Analysis and Improvement of LCD Contrast Ratio by Polymer Film on Array

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Abstract

In this paper, the mechanism of low contrast ratio (CR) in thin film transistor liquid crystal display (TFT-LCD) and its improvement measures are studied. The test results in laboratory and production line show that CR has a strong correlation with the leveling, curing and roughness of Polymer Film on Array (PFA). Through a series of improvement measures such as PFA process, technology and material formula, CR of TFT-LCD can be greatly improved.

Author Keywords

TFT-LCD; Contrast Ratio; Polymer Film on Array;

1. Introduction

In recent years, TFT-LCD has been widely used due to its advantages of low power consumption, low radiation, low space occupancy, lightweight, and aesthetics, and has become the mainstream of the market.[1] The main parameters of TFT-LCD are resolution, color gamut, [2,3] transmittance and CR.[4] The impact of CR on visual effects is very key. In general, the higher CR, the clearer image, and the more vivid color. This paper introduces a case of low CR caused by PFA, analyzing and verifying the mechanism of low CR and improvement measures.

In addition, for the future market strategy, many panel companies said that they will continue to firmly large-size high-end strategy. Market demand for large-size LCD is growing, and large-size panels often need to use PFA, the technical bottleneck of positive PFA is the need for high exposure, but high exposure will cause capacity loss. Based on this, there is an urgent need to develop positive PFA with ultra-low exposure.

2. Phenomena and Test analysis

2.1 Phenomenon description

In the process of introducing the new I PFA, the optical results of several test models show that: the I PFA will lead to low CR of the panel, and the worst model can be 7.7% lower, which seriously exceeds the optical specifications of the product, as shown in the Table 1. The mass production type which is the reference as following in this paper, I PFA is the experiment (Exp), and the mass production PFA is reference (Ref).

Table 1. CR of different model

Model NO.	CR *(Exp-Ref)△%*
A	-3.9%
B	-5.2%
C	-6.06%
D	-7.7%
E	-4.48%

2.2 Phenomenon analysis

CR is defined as the brightness L255 under the white screen (at its brightest) divided by the brightness L0 under the black screen (at its darkest) in a dark room. The contrast formula is as follows:

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

The L255 and L0 of the Exp and Ref were compared, and it was confirmed that the low CR of the Exp was mainly caused by the large L0, as shown in the Table 2.

Table 2. Comparison of L255 and L0

Item	L255	L0	CR
(Exp-Ref)△	-1	0.002	-506
(Exp-Ref)△%	-0.25%	4.41%	-6.52%

The logical tree that affects CR is preliminarily sorted out, as shown in Figure 1. Based on this, this paper mainly clarifies the correlation between PFA and low CR, and focuses on analyzing the key factors affecting L0.

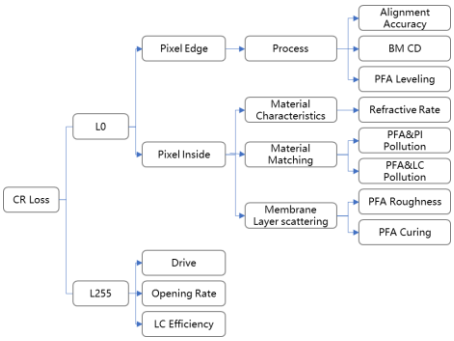

Figure 1. Low CR logical tree.

3. Test and analysis

The Pixel brightness of the panel was analyzed by Matlab, and found that the pixel L0 brightness of the Exp was larger than the Ref, and there was light leakage in the Pixel edge and surface, as shown in the Figure 2.

