Optimizing QD Polarizer for Dark-Leakage in VA Mode LCDs

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ABSTRACT

Through QD-polarizer[1], the viewing-angle and color-gamut of VA-LCD is significantly improved as well as IPS-LCD and OLED. But dark-leakage also excists just like normal VA-LCDs. The influence of dark-leakage is simulated and verfied by test. A significantly decrease (-80%) in dark luminance by optimizing the compensation value is discovered.

1 INTRODUCTION

Nowadays, liquid crystal displays (LCDs) are widely used in many applications[2,3,4]. But the optical quality of traditional LCDs is not as good as OLED and other novel display technologys, such as color gamut and viewing angle[5]. Vertical Alignment (VA) mode LCDs occupy the high level display market, because its excellent display characteristic like high contrast (CR), fast response, and so on. But in-plane switching (IPS) liquid crystal display gained big promotion in CR by adopting dynamic backlight technology, and at the same time, it shows outstanding viewing angle comparing with VA mode LCDs essentially.

Recently quantum dots (QD) are applied in LCDs to improve the picture quality. The most comprehensive application of QD display is QD backlight to improve color gamut of LCDs, however, it can not improve the viewing angle. Therefore, increasing the viewing angle is indisputably the key to the improvement of VA mode LCD technology.

Quantum Dot Polarizer (QD POL) technology applied to VA mode LCDs can significantly increase the color gamut and the viewing angle[6]. Figure 1 shows the the wider colour gamut and wider viewing angle of VA mode LCDs with QD POL whitch is contrasted with Normal VA mode LCDs.

Light leakage on four corners of an LCD panel with QD POL has been observed in terms of dark state taste. As shows in figure 2(A), there is a noticeable leakage in the four corners of the panel in a dark state, which does not cause by panel warpage. The same problem has been observed on normal VA mode LCDs, witch is magnified by the wide viewing angle of QD POL excitation light. The reason for the dark light leakage is the optical path difference. As shows in figure 2(B), LC arrange vertically when VA LCD panel in a dark state. Light in the face and oblique angle of the optical path is different, which resulted in light leakage. Dark light leakage is further enlarged in Q cell which applied QD POL, because of the light type is diffuser. Therefore, improving the dark-state taste is particularly important for mass production of QD POL.

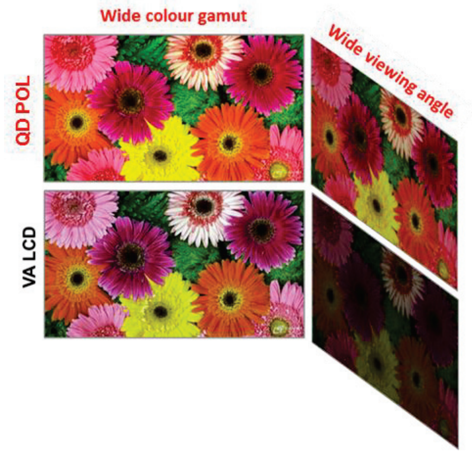

Figure 1. The wider color gamut and wider viewing angle of VA mode LCDs with QD POL, witch contrasted with Normal VA LCDs.

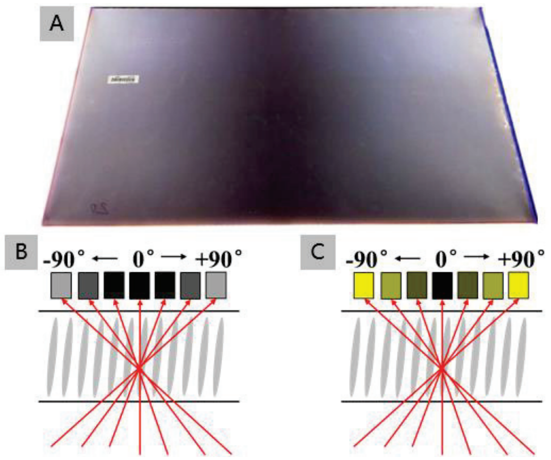

Figure 2. (A) Dark picture of panel; (B) The principle of dark leakage in the mass-produced VA mode LCD; (C) The principle of dark leakage in QD POL VA mode LCDs.

2 SIMULATION

We theoretically analyzed the influence of various factors on dark light leakage, and first established a calculation model, including one-dimensional and two-dimensional models with LCD master. The model structure mainly includes a rear polarizer, a down compensation film, liquid crystal, an up compensation film, and a front polarizer, as shown in Figure 3. The simulation conditions are shown in Table 1. The results of simulation is changed by varies down compensation values, polar angles, and azimuth angles. Also, different cell gaps, pretilt angles, and liquid crystal retardation is used as simulation conditions.

