Research on Panel Impact Factors Related to Gamma of Liquid Crystal Displays

Ganmin Zeng[1,2], Keng Chen[1,2], Laidi Wu[1,2], Yanping Yu[1,2], Ting Zhou[1,2], Junyi Li[1,2]

ganmin_zeng @tianma.cn
[1]NO.6999 Xiang'an West Road, Xiang'an District, Xiamen City, China 361101
[2]Xiamen Tianma Microelectronics Co., Ltd 361101
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ABSTRACT

Gamma curve is an important parameter of liquid crystal displays (LCD). When the curve deviates, it will cause the human eyes to feel the picture distortion. In this paper, through the relationship between Gamma and transmittance, the factors that contribute to Gamma in the liquid crystal display module are analyzed. Techwiz software is used to perform optical modeling and simulation to simulate the Gamma difference of related factor changes. Gamma will be affected by the superposition of multiple factors, so optical modeling and simulation can confirm their contribution and clarify the direction to improve the Gamma shift problem. The order of the contribution of related impact factors to LCD Gamma is as follows: Width and Space of ITO electrode (ITO_W/S) ＞ PI film thickness (PI_THK) ＞ Cell gap ≈ Passivation layer thickness (PV_THK) ≈ Misalignment (MA) ＞ Twist angle ＞ Rubbing angle.

1 Introduction

LCD play an important role in mobile phones, notebook computers, monitor screens and televisions. People have higher and higher requirements for LCD with the improvement of current living standards. Generally, the relationship between LCD display brightness and input voltage is close to an exponential curve, shown as Equation (1), the power exponent γ is called Gamma, which characterizes the photoelectric response of the LCD. For a single LCD, its Gamma curve ultimately determines the photoelectric curve and the driving voltage curve of the driver IC. Previously, relevant practitioners did research on LCD Gamma mainly on the program of driver IC[1,2]. However, in the actual production process, due to the long debugging time of the Gamma curve, only one panel can be selected for debugging, and then the obtained parameters are applied to all LCDs because of the production efficiency. In this paper, we analyzed the influencing factors of Gamma with the same drive IC voltage, and ranked their importance through model simulation. By reducing the difference of the Voltage-Transmittance curve between the whole batches of products, it will economically and practically reduce the Gamma defect rate.

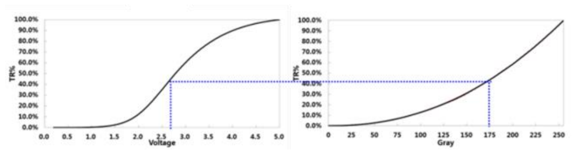
$$Y = \text{Grayscale}^{\gamma} \qquad \text{Equation (1)}$$

Y is the brightness of LCD grayscale

Grayscale is the brightness level relationship between the darkest black and the brightest white of the LCD, and it is usually divided into 256 levels from 0-255.

2 The influence factor of Gamma in LCD

Gamma is essentially a curve reflecting the photoelectric relationship of the LCD. If the Gamma curve is set to the standard γ=2.2, for a single module, the relationship between the voltage and the gray level can be determined by the V-T curve, as shown in Fig. 1. Therefore, the factors that have an effect on the V-T curve theoretically also have an effect on Gamma.



(a) V-T curve (b) Gamma curve

Fig. 1 The relationship between grayscale and voltage of LCD

The transmittance of LCD can be expressed by Equation (2)[3]. Usually, Δn is only related to the characteristics of the material itself.

$$T = \frac{1}{2}\sin^2(2\varphi)\sin^2\left(\frac{\pi\Delta n d}{\lambda}\right) \qquad \text{Equation (2)}$$

φ is the twist angle of liquid crystal

d is the cell gap of the LCD cell

Δn is the birefringence of liquid crystal

λ is the wavelength of incident light

We set up the optical model shown in Fig. 2 and use the liquid crystal static analysis function of Techwiz software to simulate the rotation of the liquid crystal in the electric field. And then obtain the corresponding transmittance of different voltages (V-T curve). Assuming that Gamma is 2.2 in all grayscale, use the V-T curve of the standard simulation model to link grayscale and voltage. Then the relationship between Gamma and grayscale can be obtained by Equation (3), In order to clearly show the change of Gamma, the Grayscale-Gamma curve is shown in Fig. 3. By changing the influence factor of Gamma, simulate a new V-T curve, and then get a new Gamma curve. Generally speaking, when the Gamma value is between 2.0 and 2.4, the human eye cannot distinguish the obvious grayscale transition distortion[4].

