High Picture Quality of LCD via WHVA Technology

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Abstract

This study proposes an 8-domain VA LCD architecture integrating high picture quality and transmittance technologies. Through pixel design optimization, ITO line/space refinement, and layer stack adjustments, a total 24% increase of open-cell transmittance was achieved while preserving color accuracy. Multi-domain pixel design, material innovation, and refractive index matching enabled Organic Light-Emitting Diode(OLED)-level picture quality, including 130° viewing angle, 1.0% reflectivity, and BT2020 95% color gamut. Combined with quantum dot backlight, this technology establishes VA LCD as a high-efficiency, premium display solution.

Author Keywords

High Transmittance; Aperture Ratio; Wide Viewing Angle; Low Reflectivity; Wide Color Gamut; High Contrast;

1. Introduction

Picture quality is a critical aspect of display technology, encompassing the visual performance of a display device and directly influencing user experience. It typically involves multiple technical parameters such as contrast ratio, viewing angle, reflectance, color gamut etc. While advancements in picture quality are essential, however they often impact the transmittance of the open cell, resulting in high energy consumption for TVs. To address this issue, a high-transmittance technology that incorporates pixel aperture ratio optimization, ITO CD optimization, and layer stack optimization is developed.

2. High transmittance technology

2.1 Pixel Aperture Ratio Optimization

The pixel aperture ratio represents the proportion of the light-transmissive area in an LCD. Increasing this ratio significantly enhances the transmittance of the LCD open cell.

Fig.1 shows the schematics of 8-domain thin-film transistor (TFT) arrays. The 8-domain design requires additional TFTs to improve viewing angle[1], inherently reducing the aperture ratio . To mitigate this, critical design rules were revised:

X-direction: Shielding metal critical dimension (CD) and spacing between shielding metal and data lines were minimized.

In [2], the pixel aperture ratio can be improved by reducing the distance between the PE layer and the Data line. In our design, reducing the PE layer requires reducing the distance between the Shielding metal of the compressed metal wire and the data.

Y-direction: TFT dimensions were halved, enabling reduced black matrix coverage on gate lines. Main pixel and sub-pixel share the same common line, which is used as a storage capacitor.

These optimizations simultaneously decreased the storage capacitor proportion from 23% to 10%, risking pixel voltage stability.

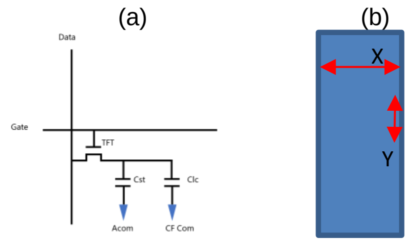

Fig. 1. (a) the schematic of 4domain pixel and (b) Pixel direction

Increased aperture ratios narrow common electrode lines, exacerbating edge dark streaks due to gate electrode interference. Using Techwiz 3D simulations, liquid crystal alignment at pixel edges was analyzed, Fig.2(a) shows the result of normal design. By redesigning the common electrode layout (Fig. 2 (b)), electric field uniformity is improved, reducing dark streaks and enhancing edge transmittance.

Through the optimizations, the aperture ratio design was refined, achieving an 18% enhancement in transmittance.

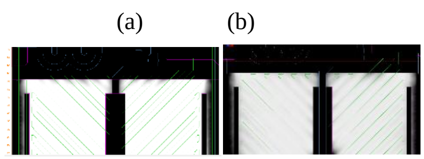

Fig. 2. (a) normal design (b) Improved design

2.2 ITO Line/Space Optimization

Besides improving the opening rate, improving the liquid crystal efficiency can also improve transmittance of open cell.At the preliminary stage of the experiment, a series of Line/Space conditions were designed on the 4 domain ITO (Indium Tin Oxide) substrate. The line width was precisely controlled within the range of 1.8 to 3.4 μm. As depicted in Fig.3., the transmittance (Tr%) exhibited a distinct peak value under diverse ITO conditions. After a comprehensive analysis of the results obtained from this verification experiment, a line width of 2.2 μm was determined as the optimal parameter for subsequent design considerations, which achieved a 2% enhancement in transmittance.

