Verification and Elimination of LCD Color Deviation Caused by Thickness Fluctuation of Gate Insulator Layer

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Abstract

We verified thickness fluctuation of gate insulator is the main cause of red/green color deviation observed n LCD white screen. The evidence is GI thickness and chromatic coordinates show a oscillating relation which reflect the interference effect. We also show that the color deviation can be eliminated by a color demura scheme.

Author Keywords

LCD; Color Deviation; Gate Insulator; CIE 1976

1. Introduction

In the high-end TV market, LCD + mini LED has outperformed OLED, mainly due to economical manufactory cost and superior HDR performance. Although OLED is incomparable in natively contrast ratio and viewing angle, HDR applications (movie and game) emphasize more in wide color gamut and high luminance, in which Mini LED BLU (in the help of QD film) has great advantage. It is easy to anticipate that with widespread of HDR applications, picture quality standard for LCD will become more stringent, and this will make it urgent to address some of the intrinsic issues of LCD. Here we focus on the issue of color deviation caused by thickness fluctuation of Gate Insulator (GI) layer.

Thickness fluctuation of GI layer causes observable color deviation is attributed to two reasons. First, refractive index of GI layer ($n_{SiNx} = 1.9$) is significantly larger than the adjacent layers, making transmittance spectrum sensitive to thickness of GI due to interference effect. Second, the thickness fluctuation of the GI layer is not solely caused by the CVD deposition process, but also by the dry etching process. Dry etching of GI layer is unavoidable in 4 Mask TFT process flow, because the same dry etching opens the a-Si channel [1] .

In this article, we verify the observable red/green color deviation is caused by thickness fluctuation of GI layer, by comparing experiment data to simulation results. We collect GI thickness and transmission spectra from of hundreds of data points, and the resultant relation between GI thickness and chromatic coordinates is essentially identical to the oscillation tendency obtained from simulations. We also demonstrated that the color deviation can be eliminated by a "color demura" scheme. That is, changing the R/G/B intensity ratio locally to compensate the color deviation.

2. Theory and Simulations

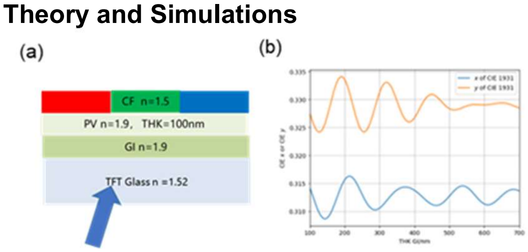

Figure 1. (a) Structure considered in simulation. (b) Simulated relation between GI thickness and CIE 1931 chromatic coordinates of transmission spectra.

To simulate how variation of GI thickness induces chromatic change, we use tmm package [2] in python programming environment. We consider a simplified structures (left subfigure of Fig. 1) consists of RGB color filter (CF), passivation layer (PV, $n_{SiNx} = 1.9$), GI and Glass. The source is placed in below the upper surface of Glass, and the detector is placed above the downer surface of CF, so that the thickness of Glass and CF has no effect to the transmission spectrum. The thickness of PV is fixed to 100nm.

The simulation results are depicted in Fig. 1(b). The CIE 1931 chromatic coordinates x and y oscillate with GI thickness, reflecting that the transmission spectrum is modulated by GI thickness due to interference effect. We also notice that the oscillating magnitude becomes weaker and the periodicity becomes larger as GI thickness increases.

3. Experimental Results

To verify the observable red/green color deviation is caused by GI thickness fluctuation, we produced a set of 65" UHD LCD panels with different GI thickness by changing deposition time. The GI thickness conditions are carefully chosen to ensure covering at least half period of the expected chromatic oscillation. For each panel, we record 9×9 points of GI thickness during production, and measured the transmitted spectrum of pure white screen at the corresponding points after production.

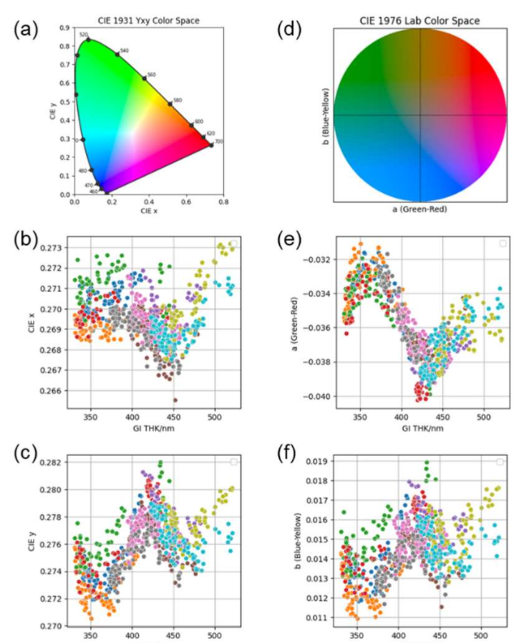

Figure 2. Experimental relation between GI thickness and chromatic coordinates calculated from transmitted spectra of white screen. The white point (L=100, a=0, b=0) of CIE 1976 Lab is set to be the averaged spectrum of our YAG BLU.

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In Fig. 2, we show the experimental relations between GI thickness and chromatic coordinates in CIE 1931 Yxy and CIE 1976 Lab. Colors of the scatterplots denote data points from different LCD panels. Although the experimental relation between GI thickness and chromatic coordinates are not as smooth as the simulation results shown in Fig. 1, we can still observe the oscillating envelops. This is the evidence that the observable color deviation is mainly caused by GI thickness fluctuation. Moreover, we note that the oscillating relation between GI thickness and *a* of Lab is most obvious. We believe this is coincided with the subjective impression that the color deviation is observed as redness and greenness, for in CIE 1976, the chromatic coordinate *a* denotes degree of redness and greenness.

