High Contrast Research of 4K ADS TV Technology

Hongling Hu, Kai Wang, Liangliang Jiang, Heng Zhang, Yajun Li, Xiaobin Li, Yinhu Huang, Byung-cheon Lim, Zhangtao Wang, Xibin Shao*

***Hefei BOE Display Technology Co., Ltd., No.3166 Tonglingbei RD, Hefei, China**

Abstract

The Contrast of 4K ADS products was improved from 1500:1 to 3000:1 by material and process optimization, which includes the application of Ultra-low Scattering Negative Liquid Crystal, Higher polarization polarizer, Thicker polyimide film and appropriately widened Black Matrix. The realization of Contrast 3000 records the highest in ADS Mode, greatly shortens the gap with VA products and also shows good applicability in high end LCD products.

Author Keywords

ADS LCD; High contrast; low Scattering; Negative Liquid Crystal; High polarization rate; Polyimide film thickness

1. Introduction

Thin film transistor liquid crystal display (TFT-LCD) is still the mainstream display technology because of its high yield, good size compatibility, long working time and low production cost [1]. TFT-LCD display modes mainly include Twisted Nematic (TN), Vertical Alignment (VA), In-Plane Switching (IPS) and Advanced Super Dimension Switch (ADS) [2,3]. The ADS display mode is widely used in large-scale, high-definition displays and LCD TVs due to its advantages of hard screen, high transmittance, large view angle (both horizontal and vertical can reach 178°) and high color expression [4, 5]. However, limited by low contrast ratio (CR for short, ~1500 @VA CR≥3000), ADS products show less competitive in high-end products. In this paper, by optimizing the material (ultra-low scattering negative liquid crystal, high polarization polarizer, etc.) and process (thicker Polyimide film thickness, wider black matrix, etc.) of 4K ADS TVS, the contrast ratio is increased form 1500:1 to 3000:1, which achieve the highest CR as far as we know and providing more competitiveness of ADS TVs in the high-end market.

2. Test equipment

CR Test equipment is Optical Test System (ENC), whose door and lighting lamp are closed during the test. And CR results in this paper are all central point data.

3. Experiment

The contrast Ratio is defined as Equation (1):

$$CR = \frac{L255}{L0} \tag{1}$$

Two methods of increasing CR are to increase L255 and decrease L0. And usually the methods to increase L255 are to increase the opening rate and optimize the pixel pitch. But for mass products, it is difficult to change the design. Moreover, transmittance of ADS mode is already relatively high. On the other hand, L0 of ADS is much higher than that of VA and CR is usually more sensitive to the decreasing L0, so in this paper the way to increase CR is mainly focus on decreasing L0, which is more effective. To investigate the influence of negative liquid crystal (N-LC), Polyimide film thickness (PI THK), BM Matrix Width (BMCD), polarizer polarization (POL P.E.) on CR, the following material & process combinations (as shown in Table 1) were verified:

Table 1. Material and process combinations of CR test

Split	BMCD	PI THK	LC	POL
Ref.	A	B	LC01+CG1	POL1
S1	A	B	LC02+CG1/2	POL1
S2	A	B	LC03+CG1/2	POL1
S3	A+2	B	LC03+CG1	POL1
S4	A	B+350Å	LC03+CG1	POL1
S5	A	B	LC03+CG1	POL2
S6	A+2	B+350Å	LC03+CG2	POL2

Ref. is the current production Parameters, S1~S5 aim at studying the contribution of single factor of material and process to CR, S6 is the optimal parameter combination.

4. Results and Discussion

Figure1 shows the CR results of different material and process combinations.

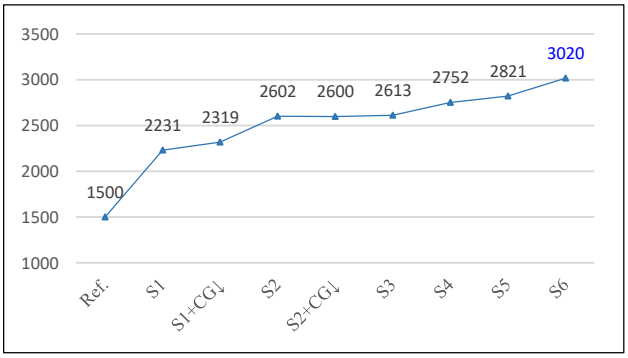

Figure 1. CR of different combinations

The S6 CR is up to 3020:1 while Ref. CR is 1500:1, and as shown in figure 2, the TV of CR 3000 has more excellent details presentation than CR 1500.

