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Analysis of Push Color Shift and Static Color Shift of Liquid Crystal Display

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ABSTRACT

Herein, the mechanism of push color shift in liquid crystal display was proposed and verified by experiments. Through further analysis of influence factors, the influence sequence of factors on static color shift was obtained. Besides, we have established a model to quickly evaluate static color shift of liquid crystal display.

1 INTRODUCTION

Liquid crystal display (LCD), an excellent display technology, plays an indispensable role in the display field and human life due to the advantages of long lifetime, good reliability, and low cost [1-3]. Although the performances of LCD are good in many aspects, there are still some problems to be solved. For example, compared with organic light emitting diode (OLED) display, LCD exhibits slightly inferior performances in terms of color shift in pure picture, which usually causes an evident gamut curve distortion at large oblique viewing angles [4,5]. Specifically, the existence of back light unit (BLU) and RGB color filter in LCD panel makes the color shift of red picture inevitable at large oblique viewing angle, but it can be improved by making further study and analysis of color shift factors.

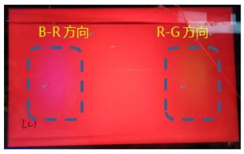
Based on the above statement, herein, we deeply analyzed the phenomenon of color shift which can't recover after push, and proposed the corresponding mechanism. Some experiments were conducted to verify the proposed mechanism. Besides, the effects of factors, like black matrix thickness, over coating layer thickness, etc, on static color shift were also investigated, and the corresponding static color shift model was established to quickly evaluate LCD static color shift.

2 PUSH COLOR SHIFT

2.1 Phenomenon

For LCD product, there was an interesting phenomenon that the color shift in pure red picture during manual handing in testing process can't recover for a long time after removing hand immediately even a long time unless an external touch force is pressed, as shown in Figure 1. Figure1.(a) showed that when observing the oblique angle, the panel produces purple color on the left and yellow color on the right, respectively, which is extremely similar to the mura on thin film transistor (TFT)-LCD bending with external force reported by Yu et al [6]. In addition, there is a positive correlation between color shift and bending degree. The research also suggested that when the pre-tilt direction of TFT and color filter (CF) has different bending degrees under external force, the black mura will occur, and it can't disappear under any other operation [6]. Nevertheless, in this work, the primary cause of color shift push is not completely consistent with the above conclusions due to the recoverable status after external touch force as shown in Figure 1(b) and (c). Therefore, we made an effort to study the generation mechanism of push color shift, which is beneficial to increase product yield.

(a) The generation of color shift



(b) The sticking of color shift

(c) The recovery of color shift

Figure 1. Process of push color shift

2.2 Mechanism

Due to the recoverable phenomenon, the volume of LC in cell was taken into account firstly. The practical volume of product can be calculated by the following equation.

$$V = M * N/\rho_{LC} \quad \text{Equation (1)}$$

Where V is the practical volume of LC, M is the practical mass of every drop, N is the numbers of LC drop, and ρ_{LC} is the density of LC. The theoretical volume of LC is the designed cavity of cell for storing LC. The practical volume of different products with similar design was listed in table 1. As for theoretical volume, it was calculated by theory. It can be seen from Table 1 that when the ratio of practical to theoretical volume is less than 98.11%, the push color shift occurs, which indicates that the practical volume of LC is the critical factor for the design of LCD.

Table1. Practical LC volume of different products

Item	product1	product2	product3	product4	product5	product6
Theoretical volume/mm3	171.339	100.71	150.45	149.33	178.73	160.278
LC drop pattern	15*9	7*10	13*9	13*9	9*15	9*15
Practical mass mg/drop	1.270	1.449	1.273	1.256	1.309	1.176
Practical LC mass /mg	171.45	101.43	148.94	146.95	176.72	158.76
Density of LC /(g/cm3)	1.018	1.018	1.008	1.008	1.008	0.9906
Practical volume/mm3	168.45	99.66	147.79	145.81	175.35	160.27
The ratio of practical to theoretical volume/(mm3)	98.31%	98.96%	98.23%	97.64%	98.11%	99.99%
Whether produce extrusion color shift	N	N	N	Y	N	N

It is well known that LCD cell consists of TFT glass, CF glass, and photo spacer (PS). Besides, it is filled with LC, as shown in Figure 2. According to force balance, whether the LC volume is enough or not, the atmospheric pressure (P) absolutely meets the following equations.

$$\mathrm{P} = P_{LC} + P_{PS} \qquad \text{Equation (2)}$$

$$P_{LC} = \rho_{LC} * G * H \qquad \text{Equation (3)}$$

Where P_{LC} is the LC pressure, P_{PS} is the PS holding force, G is the acceleration gravity, and H is the height of LC.