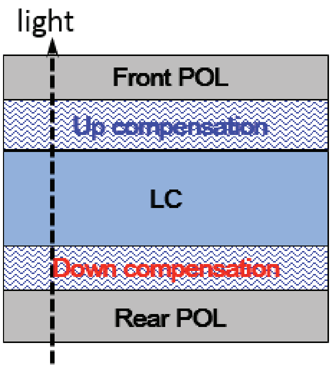

Figure3. Model structure of dark light leakage.

Table 1. Simulation condition of dark light leakage.

ITEM	Light leakage @ Azimuth	Light leakage @ Pole angle
Down Compensation (∆nd)	80~170 nm	80~170 nm
Up Compensation (∆nd)	125.6 nm	125.6 nm
Azimuth Φ	0~350°	45°
Pole angle Θ	45°	-80~80°

3 RESULTS AND DISCUSSION

Compared simulation and experimental results, there are some methods to improve the dark light leakage such as reducing cell gap, reducing LCD retardation, increasing pretile angle, and increasing compensation value within a reasonable range.

Take cell gap 3.0 μm as an example, as shown in Figure 4. It can be clearly seen that the light leakage of different wavelengths in the dark state is different, and the short-wave light leakage is more serious. Blue light leakage is the most serious, followed by green light, and red light is the least. At the same time, under the same cell gap condition, the light leakage at an azimuth angle of 45 degrees is greater than 0 degrees.

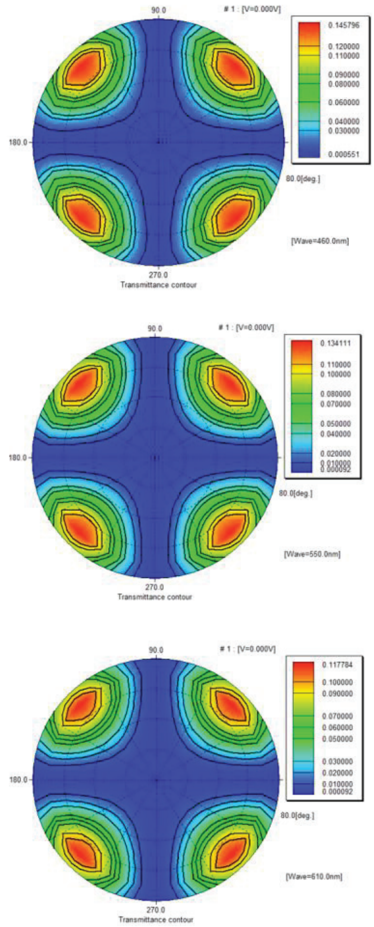

Figure 4. simulation result of LCD dark light leakage with cell gap 3.0 μm @ 460 nm, 550 nm, and 610 nm.

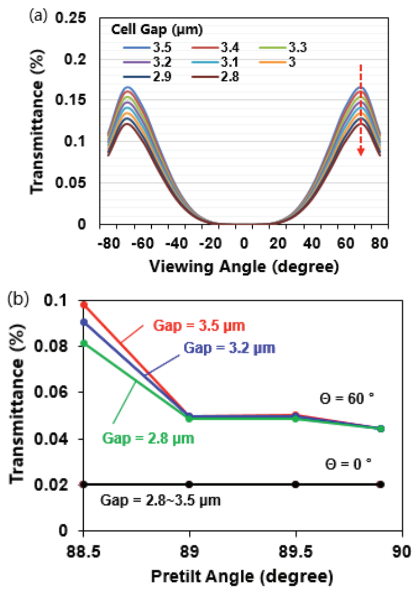

Figure 5. Simulation results of (a) LCD dark light leakage at the diagonal direction of the panel with cell gap changed, and (b) LCD dark light leakage at 0° , 60° viewing angle with pretilt angle changed.

The simulations of the light leakage at the 45 degree azimuth angle with different cell gaps and pretilt angles were performed, witch are shown in figure 5. When the polar angle is 0 degree, and the light leakage with different pretilt angles and cell gap is basically the same. Light leakage at polar angle 60 degree is slightly improved though reducing cell gap and increasing pretilt angle. Especialy, when pretilt angle is between 89~90 degree, light leakage can be reduced by 8~10%. By contrast, the improvment is not obvious in the pretilt angle range of 89~90 degree.