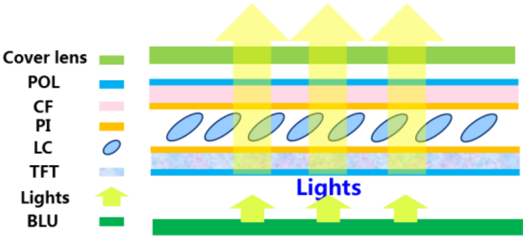


Fig. 2. Display model for Gamma simulation

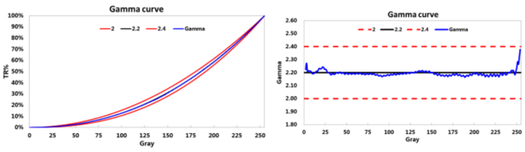


Fig. 3. Gamma curve represented by grayscale

$$\gamma = \frac{\lg[(TrG - Tr0)/(Tr255 - Tr0)]}{lg(Garyscale/255)} \qquad \text{Equation (3)}$$

TrG is the transmittance at the grayscale
Tr0 is the transmittance at the 0 grayscale
Tr255 is the transmittance at the 255 grayscale

3 Mechanism analysis

3.1 ITO_W/S

FFS LCD is taken as an example. As shown in the Fig. 4, on the TFT substrate, there are striped ITO pixel electrodes on the top layer and COM electrodes on the bottom layer. The fringe electric field generated by the ITO electrode and the COM electrode causes the liquid crystal molecules to rotate in a plane parallel to the glass substrate. The width of a single ITO electrode is W, and the space between two ITO electrodes is S. Due to process fluctuations, Width/Space of ITO electrode (ITO_W/S) will deviate from the design value, resulting in different fringe electric fields at the same voltage. The electric field distribution of the optical model is simulated by Techwiz is shown in the Fig. 5. As shown in the Fig. 6, the change of ITO_W/S leads to the change of electric field, so that Tilt angle and Twist angle of liquid crystal molecules are also changed.

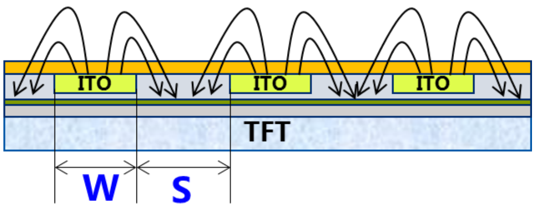


Fig. 4 The schematic diagram of ITO_W/S

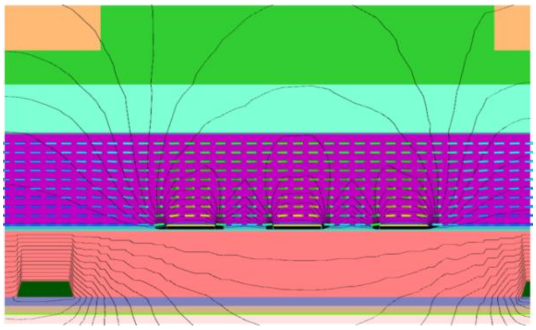


Fig. 5 Simulation of electric field distribution By Techwiz

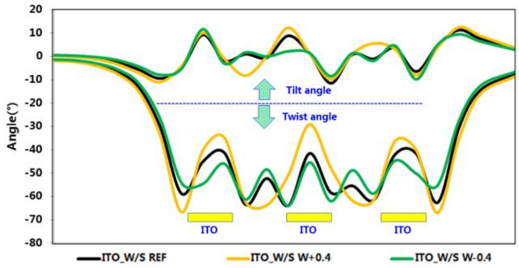


Fig. 6 Simulation of Tilt angle and Twist angle for different ITO_W/S

The Gamma curve simulation results of different ITO_W/S are shown in the Fig. 7. When the W increases 0.2um, the simulated Gamma value exceeds 2.4 at 150 gray levels. As shown in Fig. 8, the effect of ITO is verified to be consistent with the simulation results. It can be seen that the fluctuation of the ITO_W/S has a great impact on Gamma.