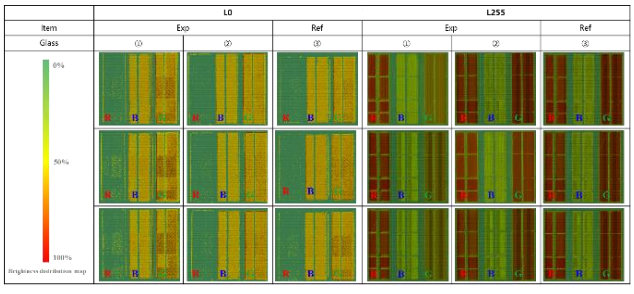

Figure 2. Pixel brightness analysis.

3.1 Pixel edge leakage analysis

The Pixel edge leaks light, and the L0 becomes larger, eventually resulting panel CR is low.

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3.1.1 BM CD

The smaller BM CD, the efficiency of BM blocking light transmission will be reduced, resulting in light leakage at the edge of Pixel, while the larger BM CD, the opening rate will be smaller, which can effectively reduce the light leakage of Pixel. Designed the experiments with the BM CD widening, the results are shown in Table 3, the widening of BM CD has no significant improvement effect on L0, so BM CD is not the cause of the low CR at the case.

Table 3. CR of different BM CD

BM CD (μm)	(Exp-Ref)△%
Ref+1	-7.8%
Ref+2	-6.8%-
Ref+3	-7.6%
Ref+4	-6.6%

3.1.2 Alignment Accuracy

When the warpage stress of PFA is too large, the warpage amount of the substrate will change, resulting in poor alignment accuracy, and then the dark state light leakage phenomenon will occur, the mechanism is shown in the Figure 3.

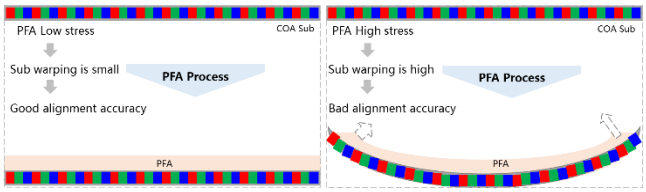


Figure 3. Different PFA stress mechanism.

From the perspective of Map, the trend of Map is consistent, so the alignment accuracy is not the cause for the low CR, as shown in the Figure 4.

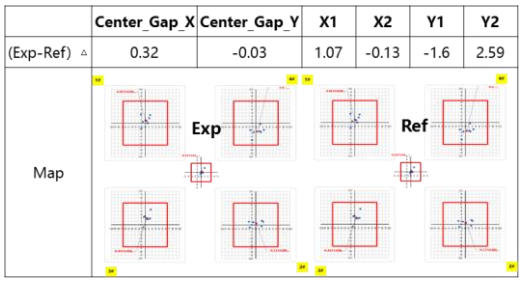


Figure 4. Alignment accuracy.

3.1.3 PFA Leveling

The worse the leveling of PFA, the more affected by the RGB, and the worse of uniform the PFA membrane surface at the RGB horn, which leads to the coordination disorder of LC and serious light leakage at the edge. The mechanism is shown in Figure 5.

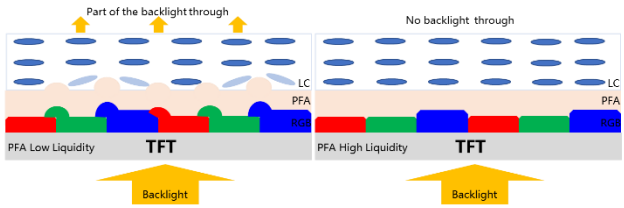
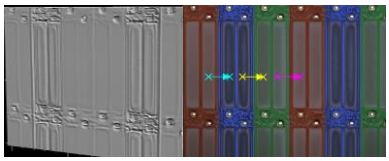


Figure 5. Different PFA leveling mechanism.

The leveling analysis of PFA with 3D OM, and the results are shown in Table 4. The leveling of the Exp was poor, and the corresponding CR was also low. The leveling of PFA will affect the light leakage at the Pixel edge, and the less leveling PFA is, the lower CR is.