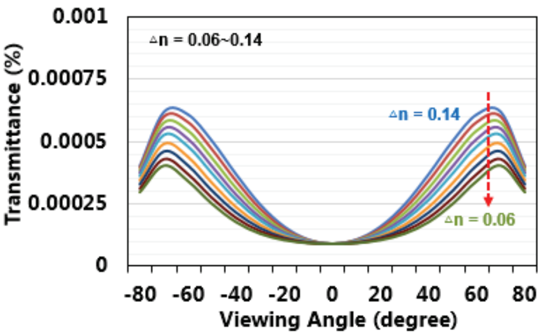

Figure 6. Simulation result of LCD dark light leakage with LC retardation changed.

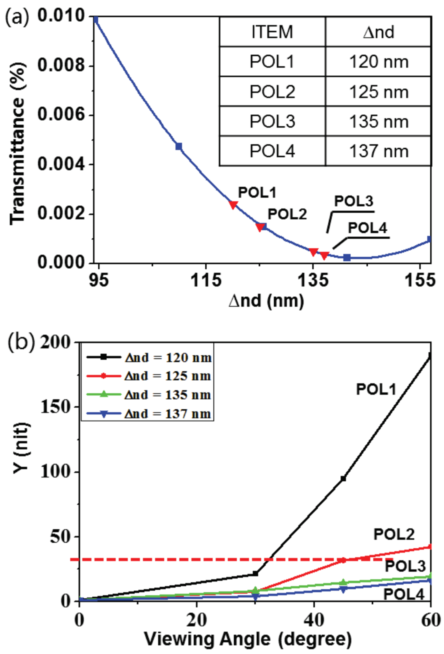

Figure 7. (a) Simulation results of LCD dark light leakage with compensation value changed at 45° viewing angle; (b) Experiment result of dark light leakage intensity at 45° viewing angle.

It is known that the dark state light leakage is related to the retardation of the liquid crystal. Figure 6 shows the simulation result of dark light leakage under different liquid crystal retardation. It can be seen from the results that with various viewing angles, the dark state light leakage decreases with the decrease of the liquid crystal retardation. The improvement of the large viewing angle is relatively obvious. The other rules are consistent with the previous results.

Increasing the compensation value can improve dark light leakage as the simulation results shown in figure 7(a). At a viewing angle of 45 degrees, as the compensation value increases, the light leakage decreases. The leakage intensity of POL4 with compensation value of 137 nm is dropped to 20% of the POL1 leakage intensity with a compensation value of 120 nm. The dark state light leakage of LCDs measured with different compensation values of QD POL are shown in figure 7(b). The light leakage intensity of LCDs with POL4 is dropped to 15% of LCDs with POL1, witch is well matched with the simulation results.

4 CONCLUSION

LCDs using QD POL showed excellent display quality. A picture of Q-Cell DEMO is shown in figure 8, and the display characteristic data is shown in table 2. A bviously improvement on color gamut compared with normal LCDs is shown both on QD BL (Backlight) technology and QD POL technology (Q-Cell). However, in terms of half brightness loss, color washout, and color shift, Q-Cell have more excellent performance, and all of these viewing angles are twice as large as QD BL technology. The application of QD POL on LCD is the best choice for VA mode LCDs with excellent display quality[7].

Figure 8. A picture of Q-Cell DEMO with QD POL.

Table2. Characteristic data of QD BL technology and QD POL technology.

Item	QD BL	QD POL
Brightness	500 nit	450 nit
CG (NTSC)	>100%	>100%
Half brightness loss	±30°	±60°
color washout	28°	55°
color shift	26°	70°

REFERENCES

[1] Miao Zhou, Lixuan Chen, et al., Photoluminescence of QD-PVA Film for Displays. IEEE EDSSC(2018).

[2] Kawamoto H. The History of Liquid-crystal displays[J]. Proceedings of the IEEE, 2002, 90(4): 460-500.

[3] Kim K H, Song J K. Technical Evolution of Liquid Crystal Display[J]. NPG Asia Materials, 2009, 1(1): 29-36.

[4] Zhen-xia Chen, Li-xuan Chen, Hsiao-Hsien Chen. A novel Liquid Crystal Displays Using Dye-Type In-cell polarize. IDW'18, pp. 533-535(2018).

[5] Hasegawa M, Hirayama Y. Use of Quantum Rods for Display Applications[J].Journal of the Society for Information Display, 2016, 24(5): 286-292.

[6] Lixuan Chen, Miao Zhou, et al.,A High Efficency and Large Viewing Angle LCD with a Quantum Dot Polarizer. IEEE ICMAT(2019).

[7] Miao Zhou, Lixuan Chen, et al., "Q-Cell: A Super Wide View Angle LCD Displaywith QD Polarizer," IEEE EDSSC (2019).