Reducing Color Shift on White Screen in Oxide Semiconductor In-Plane Switching LCD Display by Controlling the Light Intensity of Different Color Bands Through Array Film Thickness Design

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Abstract
The influence of the array film thickness design on the color shift in oxide semiconductor IPS LCD was studied. The Macloed simulation software was used to optimize the full-film thickness design. By setting the light intensity of different wavelengths in different color bands and viewing angles, the optimized film thickness design was proposed and the color shifts at different viewing angles were reduced.

Author Keywords
LCD; Color Shift; Array Film; Simulation.

1. Introduction
In recent years, display technology has been developing vigorously. TFT-LCD (thin film transistor liquid crystal display) display technology has attracted much attention due to its high resolution, rich colors, high efficiency and energy saving, long service life and relatively low radiation [1]. It is widely used in various displays of small, medium and large sizes [2]. In TFT-LCD, it is divided into TN (Twisted Nematic), VA (Vertical Alignment) and IPS (In-Plane Switching) display technologies. IPS display technology has rapidly occupied the leading position in the LCD display industry with its advantages of wider viewing angles, faster response speed and high stability in different environments [3]. With the development of display technology, people have put forward higher requirements for LCD display technology. Since oxide semiconductors have higher electron mobility and lower leakage current compared to amorphous silicon semiconductors, they have become the mainstream technology for the further development of IPS LCD [4-6]. However, consumers are becoming more and more strict about the image quality of displays. Especially for color shift at different viewing angles, it has become an important indicator for evaluating the display performance. Theoretically, the main factors affecting color shift at different viewing angles include backlight (BLU), polarizer (POL), array (Array), liquid crystal (LC), color filter (CF), etc [7]. A large number of literatures indicate that array has a greater impact on color shift on white screen at different viewing angles [1-2]. Oxide semiconductor technology generally has a relatively complex inorganic layer stack and more interfaces due to relatively poor resistance to water and oxygen of devices. The interference of light at different interfaces makes the color change at different viewing angles more complicated.

Until now, there are few studies on improving the color shift on white screen at different viewing angles related to the array of oxide semiconductor IPS LCD. The existing research on improving the color shift of oxide semiconductor LCD is mainly based on the influence of a single inorganic layer in array [2]. Moreover, they mainly analyze the reduction of the red band, cannot completely avoid problems such as color shift other than redness.

In this paper, a method based on the analysis of the entire layer in array to improve color shift, optimize the layer stacking, and reduce the color shift problem at different viewing angles is proposed. Macleod optical thin film design software is used to perform optimization of transmittance at different wavelengths and intensities in the red, green, and blue bands at different viewing angles. Through the simulation optimization of film thickness, the intensity fluctuation in the red, green, and blue bands at different viewing angles is reduced, and the consistency of fluctuations is ensured to improve the magnitude of color point changes at different viewing angles. Through the scheme proposed in this paper, combined with simulation and experimental results, it is confirmed that the color shift at different viewing angles of the product is improved, and the product display quality is enhanced.

2. Simulation and Experiment
Simulation Software, Sample Preparation and Testing Equipment: The software used for the array film simulation in this paper is Macleod optical thin film design software. The preparation of experimental samples is based on an oxide semiconductor IPS LCD with a color gamut of DCI-P3 98% produced by Mianyang HKC Optoelectronics Technology Co., Ltd. on its 8.5G TFT-LCD production line. The schematic diagram of its structure is shown in Figure 1. From bottom to top are the array-side glass substrate (Glass), gate layer (Gate), gate insulating layer (GI SiNx and GI SiOx), oxide semiconductor layer (IGZO), source-drain electrode layer (SD), first passivation insulating layer (PAS1 SiOx and PAS1 SiNx), organic insulating layer (PFA), common electrode layer (C-ITO), second passivation insulating layer (PAS2 SiNx), and pixel electrode layer (P-ITO).

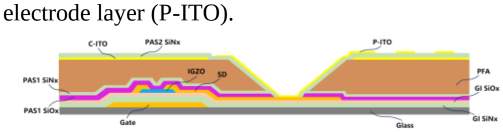

Figure 1. The schematic diagram of the stacked structure of the array film of oxide semiconductor IPS LCD.

In this paper, the F-STAR automatic optical characteristic measurement equipment (FS-3500GAR) is used, equipped with a CS3000 spectrometer for testing. The sample to be tested is tested with the same backlight. The open cell (OC) test is performed under the white state with the gray levels of 255 (L255). The test viewing angle range is from 0° to 70°, and a test step of 10° is set. In addition, the color shift phenomenon is confirmed by taking pictures at different viewing angles.