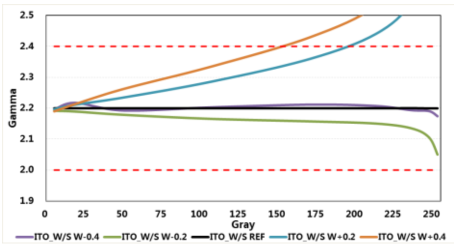


Fig. 7 The influence of ITO_W/S by simulation

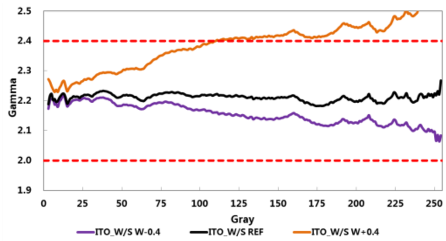
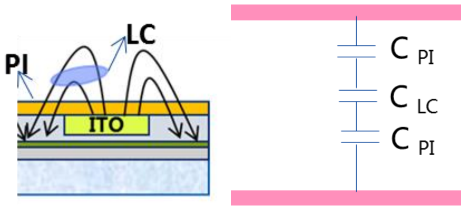


Fig. 8 The influence of the ITO_W/S by actual validation

3.2 PI_THK

As shown in Fig. 9, PI film and liquid crystal are series capacitors and share pixel voltage together. The partial voltage of the liquid crystal can be obtained by equation 4&5. When the PI film thickness (PI_THK) is increased, the ratio of sharing voltage is increased, so the liquid crystal is more difficult to rotate.



(a) (b)

Fig. 9 Equivalent circuit of LC and PI

$$C = \varepsilon S/d \qquad \text{Equation (4)}$$

$$V_{LC} = \frac{1/jwC_{LC}}{1/(jwC_{PI}) + 1/(jwC_{LC}) + 1/(jwC_{PI})} \qquad \text{Equation (5)}$$

The influence of the PI_THK change on Gamma is shown in Fig. 10, the Gamma value is positively correlated with the PI_THK. The simulated Gamma value exceeds 2.4 at 160 gray levels when the PI_THK increases by 10%. Further, the effect of PI_THK is verified to be consistent with the simulation results is shown in Fig. 11. It can be seen that the fluctuation of the PI_THK has a great impact on Gamma.

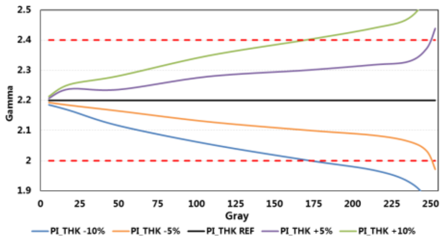


Fig. 10 The influence of PI_THK by simulation

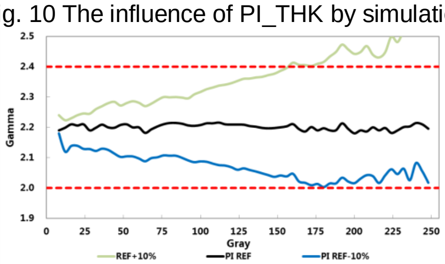


Fig. 11 The influence of the PI_THK by actual validation

3.3 Cell gap

Refer to Equation (2), LCD Cell gap change will affect the transmittance, and the influence of the simulated Cell gap change on Gamma is shown in Fig. 12. The Gamma value is negatively correlated with the Cell gap. When the Cell gap increases or decreases by 3%, the simulated Gamma value will be affected within 0.1. Therefore, the fluctuation of the cell gap has a moderate impact on Gamma.

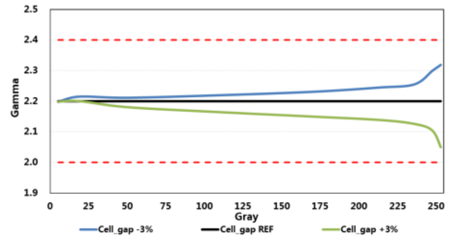


Fig. 12 The influence of Cell gap by simulation

3.4 PV

As shown in Fig. 13, the Passivation layer is the insulating layer between the COM electrode and the ITO electrode, which has an important influence on the distribution of the electric field. The effect of simulated Passivation layer thickness (PV_THK) change on Gamma is shown in the Fig. 14 Gamma value is positively correlated with PV_THK. When the PV_THK is increased or decreased by 10%, the simulated Gamma value will be affected within 0.1. Therefore, the fluctuation of PV_THK has a moderate impact on Gamma.