When the practical volume of LC is saturated or super-saturated, the cell holding force is mainly from LC. Well, LC is a kind of liquid which flows quickly like water. After removing the manual operation force, the cell bend recovers quickly and no color shift remains. However, when the LC volume is not enough, as shown in Figure 2, the primary holding force is from PS under the external force initially, and then LC turns to provide holding force. In this case, the pressure of LC follows the equation (4) below.

$$P_{LC(not\ enough)} \ll P_{LC(saturation/supersatrution)} \qquad \text{Equation (4)}$$

As a result, LC can’t resist the glass bending that causes the misalignment of ceiling and bottom glass, which is the major reason why the color shift remains, as shown in Figure 3. Nevertheless, the final external touch force destroys the balance and pushes LC flow to release the glass bending, making the color shift phenomenon disappear. To verify the effectiveness of this mechanism, we have done a series of experiments on LC margin, which can be seen in section 2.3.

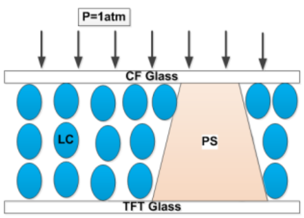


Figure 2. The model of LCD cell

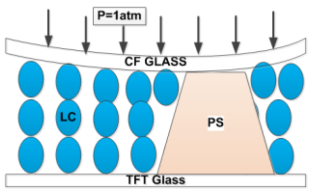


Figure 3. The model of glass bending

2.3 Experiments

The experimental conditions were listed in Table 2. We changed the practical LC volume by controlling the LC margin on one product.

Table2. The experiment of details

NO.	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Theoretical volume/mm3	149.33											
LC drop pattern	13*9											
Practical mass mg/drop	1.192	1.205	1.218	1.231	1.244	1.257	1.27	1.283	1.296	1.309	1.322	1.335
Practical LC mass /mg	139.46	140.99	142.51	144.03	145.55	147.07	148.59	150.11	151.63	153.15	154.67	156.2
Density of LC /(g/cm3)	1.008											
Practical volume/mm3	138.38	139.89	141.4	142.91	144.42	145.93	147.44	148.95	150.46	151.97	153.48	154.99
The ratio of practical to theoretical volume/(mm3)	92.70%	93.70%	94.70%	95.70%	96.70%	97.70%	98.70%	99.70%	100.80%	101.80%	102.80%	103.80%

The levels of push color shift were shown in Figure 4. According to the levels, we draw an important conclusion that the ratio of practical LC volume to theoretical LC volume should be more than 97.7% to prevent the color shift, which is also summarized in Figure 5 more clearly. The experimental results greatly verify the above mechanism, which has a certain guiding significance for the production process. However, for LCD design process, it is necessary to analyze the static color shift to optimize design.

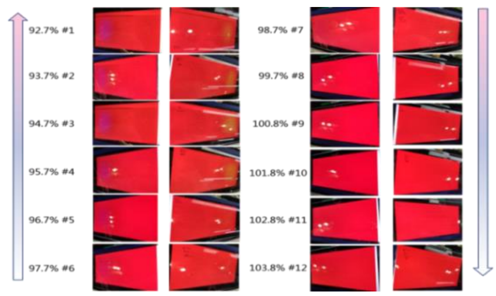


Figure 4. The levels of push color shift

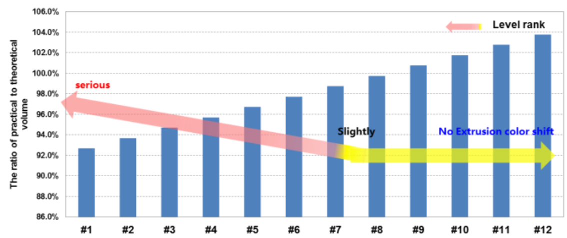


Figure 5. The relationship between push color shift levels and ratio of practical LC volume to theoretical LC volume

3 ANALYSIS OF STATIC COLOR SHIFT

3.1 Color shift of LCD

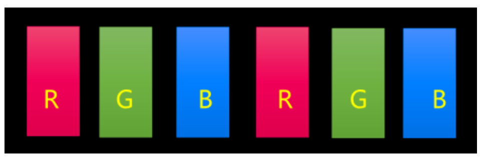


Figure 6. The color filter of LCD

As shown in Figure 6, the CF glass was coated red/green/blue (R/G/B) color filter regularly. Therefore, the color shift of R-G/R-B/G-B/G-R/B-G/B-R may be produced when there is a certain degree of misalignment between CF and TFT glass.

