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# Color Shift Improvement for IPS-Mode Wide-View Liquid-Crystal Displays<sup>†</sup>

Yanni Liu, Hui Wang, Sheng Wang, Bingbing Wu

Research & Development Center, Hefei BOE Optoelectronics Technology Co., LTD,  
No. 2177 Tongling North Road, Hefei, Anhui Province, China

## Abstract

*This article presents several methods for enhancing the color shift performance in the side - view of wide - view IPS - mode liquid crystal displays. By depositing film layers with different refractive indices at specific positions on the panel and incorporating a wide - view compensation film, it becomes possible to achieve distinct color alterations in the side - view. Moreover, techniques like placing a small - phase - difference film on the exterior of the panel can also be employed to fine - tune the side - view color.*

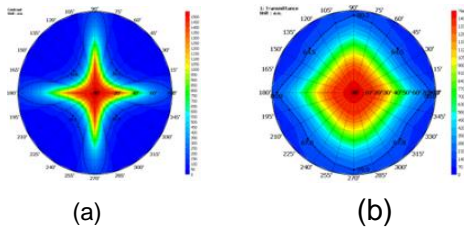
## Author Keywords

Coating film; color shift; refractive index; phase difference;

## 1. Introduction

Wide view LCDs are increasingly used in fields such as automotive and medical displays. Traditional LCDs have more light leakage in the 45 - degree azimuth direction, resulting in the smaller viewing angle. In applications with high viewing angle requirements such as medical diagnosis and automotive displays, traditional LCDs require a wide view polarizer to reduce side view light leakage and improve side view contrast (CR), as shown in Figures 1 (a) and 1 (b). Figure 1 (a) shows the full view CR without a wide view POL, while Figure 1 (b) shows the full view CR with a wide view POL [1 - 2].

However, the compensation film in a wide view POL usually has positive dispersion or flat dispersion characteristics, i.e., it only has the best compensation effect on green light, and there is some leakage of red and blue light. Therefore, a wide view POL can increase the side view contrast while also causing color shift issues, usually resulting in color shifts towards red, purple, or blue.



**Figure 1.** (a) Viewing angle without wide view POL, (b) Viewing angle with wide view POL

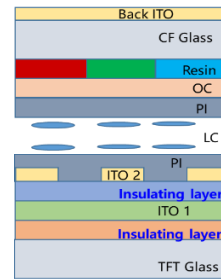
The common compensation films in wide view POL include the A plate, the B plate, and the C plate [3 - 5]. The definitions of A plate, B plate and C plate are determined by the refractive indices of the retardation plate in the X, Y and Z directions. Combining one or two compensation films can reduce side view light leakage, such as combinations of +A and +C plates, +B and -C plates, +B and -B plates etc. Each combination of compensation films can adjust the planar directional retardation ( $R_o$ ) and thickness directional retardation ( $R_{th}$ ) to achieve color adjustment of the side view light leakage. But side view colors are usually red, purple, or blue, and cannot achieve colors such as gray, gray blue, or yellow

Furthermore, when using a wide view POL on an IPS panel, if the compensation film is placed on the CF POL, the O - mode is used, which means that the transmission axis of the TFT POL is

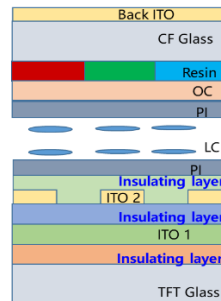
parallel to the ordinary axis of the liquid crystal molecules. If the compensation film is placed on the TFT POL, the E - mode is used, which means that the transmission axis of the TFT POL is parallel to the extraordinary axis of the liquid crystal molecules.

## 2. Coating film in panel

As shown in Figure 2, the structure of a conventional IPS LCD is presented here. In this structure, the TFT structure in the pixel aperture opening area is usually composed of insulating layer 1, ITO layer 1, insulating layer 2, and ITO layer 2. Both insulating layers 1 and 2 are made of silicon nitride ( $SiN_x$ ). The refractive index of  $SiN_x$  is around 1.89, and that of ITO is around 1.83. Since the refractive indices of the insulation layers and ITO layers are similar, the reflected light at the interfaces of these four film layers is not easily interfered or eliminated. Therefore, the transmittance of light at different wavelengths is basically the same. After using a wide view POL, the side view color of black images is mainly determined by the  $R_o$  and  $R_{th}$  of the wide view compensation film.