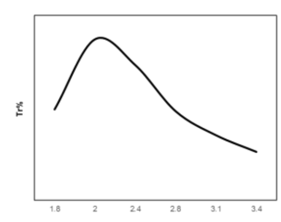

Fig.3. Relative Transmittance of different ITO space

To investigate the mechanism by which adjusting the ITO line width enhances the transmittance (Tr%), an optical microscope was employed to observe the actual display state of the liquid crystal at L255 grayscale. Table 1 shows that as the ITO space increases, the number of dark streaks rises markedly. This

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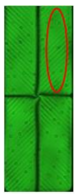
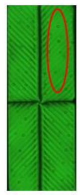
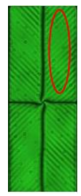
phenomenon is primarily attributed to the weakening of the electric field, which causes an insufficient tilt angle of the liquid crystal, thereby leading to a reduction in light transmittance.

Table 1. Dark streaks in optical microscope

Pitch	Ref	Ref	Ref+1μm	Ref+1μm
Space	Ref	Ref+0.2μm	Ref	Ref+0.2μm
Image				

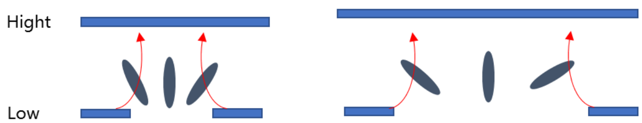


Fig.4. Schematic diagram of distribution status of LC

Fig. 4 shows the distribution status of liquid crystal under different ITO spaces.Under grayscale conditions, the voltage difference between the pixel and CFcom (Common Voltage for Pixel Circuit) is large, and when the space CD (spacing-to-width ratio) is small, the liquid crystal tilts close to 45 degrees. However, when the space CD is large, the liquid crystal tilts more than 45 degrees. This is because the increase in space reduces the electric field strength, making it difficult for the liquid crystal molecules to reach the desired tilt angle, thereby affecting the transmittance.

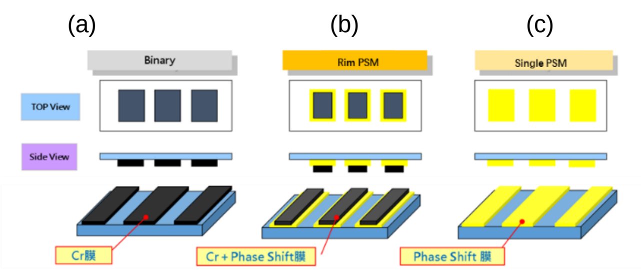


Fig. 5. Different Mask technology

In the LCD display industry, the reduction of line width imposes more rigorous demands on exposure equipment. Thus, it is crucial to explore effective methods for enhancing exposure precision. As illustrated in [3], the PSM Mask is employed to improve the exposure performance of 1.5 μm holes in LCD panel manufacturing. Consequently, the PSM photo mask is implemented to mitigate the stability issues triggered by the decrease in ITO critical dimension (CD) during the LCD production process.

Typically, the Cr photo mask as Fig. 5(a) is commonly utilized in the LCD industry. However, The pattern source on the Cr photo mask is prone to distortion due to light diffraction. To address this, we introduce a layer of phase - shift film. Rim PSM is a mask with layer of phase – shift film beneath the Cr layer as Fig. 5(b).Single PSM mask has only one layer of phase -shift film as Fig. 5(c). This setup induces destructive interference at the pattern edges, effectively minimizing the deformation of the patterned layer, which is essential for high - quality LCD panel fabrication.

In summary, by adjusting the Line/Space conditions of ITO, the transmittance can be optimized, and achieves an 2% enhancement. In practical applications, it is necessary to choose the ITO line width and spacing based on specific display requirements and process conditions to achieve the best display.