Figure 2. Displaying effect comparison

4.1 CR Vs LC and CG

It is well known that CR is inversely proportional to LC scattering coefficients (S_{CELL}), as shown in formulas (2) and (3) [6]:

$$\frac{1}{CR} \propto S_{CELL} \tag{2}$$

$$S_{CELL} = \frac{d \cdot (\Delta n(n_e + n_o))^2}{K_{ave}} \tag{3}$$

As CR is also inversely proportional to L0, so L0 can be characterized by SCELL. For a certain LC, the SCELL can be simplified to the first-order equation of △nd, like equation (4) & (5), where a is a constant, determined only by LC type. And usually the scattering coefficient of positive liquid crystal is greater than that of negative liquid crystal for its lower △n and larger Kave.

$$S_{CELL} = a \cdot (\Delta nd) \tag{4}$$

$$a = \frac{\Delta n \cdot (n_e + n_o)^2}{K_{ave}} \tag{5}$$

The equation of Tr. is given as follow (as equation (6)).

$$Tr. = \frac{1}{2}\sin^2(2\psi) \cdot \sin^2\frac{\pi \Delta nd}{\lambda} \tag{6}$$

Tr. under different △nd is simulated according to equation (6), and the fitting curve of the simulation results is binomial function of △nd, which can be represented by equation (7).

$$Tr. = -108.82(\Delta nd)^2 + 76.159(\Delta nd) - 7.8468 \tag{7}$$

Table 2. LC physical parameters

LC	△n	n_e	n_o	K_{ave}
LC02	0.0916	1.5696	1.4780	15.0
LC03	0.0838	1.5589	1.4751	18.9

For LC02 and LC03 whose physical parameters are concluded in Table 2, Tr. and SCELL curves can be drawn as shown in figure 3.

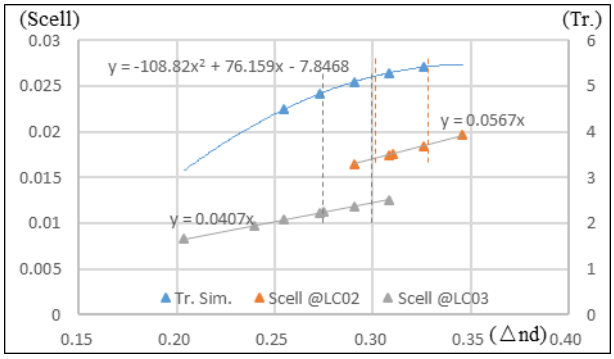

Figure 3. △nd Vs Tr. & Scell (4K N-LC)

When CG changes from CG01 to CG02, △nd of LC02 will decline from 0.3298 to 0.3023 while LC03 from 0.3017 to 0.2765. As we can see in the figure 3, the Tr. decrease of LC02 is less than that of L0, while LC03 is almost the same. So CR will increase for LC02 while CR of LC03 will remain unchanged, which is consistent with the result that CR of LC02 increased from 2231 to 2319 while LC03 from 2602 to 2600.

4.2 CR Vs BMCD

It is known that ADS mode is plane electric field display, which exists the dark field region at the edge of electrode, weak rubbing & uneven PI THK distribution region that lead to liquid crystal disorder (as shown in figure 4), so there is L0 light leakage, which will cause CR decrease.

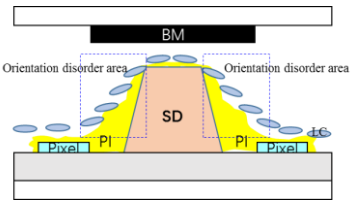

Figure 4. LC orientation disorder analysis

Since L0 is very small, the LC disorder region is usually observed in the gray-scale L255, such as the black area at the pixel edge in figure 5. And the increase of BMCD can block the L0 light leakage area, however, Tr. will decrease due to the lower aperture ratio caused by the wider BMCD.

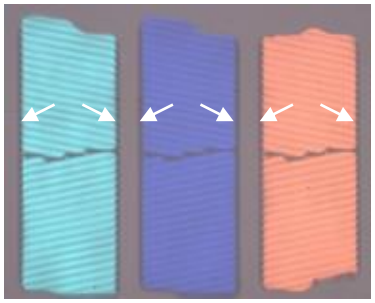

Figure 5. Dark field area under gray-scale L255

The CR Results of different BMCD increments were simulated, which is shown in figure 6. And we can see that the positive contribution of BMCD increase to CR has an extreme point due to the significant decrease of Tr. and incremental CR of 8K is larger than that of 4K for the same BMCD increase because of the wider disorder region, which caused by the thicker Gate and SD metal and the lower efficiency ITO pixel pitch.