Table 4. CR of different PFA leveling

Image	(Exp-Ref)△ THK (μm)		
	RB	BG	GR
	0.22	0.07	0.09
Image			

3.2 Pixel inside leakage analysis

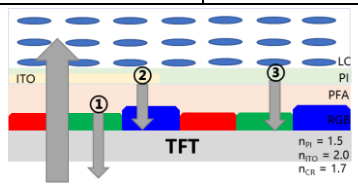
3.2.1 Refractive Rate

According to Fresnel's formula, there is a relationship between refractive index and light transmittance, and interfacial reflection will occur between two layers of media with different refractive indices, resulting in light leakage in the inside.

$$Reflectance(R) = \frac{(n_1 - n_2)^2}{(n_1 + n_2)^2}$$

The reflectance of PFA and the upper and lower film layers was calculated based on the refractive index, and the optical attenuation rate of the film layer was finally obtained. The results showed that: no matter RGB→PFA→ITO or RGB→PFA→PI, the optical attenuation rate of the Exp was smaller than that of the Ref, as shown in the Table 5. So, the difference of PFA refractive index was not the cause for the low CR.

Table 5. CR of different PFA leveling

Light attenuation rate caused by interface reflection @403nm	Exp	Ref
RGB→PFA→ITO (①,②)	1.4%	1.6%
RGB→PFA→PI (①,③)	0.2%	0.2%
Panel structure		

3.2.2 PFA&PI&LC Pollution

Mechanism speculation: RGB is affected by the penetration of PI solvent, resulting in pigment precipitation into PI or LC, which affects the LC arrangement and ultimately reduces the CR, as shown in the Figure 6.

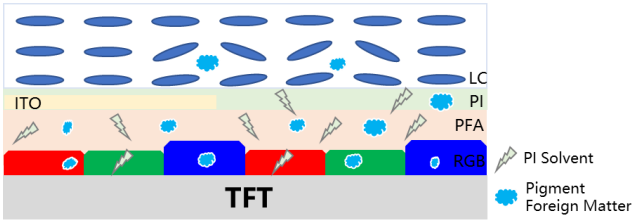


Figure 6. PFA&PI&LC pollution mechanism.

Compared with the original LC, there is no significant difference in VHR and ION of Exp and Ref panel LC, indicating that there is no significant correlation between LC pollution and CR, as shown in the Table 6.

Table 6. Data for the Ion & VHR

Temp	Ion(pC,10 V,0.1Hz)	VHR(%,5V ,16.61mS)	VHR(%,5V ,166.7mS)
Exp (20℃)	24	99.65	99.23
Ref (20℃)	23	99.66	99.25
Original LC (20℃)	23	99.66	99.25
Exp (50℃)	297	91.08	73.31
Ref (50℃)	309	90.82	72.58
Original LC (50℃)	315	90.97	72.14

In addition, the relationship between PI surface contamination and CR was also studied, and the ion concentration was calculated according to the ion signal strength of the top surface. The positive and negative ion spectral peaks and ion concentrations on the surface of the Exp and the Ref were basically the same, indicating that the ion concentration on the PI surface was not significantly correlated with the CR, as shown in the Figure 7.

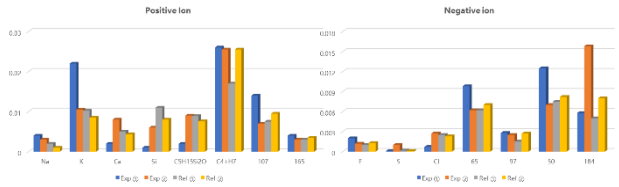


Figure 7. Positive and negative ion concentration.

3.2.3 PFA Roughness

According to past experience, the roughness of PFA will affect the roughness of ITO, and the greater the roughness of PFA, the roughness of the surface ITO will also increase. Based on this, we speculate the mechanism:

Mechanism 1: Because the temperature of PFA Oven in the factory line is lower than that of ITO Oven, when the ITO Oven the PFA under the ITO membrane will further shrink, and the ITO surface will be deformed, resulting in the increase of the membrane surface scattering, and finally make the low CR, as shown in the Figure 8.