Characterization: At present, there are many characterization methods for color shift. Here, JNCD (Just Noticeable Color Difference) value based on the CIE1976 color coordinate system are used to characterize the simulation results and sample test results. The color change of the simulation results is evaluated by combining the simulated transmission spectrum and the backlight spectrum at different viewing angles. The backlight spectrum at different viewing angles used in this paper are relatively consistent (Figure 2). The deviation of JNCD is

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mainly calculated by characterizing the farthest distance of the color points at 0° viewing angle to other viewing angles (defined as distance A), and the maximum distance between color points (defined as distance B). As shown in Figure 3, generally, the smaller the distance A and B, the smaller the color difference between different viewing angles.

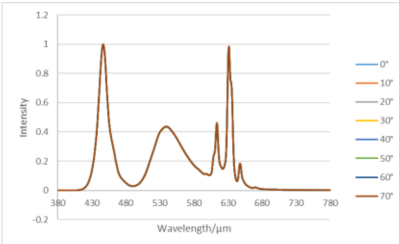

Figure 2. The normalized backlight spectrum at different viewing angles.

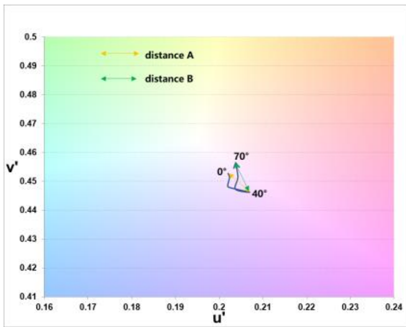

Figure 3. Illustrative of the distance A and the distance B.

Simulation Optimization Scheme: The simulation N and K value of the stacking layers are based on the array produced by the 8.5G TFT-LCD production line of Mianyang HKC Optoelectronics Technology Co., Ltd. Considering the process and electrical properties, the thickness range of the basic film for the simulation is set as follows: GI SiNx 300–400 nm, GI SiOx 55–100 nm, PAS1 SiOx 250–400 nm, PAS1 SiNx 100–300 nm, organic insulating layer (2200 nm), C-ITO 90 nm, and PAS2 SiNx 350–450 nm. The red band is mainly in the range of 590–780 nm. The green band is mainly in the range of 500–560 nm. The blue band is mainly in the range of 400–490 nm. Considering the backlight spectrum, the central wavelength of the red band is 630 nm, the central wavelength of the green band is 540 nm, and the central wavelength of the blue band is 455 nm. In the Macloed simulation software, set the target wavelength, viewing angle, and transmittance selection. Setting the wavelengths within ±30 nm of the central wavelength of different color bands, with a 15 nm step. Setting the viewing angle from 0° to 70°, with a step of 10°. Using the conjugate gradient method to respectively perform simulation optimization of different magnitudes of transmittance. Simulating the spectra at different viewing angles. Then, combining the spectra of the backlight to measure the color point change. Selecting the magnitude of transmittance with smaller color point changes. Based on the above parameter selection, changing the wavelength step of different color bands and the wavelength range to simulate the final optimized stacking scheme of film thickness.

Based on the film thickness stacking obtained through the above optimization scheme, and considering the actual electrical and process requirements, the final production film thickness stacking scheme is fine-tuned.

3. Results and Discussion

Results of Reference Conditions: The array film thickness design of the reference condition before color shift improvement are as follows: GI SiNx 387.5nm, GI SiOx 75nm, PAS1 SiOx 270nm, PAS1 SiNx 100nm, PFA 2200nm, C-ITO 90nm and PAS2 SiNx 230nm.

The left of figure 4 is the image of the product at different viewing angle. There is obvious reddening at large viewing angle on white screen. The right of figure 4 is the image of the disassembled array glass with the backlight. It can be seen that there is obvious redness at large viewing angle. The redness problem of the product is caused by the color shift of the array glass. Figure 5 shows the color point change curve of the array glass simulated by the Macloed software, the measured color point change curves of the actual array glass and the actual product at viewing angles from 0° to 70°. The color change trends of the three curves are the same. The color point change of the Macloed software simulated array glass can reflect the measured color point change of the actual array glass and the actual product. The color shift values of the distance A and B calculated from the Macloed software result of the array film thickness are both 4.51 JNCDs. The distance A and B of the actually tested array glass are 3.69 JNCDs and 3.77 JNCDs respectively. The distance A and B of the actually tested product are both 5.55 JNCDs (the distance A and B within 50° viewing angle of the actually tested product are both 5.35 JNCDs). The difference of the curves between the simulated result and the actually tested result is due to the fluctuation of the array film thickness and NK value during the actual production process on the production line, and the influence of the liquid crystal and the color filter.