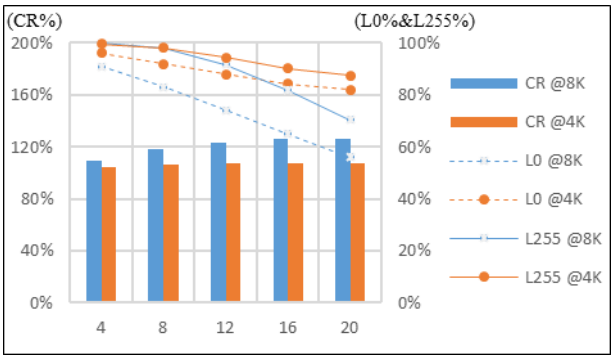

Figure 6. CR & L255 Vs BMCD

S3 Vs S2, CR only increased 11 while 8K product CR increased approximately 50 (previously verified), which is consistent with the predicted values. So we can reduce CR sensitivity to BMCD by optimizing Pixel Pitch and increase CR by widening BMCD with acceptable Tr. decline.

4.3 CR Vs PI THK

S4 Vs S2, the CR increases 150 when PI THK increases from B to B+350Å due to the improvement of anchoring force. As we all know that the thicker the PI film, the more the upper layer components which decides the alignment strength. The △angle (parameter represents the recovery ability of LC explained in figure 7) variation trend is also consistent with the CR change, that is, the thicker the PI film, the smaller the △ angle as shown in figure 8.

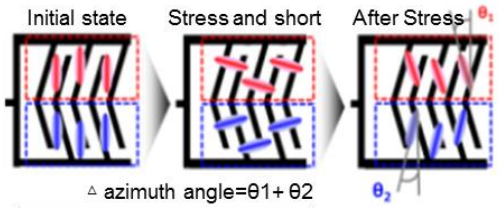

Figure 7. The define of △angle which characterizes the recovery ability of LC after powering (AC) for a period of time, and the smaller the △angle, the stronger the recovery ability, which represents the higher orientation force

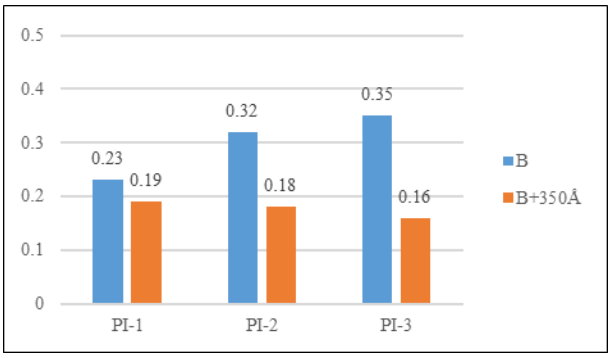

Figure 8. △angle Vs PI THK

In addition, Thicker PI thickness will contribute to better image sticking (I/S), as shown in Table 3.

Table 3. Image sticking Vs PI THK

Product	PI THK	LC	I/S @Room temperature	I/S @High temperature
8K	650Å	LC02	Area L3/199	Area L2/176
	1000Å		Area L2/180	Area L1/155

4.4 CR Vs POL P.E.

In addition to the above factors, L0 also depends on the Twist Angle, that is, the angle (ψ1 & ψ2) between LC and the upper & lower POL absorption axis and the angle (ψ3) between the POL absorption axis on the TFT and CF side as shown in figure 9.

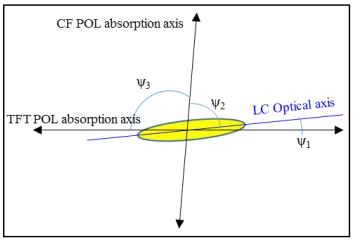

Figure 9. Panel Top view

ψ1 & ψ2 are mainly decided by the PI type and Rubbing process. And PI affects Twist Angle mainly through alignment ability, so we can choose PI with high alignment. As for Rubbing process, the position deviation between glass and the base is the main reason for larger Twist Angle. In order to study the accuracy of Rubbing process, CR corresponding to ±0.3° rotation was tested, and results are shown in figure 10. we can see that CR with no rotation is the highest and the 3σ of Twist angle is minimum. So the current Rub process is almost the optimal parameter.