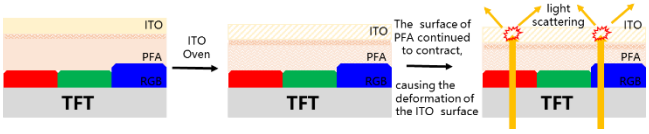


Figure 8. Schematic diagram of mechanism 1.

Based on mechanism 1, an experiment of increasing PFA Oven was designed in the Lab. The experiment results showed that the L0 decreased as the temperature of PFA Oven increased, which proved the accuracy of mechanism 1, as shown in the Figure 9.

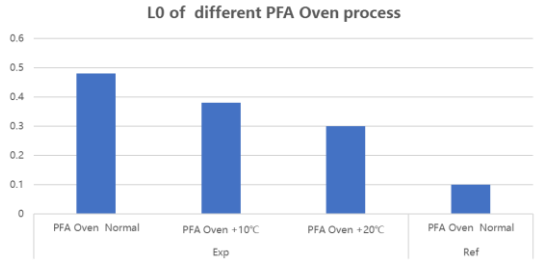


Figure 9. L0 of different PFA Oven process.

Mechanism 2: After PFA Dry Etching, the PFA surface roughness increases, which affects the surface roughness of ITO increases, and the light scattering of the membrane layer increases, as shown in the Figure 10.

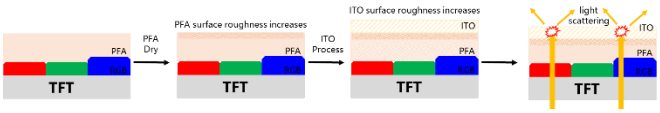


Figure 10. Schematic diagram of mechanism 2.

Based on mechanism 2, the experiment was clarified in Lab to adjust the surface roughness of different PFA. The results showed that by reducing the strength of PFA Dry, the surface of PFA was smoother, and the L0 of it was also significantly reduced, proving the accuracy of mechanism 2, as shown in the Figure 11.

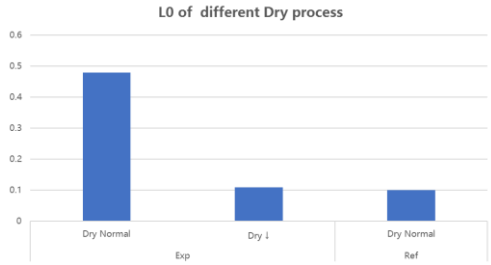


Figure 11. L0 of different Dry process.

4. Adverse improvement

Through a series of improvement measures such as PFA process, technology and material formula, the CR can be greatly improved.

4.1 PFA Process

From the above analysis, it can be seen that the CR is strongly related to the leveling, curing rate of PFA. Based on this, the corresponding process improvement was carried out for the leveling, curing rate and roughness of PFA, mainly as follows:

4.1.1 PFA THK (Thickness)

The plan is to increase the PFA THK to reduce the PFA leveling difference at the RGB horn, improve the light leakage problem, and then improve the CR. The verification results are as follows: by increasing the PFA THK by 0.04μm, the CR is improved by about 1%, as shown in the Figure 12, and the results show that the appropriate increase in PFA THK can effectively improve the CR.

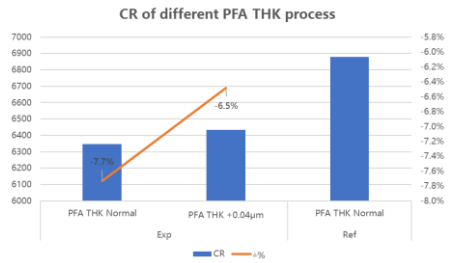


Figure 12. CR of different PFA THK process.