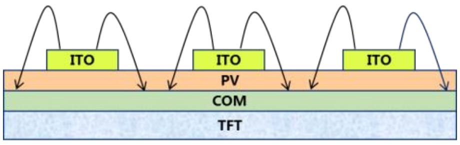


Fig. 13 The schematic diagram of PV

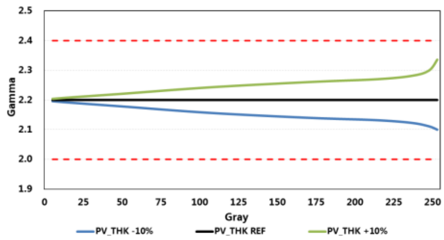


Fig. 14 The influence of PV_THK by simulation

3.5 MA

As shown in Fig. 15, misalignment (MA) represents the relative position shift of CF and TFT. When the MA is different, the electric field distribution of the TFT under the CF aperture is different. To simulate the effect of different MA on Gamma, the aperture ratio reduces the effect of Gamma in Fig. 16. When the MA shift is within 2um, the simulated Gamma value will be affected within 0.1. Therefore, the fluctuation of the MA has a moderate impact on Gamma.

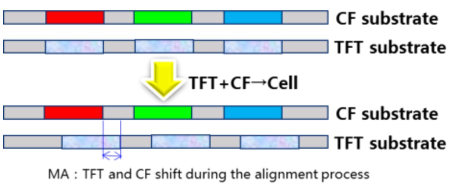


Fig. 15. The schematic diagram of MA

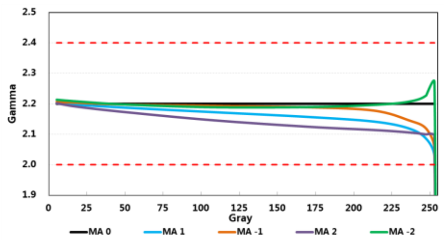


Fig. 16. The influence of MA by simulation

3.6 The others factors of Cell

The influence of the Rubbing angle, Pretilt angle and Twist angle on Gamma is shown in the Fig. 17. The above-mentioned related factors mainly have an influence at the 0 grayscale transmittance, so the influence on Gamma is mainly in the low gray scale by Equation (3). In actual production, Gamma mainly has the risk at high gray levels, so their influence on the entire Gamma curve is relatively little.

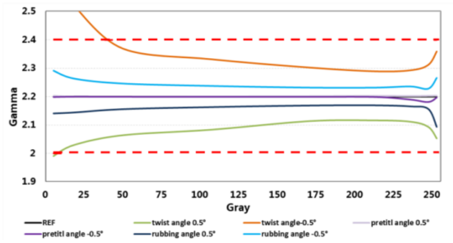


Fig. 17. The influence of Twist angle, Pretitl angle and Rubbing angle by simulation

4 Results

The mechanism of the influence factor can be reflected by Equation (2). For example, the change of TFT affects the electric field and then affects the φ. The order of the contribution of related impact factors to LCD Gamma is as shown in Fig. 18 : ITO_W/S ＞ PI_THK ＞Cell gap≈ PV_THK≈MA＞Twist angle＞Rubbing angle.

As shown in the Fig. 19, using this model in the actual production (6.x inch LTPS display panel), adjust ITO_W/S&PI_THK reduces the proportion of Gamma defect rate (exceeding SPEC2.2±0.2) from 4% to 0.06%.

Fig. 18. The order of Gamma factor influence

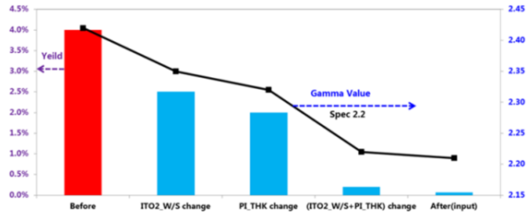


Fig. 19. Yield rate improvement in practical applications, the abscissa is the introduction of different countermeasures (Before: Countermeasures not introduced; After(input): Introduction of countermeasures for ITO_W/S+PI _THK changes)

5 Conclusions

There are many influencing factors of Gamma. This paper mainly studies the contribution of different influencing factors to Gamma shift. By establishing a simulation model, analyzing the influence mechanism and comparing the difference of factors, we get the two major contributing factors of Gamma shift, i.e., ITO_W/S and PI_THK. For 6.x inch LTPS display panel, we successfully solved its high grayscale shift problem by adjusting ITO_W/S and PI_THK. In the case of production capacity, cost and IC support, starting from the parameters with large process fluctuations (ITO_W/S and PI_THK) to reduce Gamma shift will bring greater benefits and high implementation ability. For this research, some areas are not very detailed, such as the mechanism investigation under the superposition factor, the TR% level difference of different gray levels of Gamma after applying different electric fields, the specific embodiment of the role of the panel device in the Gamma debugging process, etc., which can be used as a follow-up related personnel in the field Research direction.

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