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Analysis of Light Leakage of LCD Module and Improvement by Cell Rubbing Angle

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We discuss the light leakage issue of LCD due to stress to the polarizer from the backlight temperature. To detect light leakage, we measured black luminance and low gray scale curves by backlight running time. The result shows that gray scale curve's change at upper side of light leakage shift up and that of right and left side shift down. These phenomena are similar to phenomenon from variation of WV-TAC axis. To discuss this result, we insist the heated part of polarizer must be expanded. Finally, our experiment result by changing rubbing angle of cell shows improvement of light leakage.

Keywords: light leakage; Poincare; rubbing angle; WV-EA

1. INTRODUCTION

Light leakage of the black state is one of the biggest issues of LCD panel. Usually TN mode LCD has 2 kinds of light leakage. One is up-and-down light leakage associated with lamp temperature of the backlight and the other is light leakage of hard condition environment such as high temperature or high temperature and high humidity. The latter can be analyzed by stress of polarizer in hard condition and even calculation of light leakage is possible in view of influence of asymmetric PVA stress and homogeneous PSA stress [1]. It, however, is hard to find the study about up-and-down light leakage for lack of approaching theories and careful concerns. The known so far are the facts that up-and-down light leakage does not appear in IPS and VA mode as well as TN mode using direct lamp type backlight and that

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in the case using edge lamp type backlight, IPS and VA mode do not have light leakage except for TN mode. So this issue only arises for edge lamp type TN mode. On the contrary light leakage of hard condition can appear all TN mode not for VA and IPS mode. With these facts we can say that up-and-down light leakage is influenced by the structural relation between loaded PVA direction of polarizer and lamp direction of backlight as a stress source. About backlight Chi Mei Optoelectronics (CMO) studied up-and-down light leakage and showed the light leakage enhancement through changing backlight material to flatten temperature distribution [2].

Our topic is up-and-down light leakage. To approach quantitative analysis we introduce empirical light leakage grading method and to show affecting factors to light leakage we start measuring gray scale and from that we set simple optical calculation to extract factor. Consequence is showing experimental data for enhancing light leakage.

2. MEASUREMENT

Although light leakage has four part which are upper, lower and both of side area as shown in Figure 1(b), we measure only upper side light leakage because of domination of light leakage and easy detectable feature. And as a reference of light leakage center area is also detected. CA-210 made by MINOLTA is used as a detector to measure luminance.

Before measuring, various light leakage samples are prepared and are defined as the level of light leakage through naked eye distinction.

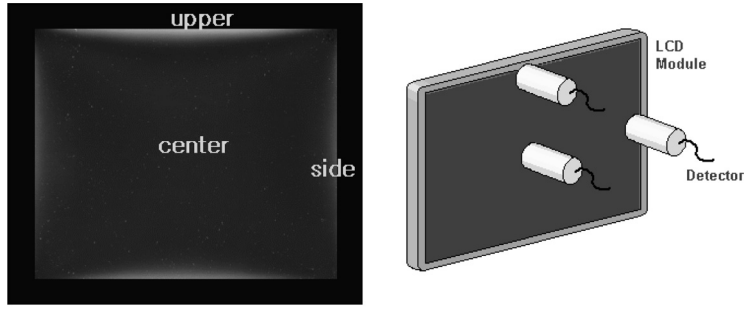

FIGURE 1 (a) The phenomena of up-and-down light leakage has 4 edges light leakage at black state. After 20–30 minutes maximum usually light leakage of upper and lower parts are dominant, however, side parts are also detectable. (b) Scheme of measuring light leakage.

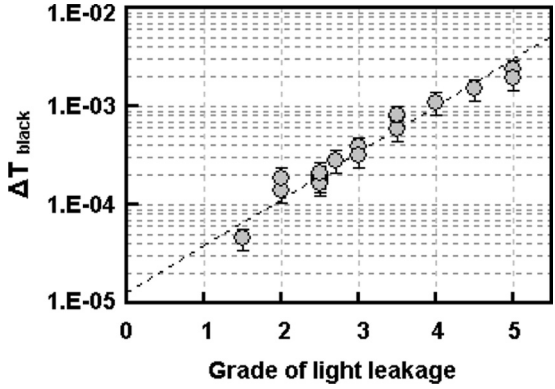

FIGURE 2 Light leakage by naked eye has linear relation with log scale of. Dot line is fitted result and is introduced as Eq. (1).