4.1.2 PFA Oven

According to mechanism 1, the temperature of PFA Oven will affect the shrinkage of ITO film at its lower layer, thus affecting CR. According to the actual verification data table of the factory line, increasing the temperature of PFA Oven by 10℃ can optimize CR from -4.75% to -2.78%, as shown in the Figure 13.

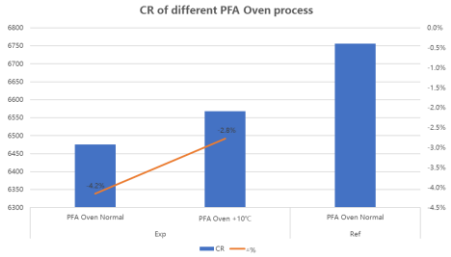
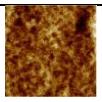


Figure 13. CR of different PFA Oven process.

4.2 PFA Technology

According to mechanism 2, after PFA Dry Etching, the surface roughness of the film will increase greatly, which will affect the roughness of the underlying ITO, and then lead to increase of light scattering, which will affect CR. Based on this, by tuning the PFA Dry Etching process to improve the uniformity of etching rate and the surface roughness is be reduced, as shown in the Table7.

Table 7. Roughness of different PFA Dry technology.

Item	Exp			Ref
Image	Dry normal	Dry ↓	Dry ↓ ↓	Dry normal
Image				
Sa (nm)	3.21	2.43	0.99	1.2

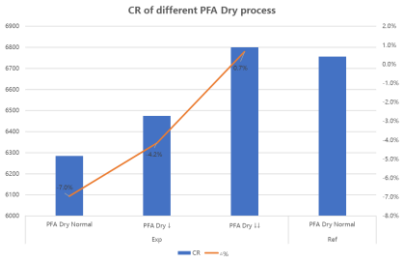


Figure 14. CR of different PFA Dry process.

Through the actual verification data of the plant line, the contrast can be improved by 7% through the optimization of PFA Dry process, as shown in the Figure 14.

4.3 PFA Formula

The I PFA verified in this paper is a super-sensitive positive photoresist with low exposure power such as less than 40mj. In terms of I PFA composition, in order to improve the sensitivity and reduce the capacity, the additive is introduced into the cross-linked group γ, which is easy to be etched, although it can greatly improve the sensitivity, but ultimately lead to the leveling and film surface roughness, and the optical performance of product is low CR.

The main improvement of the material surface is to reduce the group γ that is easy to be etched, so that the etching of PFA in the Dry process is more uniform, and the roughness of the film surface is reduced. Through the material formula margin test, it can be known that the more cross-linked group γ content, the smaller the dark state brightness, and the larger consumption, as shown in the Figure 15.

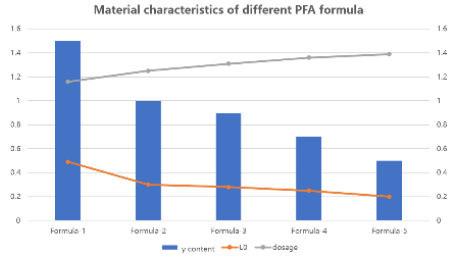


Figure 15. Material characteristics of different PFA formula.

In fact, the composition of materials is more complex, and there is a Trade-off relationship among many material characteristics, and it is often necessary to reach a balance among these characteristics.

5. Conclusions

This paper studies the mechanism of low CR of TFT-LCD and its improvement measures. Through a large date of investigations and reasoning, the initial conclusion is that the anomaly comes from the transparent layer PFA material. A series of experimental results show that the leveling, curing and roughness of PFA will affect the light scattering on the film surface, and eventually lead to the high L0 of the panel. Through a series of CR improvement measures such as process, technology and material formula, the CR of the product is greatly improved in the end, which provides ways for the CR improvement of TFT-LCD in the future, and improves the company's efficiency and competitiveness.

6. References

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