**Figure 2.** Conventional structure of IPS LCD



**Figure 3.** New structure of IPS LCD

The new structure described in this article is shown in Figure 3. In this structure, the TFT structure in the pixel aperture opening area is usually composed of insulating layer 1, ITO layer 1, insulating layer 2, ITO layer 2, and insulating layer 3. Layer 3 can also be omitted. Among insulating layers 1 to 3, at least one of them contains  $SiO_2$ , because  $SiO_2$  has a refractive index of about 1.47, which is significantly different from those of  $SiN_x$  and the ITO layers. As a result, the reflected light at the interface between the two media can be easily interfered and eliminated, which can increase or decrease the transmittance of certain wavelengths of light. By adjusting the thickness of the insulating film layer, the transmittance of specific wavelengths can be regulated. The variation in the transmittance of certain wavelengths of light is

superimposed on the color of the leakage light of the wide view POL, leading to a change in the side view color of the leakage light.

We adjusted the material type and thickness of insulation layers 1 - 3 to verify their impact on the side - view color. We employed a wide view POL with +A and +C plates in O - mode, where the transmission axis of the TFT POL is parallel to the ordinary axis of the liquid crystal molecules. The experimental conditions and results are presented in Table 1.

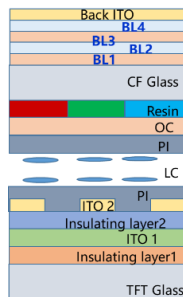
From the test results, the side view color is blue - gray under condition S3. In contrast, under condition S4, it is greenish. By analyzing the reflection from the TFT surface of the single panel, we can infer that the relatively low intensity of the blue band in the reflected light of S3 leads to a higher blue transmittance, giving the side view a bluish tendency. The reflected light of S4 is more reddish - purple, indicating a higher transmittance in the green band, so the side view color tends to be green.

**Table1.** The color shift with coating film in panel

Item	Main	S1	S2	S3	S4
Insulating layer1	SiNx(0.35um)	SiO2(0.35um)	SiNx(0.3um)+ SiO2(0.1um)	SiNx(0.35um)	SiNx(0.2um)
Insulating layer2	SiNx(0.6um)	SiNx(0.15um) + SiO2(0.35um)	SiNx(0.15um) + SiO2(0.35um)	SiNx(0.15um) + SiO2(0.35um)	SiO2(0.2um)+ SiNx(0.2um)
Insulating layer3	-	-	-	-	SiO2(0.2um)
Side-view color (POL with +A and +C plates in O- mode)					
Reflected color of the TFT surface					

**3. Coating film on panel:**

Similarly, Coating films on the back of CF glass with high and low refractive index materials can also increase the reflectivity or transmittance of specific wavelengths of light, thereby achieving color changes in the side view angle. The conventional LCD display structure is shown in Figure 2, where the CF back structure has a layer of back ITO to achieve electrostatic discharge. The new structure described in this article is shown in Figure 4. We kept the various film layers inside the panel unchanged and made only transparent films with different refractive indices on the outer surface of CF glass. The BL1~BL4 in Figure 4 represent film layers with high and low refractive indices, respectively. The film layer on the surface of CF is not limited to the four layers as shown in Figure 4. It can be made into more or fewer layers such as three, five or six layers. In addition, the high and low refractive index film layers are not limited to SiNx and SiO<sub>2</sub>. For example, SiNx can be replaced with other high refractive index film layers such as Nb<sub>2</sub>O<sub>5</sub> (refractive index of about 2.3 @ 550nm).



**Figure 4.** New structure on the back of CF Glass

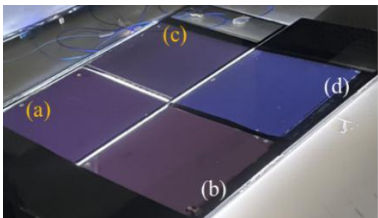
We verified the effect of different coating thicknesses on the side view role deviation of the CF surface, as presented in Table 2. Among these, the wide view POL with a B0 plate operates in E - mode, in which the TFT POL transmission axis is parallel to the extraordinary axis of the liquid crystal molecules. The coating conditions and color shift results are shown in Table 2. From the verification results, it can be observed that when combined with the S6 coating conditions, the surface reflection of the panel without POL appears red, whereas when a wide view POL is applied, the side view color appears gray.