Levels are divided in 5 grades. Although grading 5 levels was emotional, the careful concern was followed by keeping discriminating person and by using several references to minimize emotional conclusion for every grading.

To make the quantitative we defined the transmittance of black which is black luminance divided by white luminance. The transmittance of black can disregard influence of backlight luminance variation. Subsequently it is introduced the difference between black transmittance of upper light leakage area and center area. Finally we could find the relationship between light leakage and levels. It is

$$\ln \Delta T_{black} = 1.09X - 11.25 \tag{1}$$

Where, X is the level of light leakage. Figure 2 shows the result of matching between ΔT_{black} and levels of light leakage with naked eyes. As expected, because of exponential relation, the emotional light leakage is more sensitive for low grade of light leakage. Equation (1) is used for grading light leakage and for showing enhancement of light leakage through our experiment.

3. RESULT AND ANALYSIS

3.1. Analysis of Light Leakage

Light leakage varies with running time of LCD module and gets strong gradually. We could measure light leakage luminance with time, however it was interesting changing low gray scale which

usually covered gray levels from 0 to 20, shown in Figure 3. It shows that after some time strength of light leakage accompanies change of gray scale curves or shift. Evidently that of center area is not changeable, but the upper and side have opposite shifting direction to each other.

Usually gray scale can shift for several cases when rubbing angle of cell varies, when WV-TAC axis varies, when cell gap varies and when voltage applied in cell varies. In this case, however, variation of cell gap, rubbing angle and voltage does not make sense, because the condition just running LCD module does not has enough high energy to change cell gap, rubbing angle and voltage. So we can say gray scale change is influenced by WV-TAC variation. And we can say the source of variation of WV-TAC is temperature of backlight lamp. Of course this is our postulation, but following experimental result can support this assumption.

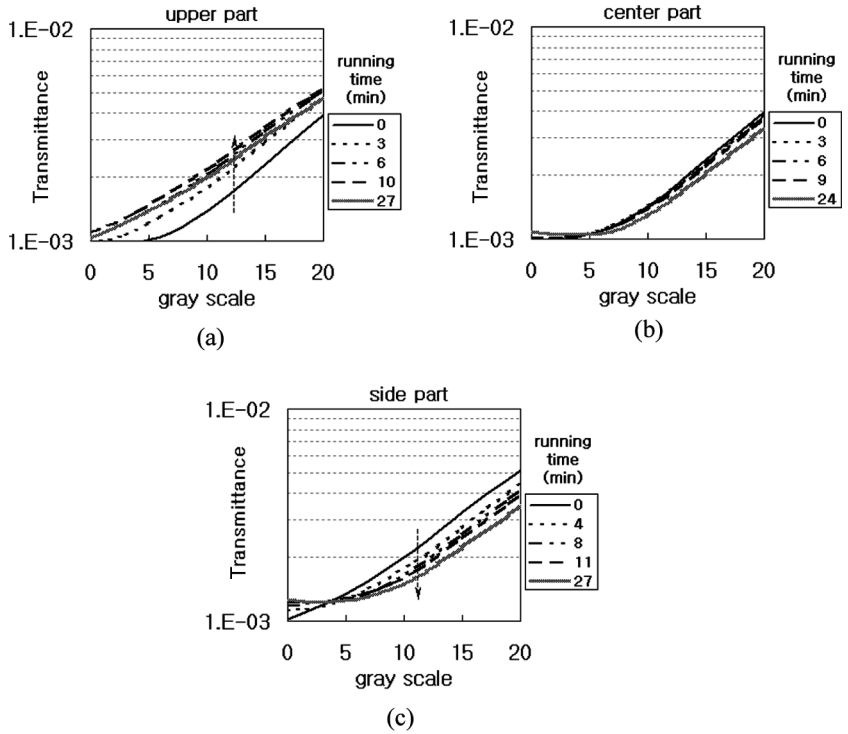

FIGURE 3 Change of gray scale curves with LCD running time. (a) Gray scale curve shifts upward and black luminance increases in light leakage of upper part, (b) is of center part, and (c) is of side part and it opposes to (a).