Figure 4. The image of the product at position 1 at different viewing angle (left). The image of the array at position 1 at different viewing angle (right).

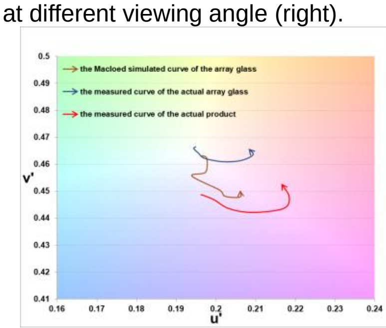

Figure 5. The color point change curve of the array glass simulated by the Macloed software, the measured color point change curves of the actual array glass and the actual product at viewing angles from 0° to 70°.

Results of The Optimized Array Film Thickness by Simulation: Figure 6 shows the color shift value calculated by matching the transmittance spectrum simulated by adjusting the light intensity in different color bands with the backlight spectrum at different viewing angles. When the transmittance is 90% set in the Macloed software, a smaller color shift value is obtained. The distance A and B are 0.64 JNCD and 0.71 JNCD respectively. Compared with the actual sample array glass before improvement, significant improvement is achieved. Figure 7 shows the transmittance spectra at different viewing angles with a transmittance setting of 90%, 50% and 95% in the Macloed software. It can be seen that the transmittance fluctuations in different color bands are small, and the transmittance fluctuations in different bands at different viewing angles are relatively consistent, resulting in small color shifts at different viewing angles with the transmittance setting of 90%. The film thickness stacking obtained with the transmittance setting of 50% has a weak restriction on the wavelength fluctuations, resulting in large differences in wavelength intensity fluctuations and obvious inconsistencies between different bands. The film thickness stacking obtained with the transmittance setting of 95% has excessive restriction on the wavelength fluctuations. The simulation is difficult to achieve a film thickness stacking that meets the set transmittance intensity requirements for all bands, resulting in small fluctuations in some bands that meet the set value, while in some other bands that cannot meet the set value. There is obvious inconsistency in fluctuations between different bands, leading to a large color shift. Therefore, in order to improve the color shift problem at different viewing angles, the transmittance spectra at different viewing angles obtained after optimizing the film thickness need to have relatively small fluctuations, and at the same time, the fluctuation between different color bands need to be relatively consistent.

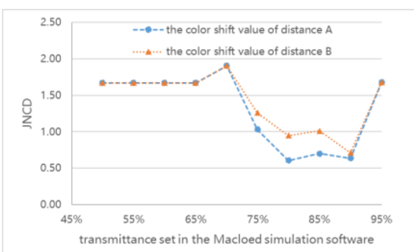

Figure 6. The color shift value simulated by the Macloed simulation software with different transmittance set.

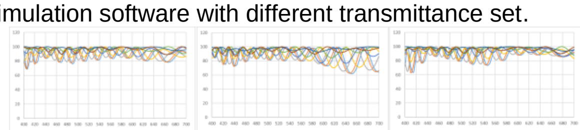

Figure 7. The transmittance spectra at different viewing angles with a transmittance setting of 90% (left), 50% (middle) and 95% (right) respectively in the Macloed software.

To confirm the influence of changing the wavelength step of different color bands and the wavelength range of different color bands on optimizing the film thickness, simulation analysis is performed based on setting the transmittance of 90% in the Macloed software. As shown in Figure 8, it shows that a wavelength step of 15 nm has a smaller color shift value, and the different wavelength ranges have smaller color shift values within 30 nm of different color bands.

Based on the above simulation parameter settings, the film thickness optimization scheme are as follows: GI SiNx 340.9nm, GI SiOx 54.8nm, PAS1 SiOx 282.3nm, PAS1 SiNx 155.2nm, PFA 2200nm, C-ITO 90nm, and PAS2 SiNx 382.9nm.

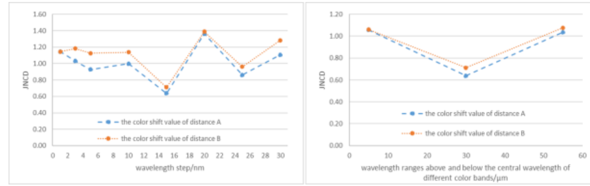

Figure 8. The color shift value with different wavelength step (left). The color shift value with different wavelength ranges (right).

Experimental Results of The Optimized Film Thickness Scheme: In factory production, considering the electrical properties of the TFT in the array and the process requirements, the optimized thickness scheme in the experiment is as follows: GI SiNx 357.5nm, GI SiOx 75nm, PAS1 SiOx 300nm, PAS1 SiNx 150nm, PFA 2200nm, C-ITO 90nm, PAS2 SiNx 380nm. Compared with the film thickness design before the color shift improvement, the color shift value of the experimental film thickness design is smaller. The distance A and B are 0.61 JNCD and 1.15 JNCD respectively, shows obvious improvement.