2.3 Layer Stack Optimization

Aperture area of pixel is mainly composed of array and CF. Different Thin film such as gate insulator (GI), indium tin oxide (ITO), and polyimide (PI) etc. layer combination experiments to verify the effects of different combinations. The results of these experiments provide us with important references to help us improve the performance of our products.

multi-factor optimization was performed by integrating these individual optimal conditions. As illustrated in Table 2, the combined modifications resulted in a total transmittance improvement of nearly 4% in the experimental prototype.

Table 2. Test Result of combined modifications

ITO THK	PI THK	Insulation layer THK	Tr%	Ratio
Ref	Ref	Ref	5.38%	/
Ref+100Å	Ref-300Å	Ref-30Å	5.59%	~4%

3. High picture quality technology

3.1 Viewing angle improvement

With the high transmittance technology, measures with low transmittance can be conduct to improve picture quality.

In our work, gamma curves of LCD side and front views are analyzed to quantify color shift and color washout of VA display. Generally, color shift represents the degree of side-view RGB coincidence. The more overlapped of RGB side-view curves, the display exhibits less content of color shift. Color washout is interpreted as the degree to which the side-view curves deviate from the front-view curves. Comparatively, the closer of the side gamma curves to the front ones, the better of color washout. To achieve wide viewing angle of VA panel, special pixel design and process matching strategies are simultaneously applied in our LCD VA 8 domain display.

As shown in Fig.6(a), it is our typical VA 8-domain design. For R and G pixel, the ITO line values are larger than that in B pixel to reduce the side brightness of B so that RGB side gamma curves are more coincident. The more coincident of RGB side gamma curves, the less color shift level of LCD panel, contributing to similar picture quality under large viewing angle compared to that at the front view.

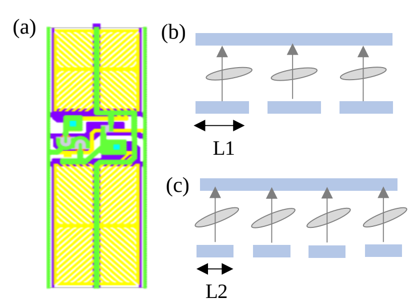


Fig 6. (a) Normal VA 8-domain pixel Design; (b) RG pixel ITO design, and (c) B pixel ITO design in high picture-quality pixel.

The driving principle of VA 8-domain pixel determines that the upper and lower 4 domains exhibit different voltage, contributing to different brightness at 255 grayscale. As shown in Fig. 7(b), main TFT（Thin Film Transistor） controls the upper half pixel while the below half pixel is controlled by both sub TFT and cs TFT. If the width or channel length of cs TFT is finely tuned, the brightness and viewing angle of this pixel are tuned accordingly. In our pixel, large width of cs TFT is intentionally applied to achieve better viewing angle at the expense of transmittance, which brings side RGB gamma curves closer to the front ones, leading to lower color washout of our VA panel.

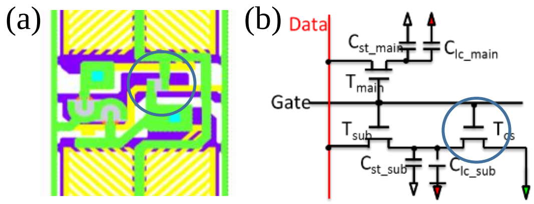


Fig. 7. Electric schematic diagram of LCD VA 8 domain.

Besides, the cell gap of RGB pixel is reduced from 3.2μm to 2.9μm so as to narrow the luminance difference between front and side gamma curves and as shown in Fig. 8. As a result, all RGB side gamma curves are approaching to the front ones, which is beneficial for lower color washout in our system.

$$Tr\% = \frac{1}{2}\sin\varphi^2 \, sin(\frac{\pi\Delta nd}{\lambda})^2$$

Fig. 8. LCD Transmittance equation.