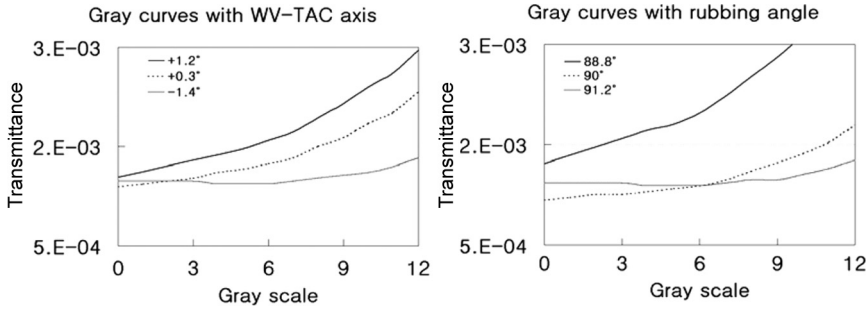

FIGURE 4 Shift of gray curve can be seen in the case of WV-TAC axis and rubbing angles empirically. (a) '–' direction of WV-TAC axis makes gray scale curve shift down and (b) increasing rubbing angle makes gray scale curve shift down.

Figure 4 shows variation of gray scale curve with WV-TAC axis and rubbing angle of cell. The definition of WV-TAC axis direction is indicated in Figure 5(a). From Figure 4, to shift up gray scale there are two cases that going to '+' direction for WV-TAC and decreasing rubbing angle from 90°, and it can be compared with upper light leakage area respectively. The case of shifting down gray scales is vice versa and it can also be compared with side light leakage area.

Evidently the temperature in the region between lower polarizer and backlight is higher than outside of LCD module. So it makes sense

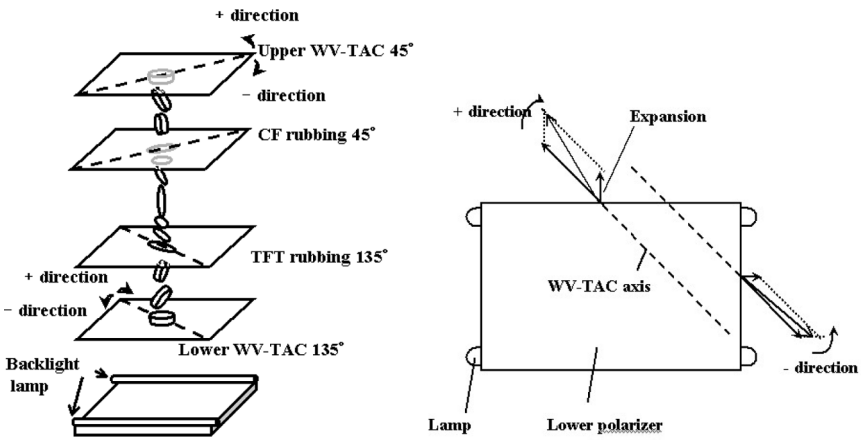

FIGURE 5 The scheme of (a) optical axis of TN LCD and (b) WV-TAC axis variation caused by lower polarizer expansion.

that lower polarizer is mostly affected part for light leakage. From Figures 3 and 4, upper area of light leakage is affected by WV-TAC axis tilting to '+' direction and side is affected by WV-TAC axis tilting to '−' direction. The expansion of bottom polarizer can give reasonable explanation about why upper area and side area of light leakage have different gray scale shift each other and about tilting WV-TAC axis. Figure 5(b) is the scheme of axis result of WV-TAC by expansion of lower polarizer.

We do not consider tilting WV-TAC axis is only reason for light leakage, moreover expansion of polarizer is more important, because even TN mode just using normal polarizer also has up-and-down light leakage. Although we could not find direct evidence relation between polarizer expansion and light leakage, we think understanding of optical explanation for WV-TAC can help improve light leakage.

3.2. Poincaré Analysis for WV-TAC and Rubbing Axis

So far we have tried to explain the effect of WV-TAC axis and light leakage. Here, we introduce calculation of trend of black transmittance through varying WV-TAC axis in addition to rubbing angle. Poincaré analysis is sufficient for calculation [3]. Before doing calculation we have to define retarders and their axis. Retarders can be upper and lower WV-TAC and anchored liquid crystals. Even though let liquid crystals stand vertically to make black state, there are still anchored liquid crystals which are twisted and tilted so it would make residual retardation. Retardations of anchored liquid crystals can be calculated as

$$\mathrm{Re}_{residual} = \sum_i (\theta_i) \times \mathrm{Re}_i \tag{2}$$

where, Re_i is the retardation of ith liquid crystal layer which can be defined by unit layer retardation, which is described by total cell retardation over number of liquid crystal layers, and θ_i is the tilted angle of ith liquid crystal layer. Figure 6 is the simulation result of liquid crystals' director at black state assuming that liquid crystals are composed of 40 layers and total cell retardations are 420 nm. In figure, it is clear that just small range near rubbed angle has most of retardation.