Figure 9 shows the color point change curves of the experimental array film thickness scheme simulated by the Macloed software, the measured color points of the actual array glass and the actual product at viewing angles from 0° to 70°. It can be seen that all of the curves are small. The different of these curves is due to the fluctuation of the array film thickness and NK value during the actual production process, the influence of the liquid crystal and the color filter. However, compared with the result before the color shift improvement, the color point change of the experimental condition is smaller. The improvement of the reddish problem is effective. Tables 1-1 and 1-2 show the results of comparing the color shift values before and after improving the color shift. It can be seen that the color shift values of both simulation and actual sample tests are significantly reduced after the color shift is improved. Figures 10a and 10b show the comparison of the actual visual effects of the array glass and the products made under the conditions before and after color shift improvement. It can be seen that the color shift after improvement is significantly improved, which is consistent with the simulation color point change results.

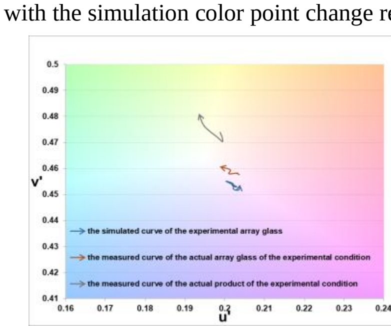

Figure 9. The color point change curves of the experimental array film thickness scheme simulated by the Macloed software, the measured color points of the actual array glass and the actual product at viewing angles from 0° to 70°.

Table 1-1. The results of comparing the color shift values of the distance A before and after improving the color shift

Distance A	Simulation /JNCD	array glass test /JNCD	product test @ 0~70° /JNCD	product test @ 0~50° /JNCD
before improvement	4.51	3.69	5.55	5.35
after improvement	0.61	1.46	2.25	0.91

Table 1-2. The results of comparing the color shift values of the distance B before and after improving the color shift

Distance B	Simulation /JNCD	array glass test /JNCD	product test @ 0~70° /JNCD	product test @ 0~50° /JNCD
before improvement	4.51	3.77	5.55	5.35
after improvement	1.15	1.46	3.08	0.91

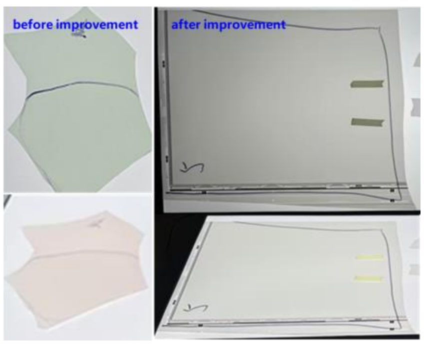

Figure 10a. The comparison of the actual visual effects of the array glass before and after the color shift improvement.

Figure 10b. The comparison of the actual visual effects of the products before and after the color shift improvement.

4. Conclusion

A method based on the analysis of the entire array film layer to optimize the film stacking, and reduce the color shift at different viewing angles is proposed to improve the color shift problem of the oxide semiconductor IPS LCD on white screen. By disassembling the products before color shift improvement, it was confirmed that the array glass caused the reddish problem on white screen of the product. Through software simulation and actual measurement, the simulated color change at different viewing angles of the Macloed simulation software had a consistent trend with the measured color change of the array glass and the product was confirmed. By using the Macloed simulation software to adjust and set the transmittance at different viewing angles of different color bands, the wavelength step, and the wavelength range of different colors, the optimized film thickness scheme was obtained through simulation. Combining the simulation and experimental results, it was confirmed that the optimized array film thickness stacking scheme can effectively reduce the color shift value. The maximum color shift value of the distance B within 0°–70° viewing angle range of array glass simulation is improved from 4.51 JNCDs before improvement to 1.15 JNCDs under experimental conditions. The optimized conditions show obvious improvement in the measured color shift value compared to the samples before improving the color shift. The measured color shift values and visual effects of array glass and products were both well improved. Especially within a 50° viewing angle, the color shift values of the distance A and the distance B under the conditions before improvement were 5.35 JNCDs, and the color shift value under the optimized conditions were 0.91 JNCD. Finally, we believe that the oxide semiconductor IPS LCD color shift improvement method proposed in this paper can be used for color shift improvement caused by LCD array films of various types and color shift improvement caused by film stacking of other product types (such as OLED) due to its optimization of light intensities of different color bands.

5. References

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