Fine designed pixel together with cell gap optimization, our VA LCD panel obtains an average CESI viewing angle of over 130°, which is a noticeable progress compared to normal panel with a typical CESI value of ~100°. Moreover, a high CESI value of ~170° is achieved with the perfect match between pixel design and process conditions. Apparently, RGB side gamma curves are closer to the front one in our panel than that in normal panel as shown in Fig. 9. Moreover, RGB gamma curves are more coincident in our panel. Both CESI value and gamma curves reveal that our panel exhibits better color washout and color shift than normal panel.

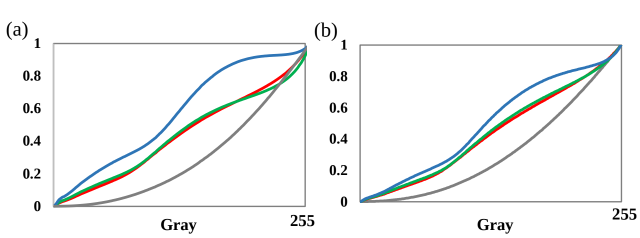


Fig. 9. (a) Right and side view of (a) normal, and (b) high picture-quality VA panels.

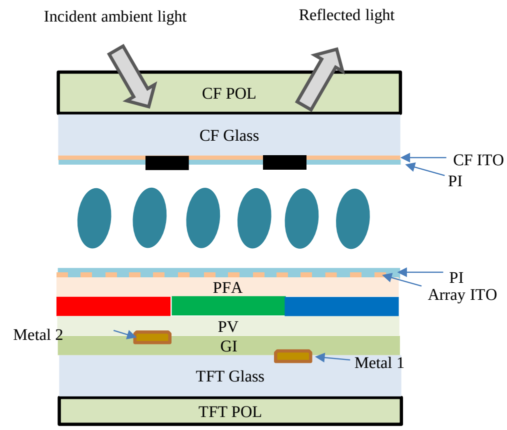


Fig. 10. Typical layers in COA VA display.

3.2 Low reflectivity

Besides viewing angle, reflectivity is another important parameter to achieve high picture quality of LCD display. Normally, COA (color filter on array) structure is applied in large-size display due to its advantages of higher transmittance and better curved display production. Inevitably, COA structure exhibits some disadvantages, such as relatively high reflectivity compared with Non-COA structure because there is no color filter on the CF layer to absorb the ambient light.

As shown in Fig.10, the incident ambient light goes through CF POL, CF glass, CF ITO, PI, liquid crystal and PFA layers before reaching RGB color filter, contributing to relatively high reflectivity of COA structure. The match of refractivity between each two adjacent layers matters a lot for achieving lower reflectivity according to the formula in Fig 11(a). As shown in this formula, reflectivity is proportional to the refractive difference of adjacent two layers. The larger of the refractive difference, the more apparent increase of the calculated reflective value. As a result, two strategies are generally employed to decrease the reflectivity. One is narrowing the difference of two refractive values and the other is inserting another layer between these two layers with the refractive value just between n_1 & n_2.

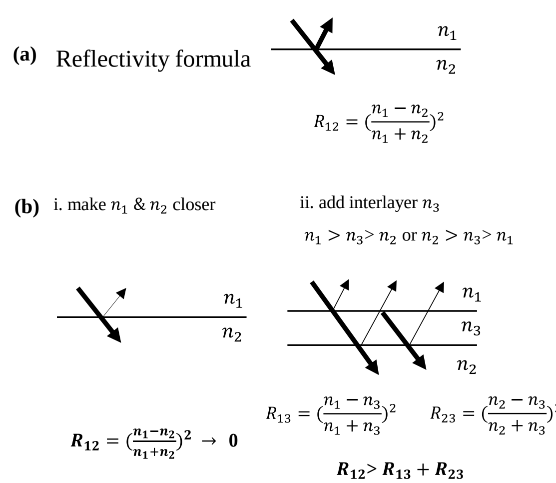


Fig. 11. (a) Formula of reflectivity between two layers. (b) Two strategies to decrease the reflectivity of two layers: i. make n_1 & n_2 of two layers closer, ii. Add extra interlayer between original two layers.