Cell retardations can be separated into CF (from 90° to 45° in Fig. 6) and TFT part (from 135° to 90° in Fig. 6) and from Figure 6 and Eq. (2) each retardation of CF and TFT part is calculated as about 50 nm. For further simplicity let's assume that anchored liquid crystals of CF and TFT part are composed of 3 layers. Each layer shares 50 nm

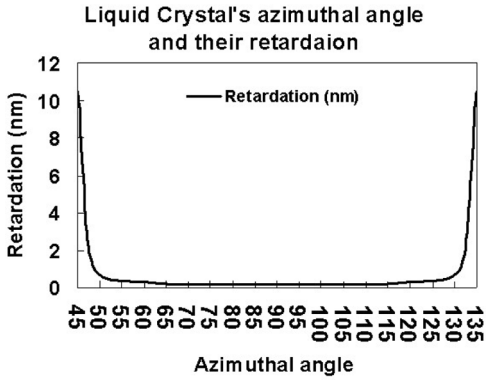

FIGURE 6 At normal incident direction of LCD, distribution of liquid crystal retardation is focused in the range near rubbed angle.

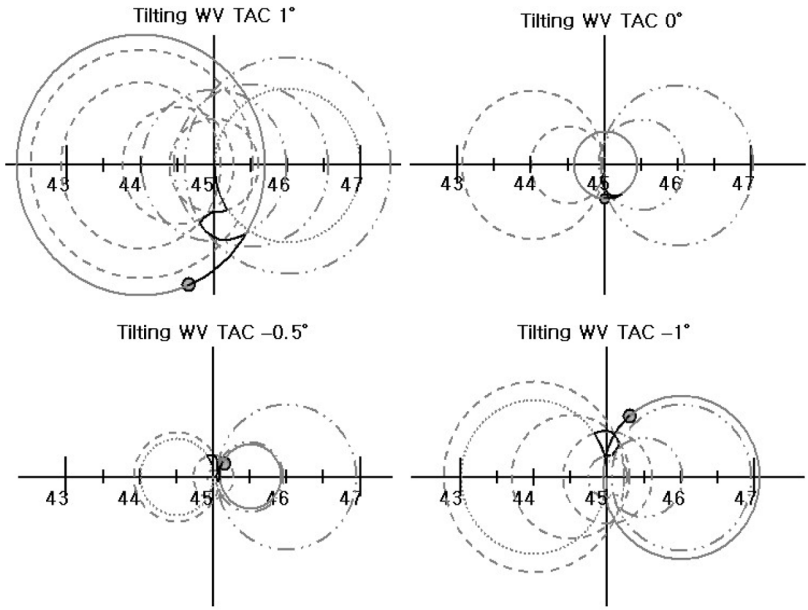

FIGURE 7 Poincaré analysis for WV-TAC axis from '+' to '−' angle range. Black luminance can be analyzed as distance between starting point (45°) and final point (135° which is same as 45° in 2D approaching). Black luminance is better at −0.5° than 0°.

retardation non-linearly and shares azimuthal range of 1 degree linearly.

Another retarder, WV-TAC, is simple that has retardations of 45 nm and optical axis of 45° and 135°.

Retarder axis covers small angle area, so it is enough to draw in 2 Dimensions. Indicating point for polarizing state follows normally designed sequences of retarders.

For instance, the sequence follows lower linear polarizer (45°), lower WV-TAC (45°), 1st TFT LC layer (135°), 2nd TFT LC layer (134.5°), 3rd TFT LC layer (134°), 1st CF layer (46°), 2nd CF layer (45.5°), 3rd CF layer (45°), upper WV-TAC (135°) and upper linear polarizer (135°). The result of Poincaré analysis for various WV-TAC and rubbing angle is shown in Figures 7 and 8.