To further prove that the chromatic coordinate *a* of Lab is closely related to the subjective evaluation of GI color deviation, in Fig. 3 we show the distribution of the chromatic coordinate *a* (of CIE 1976 Lab) of each LCD panel, and list the corresponding JND values of color deviation at the top of each subfigure. Generally, Panels with wider range of *a* are labeled with a larger JND value. However, we also notice that the lowest JND value 2.5 was assigned to the panel (ID 79AB04) with medium range of *a*. We guess it may be attributed to the wide-open distance between the redness area and greenness area in this panel.

4. Method of Eliminating Color Deviation

In this section, we will show that the GI color deviation can be effectively eliminated by a color demura scheme. To compensate the color deviation, we adjust the distribution of R/G/B intensity separately, with the aim of minimizing variation of a and b, and preserving L as high as possible. We show an example dealing with Panel ID 78AZ05 in Fig. 4. It is worth noting that, white point (L=100, a=0, b=0) of Lab in Fig.4 is different to that in Fig. 2 and Fig. 3. In Fig. 2 and Fig. 3, we set the white point as the averaged spectrum of YAG BLU, because we have to compare chromatic coordinates across different panels. In Fig. 4, we set the white point as the averaged spectrum of the white screen, for the consideration that we can simply set the target value of a and b as zero.

5. Discussion

The key point of clear verification and neat elimination of the GI color deviation is to use Lab chromatic coordinates of CIE 1976, rather than the commonly used Yxy of CIE 1931. This is because the GI color deviation is mainly manifested as redness and greenness, and the degree of redness or greenness are quantified by a single coordinate in Lab chromatic space.

6. References

[1] Jean H. Song *et. al.*, *SID'05 Technical Digest*, vol. 33, p. 1038 (2005).

[2] Steven J. Byrnes, arXiv:1603.02720 (2006)

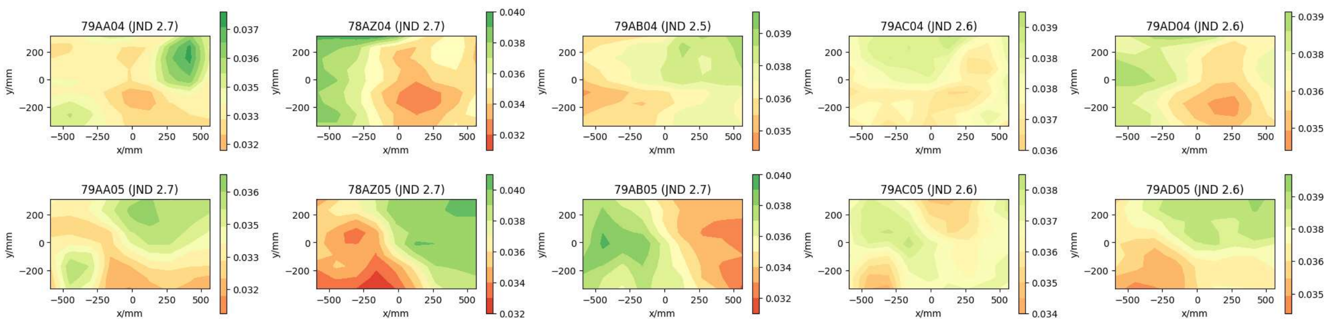

Figure 3. Distribution of the chromatic coordinate a of CIE 1976 Lab, with title showing the Panel ID and JND values of color deviation.

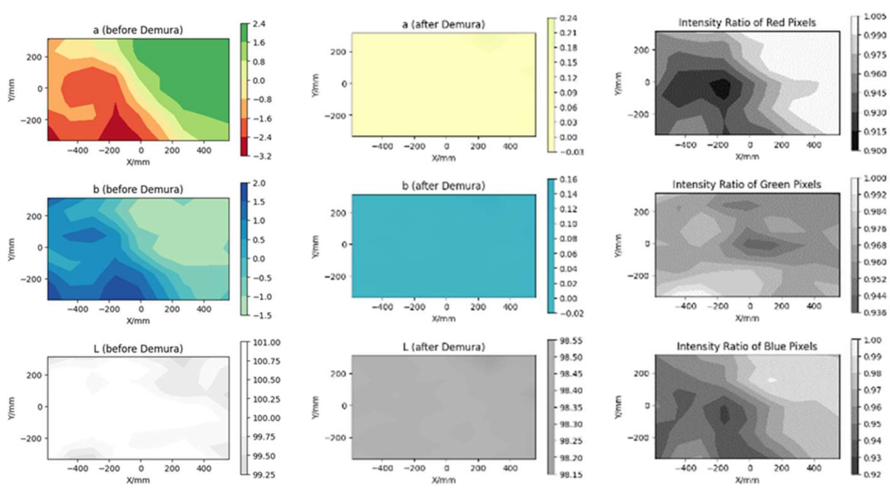

Figure 4. Demonstration of color demura scheme to eliminate GI color deviation. Left column: Lab distribution of Panel ID 78AZ05 before demura. Center column: Lab distribution of the same Panel after applied color demura. Right column: R/G/B intensity ratio of the color demura scheme.