Table 3. Refractive index of layers in VA COA display.

layers	refractive index n	Reflectivity between adjacent layers
CF Glass	1.52	$\mathbf{R_{Glass-ITO}}$ **0.96%**
CF ITO	1.85	$\mathbf{R_{ITO-PI}}$ **0.53%**
CF PI	1.60	R_{PI-LC} 0.15%
LC	1.48	R_{LC-PI} 0.15%
Array PI	1.60	$\mathbf{R_{PI-ITO}}$ **0.53%**
Array ITO	1.85	$R_{ITO-PFA}$ 0.06%
PFA	1.95	/

Refractive index of different layers in our COA system are collected in Table 3. Based on the formula in Fig. 11(a), reflective values between two adjacent layers are calculated in Table 3 as well. Obviously, the reflectivity between CF glass & CF ITO, CF ITO & CF PI, and array PI & array ITO layers are relatively larger than others, resulting in increased reflectivity in our COA system. In our work, the corresponding methods are used to minimize the reflectivity. For CF glass & CF ITO, the refractive difference is comparatively large. The more effective method is adding an interlayer between these two layers with a refractive index around 1.7. For CF ITO & CF PI, and array PI & array ITO, by tuning the thickness and characteristics of two adjacent layers, the refractive difference is effectively reduced. All the above strategies together with the low-reflectivity polarizer, our COA panel achieves a low reflectivity of ~1.0%. By intentionally tuning the characteristics of the layers inside our panel, COA structure can exhibit Non-COA comparable reflectivity while still maintains its advantages.

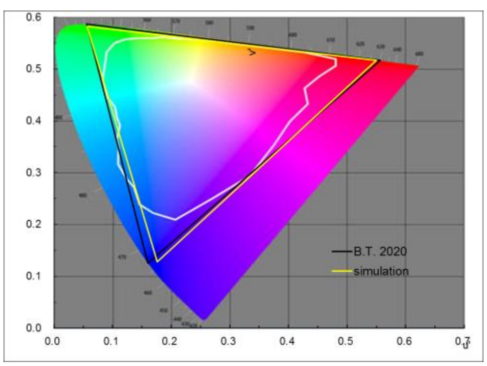


Fig. 12. Color gamut of LCD panel.

3.3 High color gamut

As the development of LCD technology, high color gamut is one of the main streams for high picture-quality display. For OLED display technology, it is easier to obtain high color gamut because its active luminescence characteristics. Accordingly, QLED technology is applied in LCD display areas to increase the picture quality especially the color gamut of the TV set. QLED technology represents that the backlight module is normally composed of B LED and quantum dot film so that white light is obtained after the color conversion of B LED with quantum dots.

Generally, the normal OC together with the QLED technology exhibits a color gamut of BT2020 <85%. To pursue higher color gamut, RGB color filter materials and the RGB peak positions of backlight are simultaneously tuned. Ultimately, a high color gamut of BT2020 95% is achieved due to better match between OC and the backlight spectrum. Additionally, higher color saturation of side view is obtained after the front-view color gamut is elevated, which is beneficial for VA subjective viewing angle. Wide viewing angle technology together with high color gamut contributes to IPS-comparable subjective viewing angle in our system, thoroughly solving the headache viewing angle problem of VA picture quality.

4. Conclusion

This study demonstrates an advanced 8-domain VA LCD architecture that integrates high picture quality and transmittance optimization. By refining pixel design, optimizing ITO line/space parameters, and adjusting layer stacks, a total 24% open-cell transmittance increase was achieved. Multi-domain pixel design and refractive index matching enabled OLED-comparable performance, including a 130° viewing angle, 1.0% reflectivity, and BT2020 95% color gamut. The synergistic use of quantum dot backlight and process-material innovations resolved VA LCD's historical limitations in viewing angle and reflectivity. These advancements establish VA LCD as a competitive solution for high-end displays, balancing superior visual performance with energy consumption, thus positioning it as a viable alternative to OLED in premium applications.

5. Reference

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