The LCD master2D software was used to simulate the color shift of R-G/R-B/G-B/G-R/B-G/B-R under the same misalignment degree, and the results were shown in Figure 7. It can be seen that the color shift of R-G is the most serious at visual angle of 60°, which is a reasonable explanation for why color shift under pure red picture is most easily detected. Furthermore, eyes are sensitive to light of 550 nm spectrum, which is the wavelength of G color [7]. Thus, the color shift phenomenon for R-G is most likely to occur.

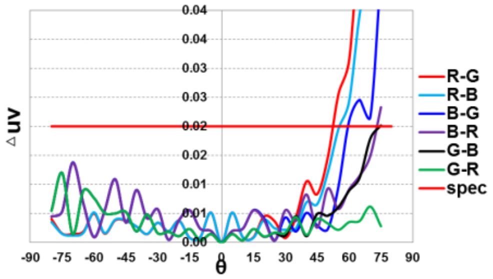


Figure 7. The color shift of R-G/R-B/G-B/G-R/B-G/B-R

3.2 Factors analysis

To analyze the factors of static color shift, LCD structure model was established, as shown in Figure 8. Through the light path analysis, the probable factors were list as black matrix thickness (BM THK), over coating layer thickness (OC THK), cell gap, misalignment (MA), and the distance between BM to pixel edge (BM-ITO2). The effects of the above factors on color shift of LCD were simulated by LCD master2D software, and the results of color shift at visual angle of 60° were in Figure 9~13.

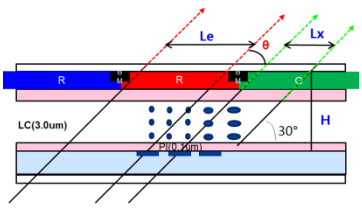


Figure 8. The structure model of LCD

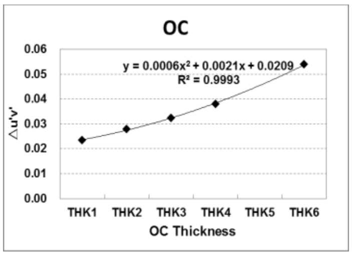


Figure9. The effect of OC THK

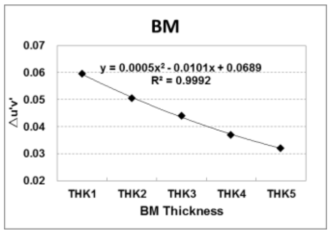


Figure10. The effect of BM THK

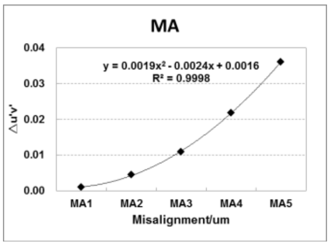


Figure11. The effect of MA

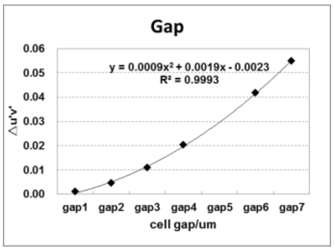


Figure12. The effect of cell gap

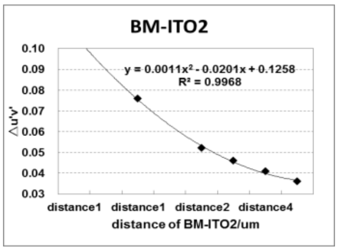


Figure13. The effect of distance of BM-ITO2

Simulation results showed that the relationship between color shift at visual angle of 60° and factors satisfies the following equation.

$$y = ax^2 + bx + c \qquad \text{Equation (5)}$$

Where a, b, and c are regression coefficients (a is squared effect term, b is the liner effect term, and c is constant term). All regression coefficients were listed in Table 3. It can be seen from Table 3 that all of determination coefficients (R^2) are more than 0.9990, indicating selected equation can well describe the relationship between color shift and factors. Among the three regression coefficients, a plays the most significant role in determining the color shift. The effects of factors on color shift increase with the increase of a value. Therefore, the effects of factors on static color shift decrease in the sequence of cell gap＞BM-ITO2＞OC＞MA＞BM. As the BM thickness increases, the color shift performance of LCD is improved. However, the BM thickness normally ranges from 1.0 to 1.5 um. It seems that the longer distance of BM to pixel edge will lead to the more excellent performance of color shift. In addition, OC THK, cell gap, and MA have negative effects on color shift performance, so the designer should take all factors into account seriously. To evaluate color shift quickly and accurately without LCD master2D software, a color shift model was established, as shown in section 4.