**Table2.** The color shift with coating film on panel

Layer	Thickness-main	Thickness-S5	Thickness-S6
CF Glass	0.2mm	←	←
SiNx	/	280Å	200Å
SiO2	/	453Å	200Å
SiNx	/	500Å	300Å
SiO2	/	420Å	450Å
CF back ITO	150Å	←	←
POL with B0 plate in E -mode			
Reflective color at CF surface Of single panel			

In addition, we also investigated the color shift of different types of compensation films under the same coating conditions. We discovered that, with the same coating conditions in place, different types of compensation POLs have distinct impacts on the color of the side viewing angle.

We employed the coating conditions S5 as specified in Table 2, and the wide-view POL was set in the O-mode. When a specific +B&-B compensation film was utilized, the color of the side view shifted from purple to red, as illustrated in Figure 5. In this figure, 5(a) represents the color without any coating, and 5(b) represents the color under the coating condition S5. On the other hand, when a certain +A&+C compensation film was used, the color of side view changed from blue-purple to blue, also as shown in Figure 5. Here, 5(c) is the color without coating, and 5(d) is the color with the coating condition S5.



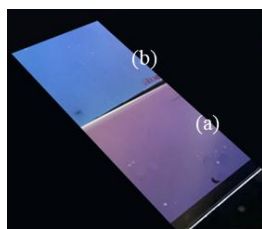
**Figure 5.** Color shift of different types of compensation films in the same coating conditions

(a) +B&-B wide view POL+ no coating, (b) +B&-B wide view POL+ coating condition S5, (c) +A&+C wide view POL+ no coating, (d) +A&+C wide view POL+ coating condition S5

#### 4. Add small retardation film:

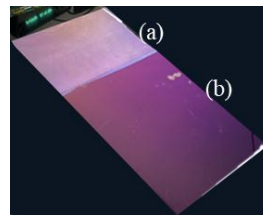
In conventional applications of wide view POL in IPS LCD, if the compensation film is on the CF POL, the protective layer in the TFT POL is usually a zero - TAC film (which usually has a retardation smaller than 5nm). If the compensation film is in the TFT POL, the protective layer in the CF POL is a zero - TAC film. When we change the zero - TAC to Normal TAC (which usually has a small retardation of about 10 - 80nm), the side - view color will also change. The specific color change is related to the type and compensation value of the compensation film.

We tested the color shift of different wide view POLs when combined with Normal TAC (with a retardation of 20nm). Figure 6 shows a wide view POL1 with a pair of +A and +C plates (which  $R_0 = 120\text{nm}$ ,  $R_{th} = -50\text{nm}$ ). Compared to using zero - TAC, using normal TAC results in a color shift from blue - purple to blue. Figure 7 shows a wide view POL2 with another pair of +A and +C plates (which  $R_0 = 120\text{nm}$ ,  $R_{th} = -2\text{nm}$ ). Compared to using zero - TAC, using normal TAC results in a color shift from light purple to dark purple.



**Figure 6.** Color shift with different retardation TAC

(a) wide view POL1+zero TAC POL, (b) wide view POL1+ normal TAC POL



**Figure 7.** Color shift with different retardation TAC

(a) wide view POL2+zero TAC POL, (b) wide view POL2+ normal TAC POL

#### 5. Simulations

It is well - known that the introduction of phase difference can influence the color of the side - view angle. However, although the coating layer is an inorganic film without phase difference, it still exerts a certain impact on the viewing angle. Thus, this article mainly focuses on simulating the effect of the coating on the viewing angle. Through simulation, we can determine the optimal coating conditions for different types of compensation films, thereby providing a foundation for improving side view deviation in the future.

In the Techwiz simulation software, we employ Berrenman's 4x4 matrix method to calculate the reflected and incident light at each film interface. First, we input the refractive - index parameters of the coating material. Then, we set different coating thicknesses. Finally, a simulated full view color - shift map in the black image is output. For the simulation, we refer to the structure in Figure 3, where Insulation Layer 3 has no film layer. We adjusted the thicknesses of Insulation Layers 1 and 2, with the thicknesses of these two layers ranging from 0.1  $\mu\text{m}$  to 0.4  $\mu\text{m}$  respectively.

The simulation results for the +A&+ C compensation films and the B0 compensation film are presented in Table 3. Based on the simulation results in Table 3, it can be observed that when using the same wide view compensation film but different coating conditions, the color shift and light leakage of the side viewing angle vary. Moreover, we also found that under the same coating conditions, different wide view compensation films have different effects on the color shift and light leakage of the side viewing angle.

