CONCLUSION

In this paper, we proposed a method to improve the gray level inversion of the original VAC-FFS structure through reducing the number of slits which can lower the proportion of top ITO electrodes, it has the advantages of simple process and no need for complicated driving. By comparing the anti-peep performance in privacy mode of the three structures, the 3slits structure is better at 50° polar angle. We believe our studies will have influence on further researches on private protective LCD in the competitive personal display market. We expect that this distinct viewing angle difference between the two modes will open up further intriguing opportunities for applications of liquid crystal displays.

5. REFERENCES

[1] Hisatake, Y., Kawata, Y., and Murayama, A. (2005).Soc. Inform. Display Tech. Digest 36, 1218.

[2] J. I. Baek, K.-H. Kim, S. R. Lee, J. C. Kim, and T.-H. Yoon, “Viewing angle control of a fringe-field switching cell by electrical tilting of liquid crystal,” Jpn. J. Appl. Phys. 47, 1615–1617 (2008).

[3] Chi-Huang Lin, Ru-Hsien Chiang, Ming-Li He, Chia-Wei Chen and Chie-Tong Kuo, “Viewing angle switching LCDs using large optically anisotropic behaviors of twisted-nematic LCs” IDW’10, LCTp4 – 2 (2010).

[4] Woo Il Kim, Eun Jeong Jeon, Seong Su Kim, Mi Hyung Chin, Young Jin Lim,Kwang-Un Jeong and Seung Hee Lee, “Viewing Angle Switching of Liquid Crystal Displays Driven by Fringe Field Switching,” SID’09,1601–1603 (2009).

[5] Linlin Wang, Limei Jiang, Zifang Su, Yanbin Qiao, Peter Liao and Smart Chung, “Viewing Angle Controllable LCD with Specified Array Structure for Ultra High Definition Display,” SID’2018,1765–1768 (2018).