Table3. The regression coefficients

Item	a	b	c	R^2
OC	0.0138	-0.0170	0.0241	0.9993
BM	0.0056	-0.0442	0.0981	0.9990
MA	0.0074	-0.0048	0.0016	0.9998
Gap	0.0226	-0.0811	0.0694	0.9993
BM-ITO2	0.0188	-0.3478	1.6394	0.9999

4 EVALUATION MODLE

As shown in Figure 8, Le stands for the effective transmittance zone in pure red picture at visual angle of 60°, and Lx stands for the mix-transmittance zone, which can be calculated by Equation(6)~(7) below. The ratio of Lx to Le stands for the degree of color shift at physical view.

$$\mathrm{Lx} = (\text{cell gap} + \text{OC THK} + \text{PI THK} + \text{G THK} - \text{BM THK}) * \sqrt{3} \quad \text{Equation (6)}$$

$$\mathrm{Le} = \text{transmittance pitch} - \text{BM THK} * \sqrt{3} \quad \text{Equation (7)}$$

Because LC is controlled by voltage, the transmittance of panel would be changed by the distribution of voltage in sub pixel range, and the transmittance in pixel edge is usually weak, as shown in Figure 14.

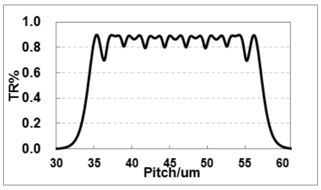


Figure14. The transmittance distribution of panel in sub pixel range

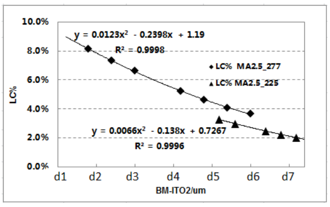


Figure15. The relationship between LC% and the distance of BM-ITO2

As we can see from Figure 14, the transmittance decreases rapidly in the edge of pixel. As a result, the distance of BM-ITO2 (BM to pixel edge) makes a great sense. At the conditions of without color filter, visual angle of 60°, and misalignment of 2.5 um, the luminance change with the distance of BM-ITO2 at 277PPI can be simulated by LCD master2D software separately. We defined the LC% as the luminance ratio of Lx to Le. The relationship between LC% and the distance of BM-ITO2 can be correlated by the equation (8), and the corresponding figure was exhibited in Figure 15.

$$y = 0.0123x^2 - 0.2398x + 1.19, R^2 = 0.9998 \quad \text{Equation (8)}$$

Combined Equation (6)~(8) and color chromaticity simulation calculation equations, the color shift of pure red picture at visual angle of 60° under misalignment of 2.5 um can be calculated quickly without LCD master 2D software. Table 4 shows the calculated results obtained by established model, and simulated results obtained by software. It can be seen clearly that the deviation of calculation to simulation is less than 0.003, which the calculated result is reliable.

Table4. The calculation results and simulated results

Item	PPI	Lx	Le	LC%	calculated △u'v'	simulated △u'v'	△
product1	260	9.00	24.30	3.89%	0.014	0.012	0.002
product2	280	10.50	22.00	4.70%	0.020	0.017	0.003
product3	213	9.90	31.10	3.46%	0.009	0.007	0.002
product4	210	10.70	32.10	3.89%	0.011	0.008	0.003

5 CONCLUSIONS

In this work, the explanation for the phenomenon of color shift which can't recover after push was put forward. The ratio of practical LC volume to theoretical LC volume should be more than 97.7% to improve the process yield. Through further analysis of static color shift factors, it was found that the effects of factors on static color shift decrease in the sequence of cell gap＞BM-ITO2＞OC＞MA＞BM. Finally, a novel solution to evaluate LCD static color shift reliably and quickly was proposed.

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