By referring to the aforementioned methods, we can also simulate the coating conditions on the back of the CF glass.

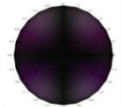
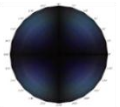
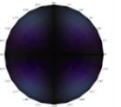
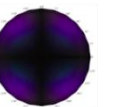
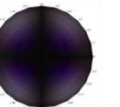
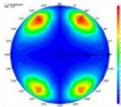
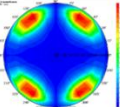
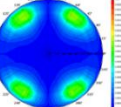
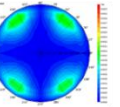
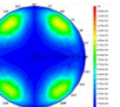
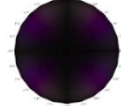
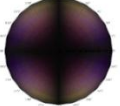
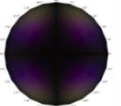
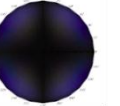
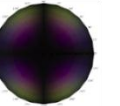
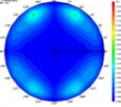
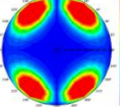
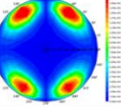
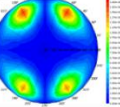
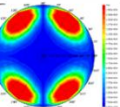
Ultimately, we conducted a verification by comparing the simulation results of the coating conditions inside the panel with the actual measurement data. The results are presented in Table 4. As can be seen, the color - shift trends between the simulation and the actual measurement are basically consistent.

#### 6. Conclusion


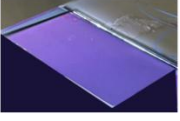
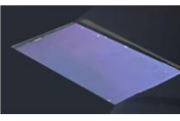
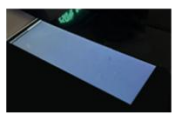
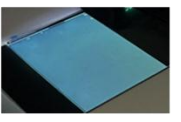
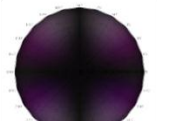
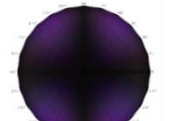
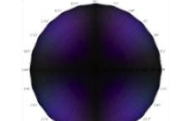
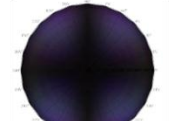
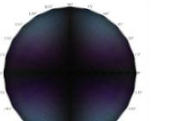
This article proposes several approaches to enhancing the side-view color performance of wide view IPS displays. Through both simulation and practical measurement, it has been discovered that by depositing transparent film layers with significant refractive index differences either inside or outside the panel, it is feasible to fine-tune the color of the leakage in the large-view dark state. Additionally, incorporating small-phase-difference film layers can also rectify the side-view color. When altering the retardation of the compensation film in the wide view POL fails to yield the desired color outcome, the options of applying a coating and introducing a small-retardation film can be considered. The simulation method presented in this article can serve as a

theoretical foundation for the design of coating layers.

**Table 3** Simulation of coating inside the panel

Item		①	②	③	④	⑤
Insulating layer1	SiNx	0.35um	0.1um	0.2um	0.3um	0.4um
	SiO2	-	0.1um	0.2um	0.3um	0.4um
Insulating layer2	SiNx	0.6um	0.1um	0.2um	0.3um	0.4um
	SiO2	-	0.1um	0.2um	0.3um	0.4um
Insulating layer3		-	-	-	-	-
POL with +A and +C plates in O-mode	Color shift at full view					
	light leakage at full view					
POL with B0 plate in E-mode	Color shift at full view					
	light leakage at full view					

**Table 4** Simulations and actual measurements

Item		Main	S1	S2	S3	S4
Insulating layer1		SiNx(0.35um)	SiO2(0.35um)	SiNx(0.3um)+ SiO2(0.1um)	SiNx(0.35um)	SiNx(0.2um)
Insulating layer2		SiNx(0.6um)	SiNx(0.15um) + SiO2(0.35um)	SiNx(0.15um) + SiO2(0.35um)	SiNx(0.15um) + SiO2(0.35um)	SiO2(0.2um)+ SiNx(0.2um)
Insulating layer3		-	-	-	-	SiO2(0.2um)
Color shift at full view (POL with +A and +C plates in O-mode)	Measurement					
	Simulation					

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