In Figure 7, although WV-TAC varies same range of '+' or '−' direction, varying black transmittance is not symmetry. To lower black transmittance it is better WV-TAC tilts to '−' direction, however after some '−' range black transmittance increases again that can be explained as gray inversion. Figure 8 also shows similar trend of black transmittance. When setting rubbing angle as higher than 90°, black transmittance is getting small. But after some range black transmittance is getting higher. We can say that titling WV-TAC to '−' direction is similar with increasing rubbing angle and vice versa.

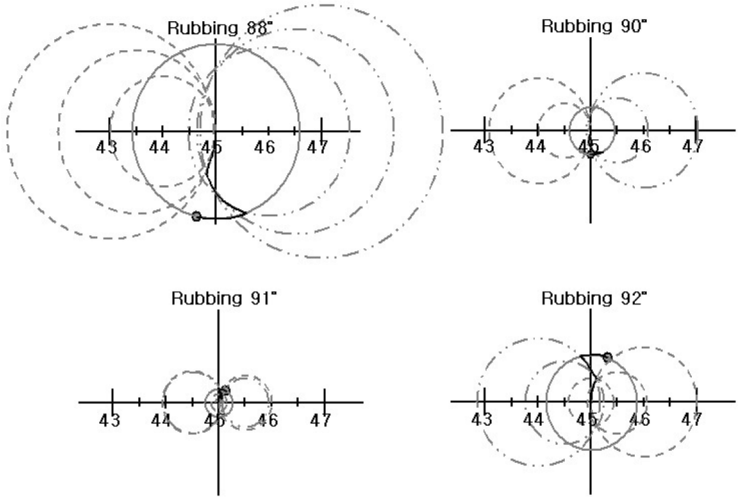

FIGURE 8 Poincaré analysis for rubbing angle from 88° to 92°. Black luminance is better at rubbing 91° than 90 deg.

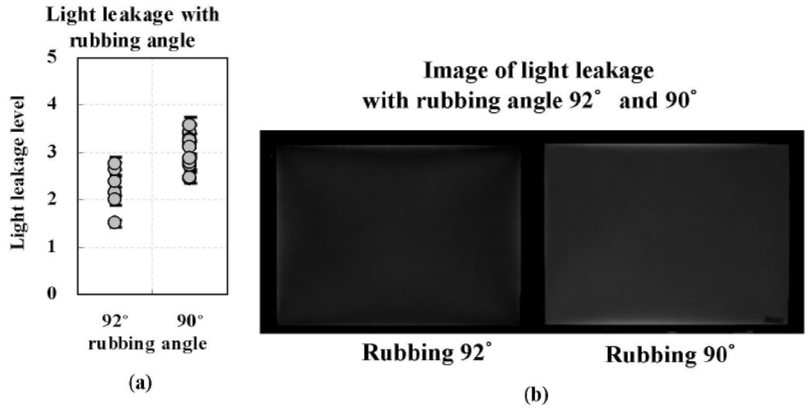

FIGURE 9 Result of light leakage test (a) is quantitative light leakage level and (b) is real image of light leakage.

3.3. Light Leakage Test

We experimented splitting rubbing angle as 90° and 92° for enhancement of light leakage. After running LCD module WV-TAC axis of polarizer would move to '+' direction, then increasing rubbing angle can help as mentioned above. In fact making WV-TAC axis artificially is difficult, so we focus on rubbing angle. To minimize influence of WV-TAC we used same Lot polarizer which is made in same time and same roll material. The result of test is shown in Figure 9, which shows quantitative enhancement and the image of light leakage.

92°rubbed LCD panel has lower gray scale curve than that of 90°, so 92° rubbed LCD panel would have lower starting point for shifting up gray curve. 92° rubbed LCD panel has weaker light leakage in upper and lower part, but side part has stronger light leakage as side effect and it is also detectable in the image of light leakage Figure 9(b). Another side effect is lowered Contrast Ratio. Most of 92°rubbing sample does not have maximum Contrast Ratio because of low gray inversion which is explained in Poincaré analysis as mentioned above.

4. CONCLUSION

We have presented light leakage phenomenon with optical property of shifting gray curve in light leakage area. Shifting direction of gray curves is opposite between upper and side part of light leakage. Experience about optical property of WV-TAC and rubbing angle can also show same feature of gray scale shift and it is also possible to

analyze optical property using Poincaré analysis. To show enhancement of light leakage, testing rubbing angle 92° was performed and showed with experiment and real image with leveling method of light leakage. However setting rubbing angle as 92° has side effects that are increase of light leakage in side part and insufficiency to meet maximum contrast ratio.

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