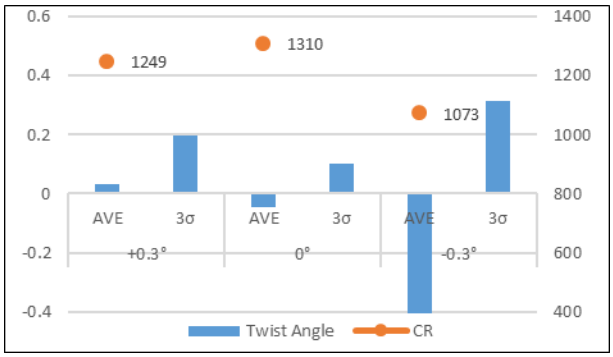

Figure 10. CR Vs CF Rub Angle

Ψ3 is related to POL P.E. and POL adhesion accuracy. And POL P.E. can be expressed by formula (6) & (7) [7]:

$$CR = \frac{1 + (P.E./100)^2}{1 - (P.E./100)^2} \tag{6}$$

$$P.E. = \sqrt{\frac{T_P - T_C}{T_P + T_C}} \times 100 \tag{7}$$

The definition of T_P & T_C is shown in Figure 11.

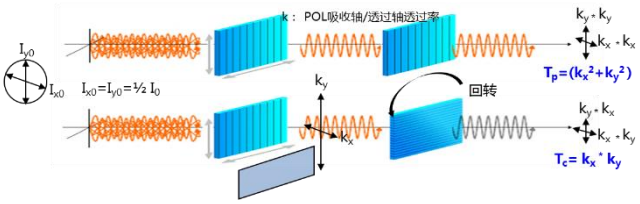

Figure 11. POL absorption and transmission axis

Obviously, as the POL P.E. increases, the CR increases. And the effect of POL P.E. and adhesion accuracy on CR is direct, unlike LC, the superposition effect of other layers should be considered. So even with smaller promotion of POL P.E. and attachment accuracy, CR increase is obvious, which is consistent with the result S4 Vs Ref., that is, P.E. increases by 3‰, CR increases by 219. And POL attachment accuracy is not tested in this paper.

5. Conclusion

The effect of material and process on CR was studied in this paper. And through material & process optimization, such as adopting ultra-low scattering negative liquid crystal with optimal cell gap, higher P.E. POL, wider BMCD and thicker PI film, etc., CR of 4K ADS TV has increased from 1500 to 3000, which means that the ADS TVs not only have higher transmission and wider perspective but also have a comparable contrast compared with VA products. And for CR promotion methods, we summarize the following conclusions:

1) The decrease of △n and the increase of K Value of LC are beneficial to the decrease of LC scattering coefficient, but it also means the lower Tr. at the same cell gap and longer response time. And even when △n decreases to a certain value (as 0.0838), CR decreases with the decrease of CG. So the value of K can be appropriately increased under the condition that the response time is satisfied, and it is very important for the selection of CG when LC has a small △n.
2) The increment of BMCD needs to consider the loss of Tr., and in addition, we can choose the appropriate BMCD increment to improve CR according to the optical efficiency of different products.

3) Developing high alignment PI and increasing PI THK are both beneficial for CR improvement.
4) A small improvement of POL P.E. and attachment accuracy can contribute to a large increase in CR.

References

[1] Falu Yang, Junrui Zhang, Xi Xiang, Youngyik Ko and Feng Bai, SID Symp. Dig., P. 318 (2014).

[2] Y. Takahashi, T. Uesaka, T. Hirai and H. Mazaki, SID Symp. Dig., P. 491 (2010).

[3] S.H Lee, S.L. Lee and H.Y. Kim, Appl. Phys. Lett. 73, 2881(1998), Asia Display, P371(1998)

[4] Y. M. Jeon, I. S. Song, S. H. Lee, H. Y. Kim, S. Y. Kim, and Y. J. Lim, SID Symp. Dig., P. 328 (2005).

[5] Hongming Zhan, Zheng Xua, Dan Wang, Xibin Shao, Seongkyu Lee and Suling Zhao, "Low-voltage, high transmittance fringe-field switching mode liquid crystal for monitor display", Liquid Crystals Vol. 41, No. 6, 755–760 (2014)

[6] Dang Wang, Yajun Li, Yangcan Shen, Hongming Zhan, Yinhu Huang, Baoqian Wang, Zhangtao Wang, Hailin Xue, Xibin Shao, SID Symp. Dig., P. 224 (2020).

[7] Hoon Sub Shin, Yuri Won, Ramesh Manda, Mira Jo, Tae Hyung Kim, Young Jin Lim and Seung Hee Lee, SID Symp. Dig., P. 154 (2020).