

Study on Optimization Methods for the FoV Performance of Under-Display Ambient Light Sensors in AMOLED

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Abstract

This study focuses on the under-display ambient light sensors (ALS) in smartphones, specifically investigating the impact of AMOLED panels on field of view (FOV). By establishing a three-dimensional model of the complete film layer stack of the display panel, we obtained simulation results that closely matched the experimental data. The research reveals the mechanisms by which panel design affects oblique incident light. By optimizing the panel design, the FOV capability of ALS can be effectively enhanced. Ultimately, we developed a simple and rapid method to evaluate the impact of AMOLED panels on FOV performance, providing significant guidance for panel design.

Author Keywords

ambient light sensor; field of view; AMOLED

1. Introduction

In recent years, smartphones have become indispensable tools in people's daily lives, with rapid advancements in both hardware and software technologies. An increasing number of sensors are being integrated into smartphones, greatly expanding their application scenarios and transforming them from simple communication devices into multifunctional smart terminals. Among these sensors, the ambient light sensor (ALS), typically located beneath the smartphone's display, detects environmental light intensity to automatically adjust screen brightness. This function enhances screen visibility, improves user visual comfort in various environments, reduces power consumption, and extends battery life^[1]. The field of view (FOV) is a crucial performance metric for ALS, defining the maximum angular range that the sensor can detect^[2]. For example, FOV 50 is defined as the angle at which the intensity of light received by sensor decreases to 50% of that received under vertical incidence, as angle of incidence increases. According to the cosine response characteristics of light sensors^[3], the ideal maximum value for FOV 50 is 60°. However, for smartphones, display panel covering the ambient light sensor significantly alters its FOV, thereby affecting the sensor's perceptual performance.

This study is based on mainstream AMOLED (Active Matrix Organic Light-Emitting Diode) display panels currently available in the market. A comprehensive three-dimensional geometric model has been established, encompassing underlying pixel array to OLED device. Through optical simulations, the impact of AMOLED display panels on the FOV performance of ALS has been investigated.

2. Modeling and Simulation

The FOV performance of ALS is closely related to the geometric structure of optical systems and the cosine-corrected diffuse dome. To eliminate extraneous influencing factors and simplify simulation model, this study treats the ambient light sensor as a cohesive unit. Additionally, three-dimensional

modeling software has been used to replicate the complex multilayer film stack within OLED panel, aiming to accurately simulate the impact of the OLED panel on the FOV of ALS.

2.1 Geometry of Simulation Model

To achieve independent driving of each pixel in display area and ensure excellent optoelectronic characteristics, OLED panels employ a finely detailed pixel array design. The design layout includes intricate multilayer metal interconnections and vias, forming a unique pattern when projected onto a two-dimensional plane. When external light is incident perpendicularly (i.e., at an angle of 0°), the attenuation of light passing through the OLED panel can be directly assessed through the projected pattern of design layout (typically assuming that metals are opaque and binarizing the stacked pattern).

However, for the under-display ambient light sensor, which is located beneath the OLED panel, external light must pass through the panel to reach the sensor. Given that external light arrives at an angle, it undergoes multiple refractions and reflections within the OLED panel, making it impossible to directly evaluate light attenuation using a two-dimensional normal projection pattern. To address this challenge, this study integrates the layout design of OLED panel with the actual film thickness, utilizing three-dimensional modeling software to construct a 3D stacked geometric model of the internal metal interconnections and inorganic/organic layers (Figure 1). This model comprehensively covers the underlying pixel array, OLED devices, and touch unit, showing a high degree of correspondence with actual internal structure of the manufactured OLED panel.

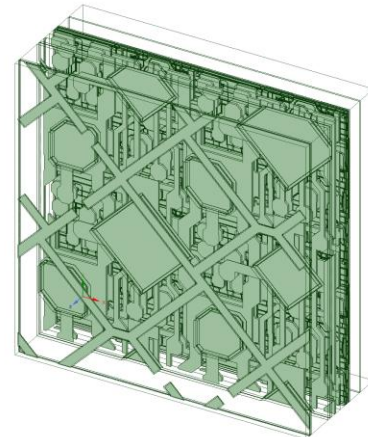


Figure 1. Three-dimensional model of OLED panel

2.2 Parameters of Simulation

After establishing the geometry of OLED panel model, a simulation model was constructed based on the testing method for the FOV of ALS (as shown in Figure 2). The geometry of panel model was imported into optical simulation software,

where optical properties were assigned to each layer of films. An illuminance receiver, simulating the ambient light sensor, was placed beneath the panel, while a parallel light source (D65) was added above the panel to simulate incident environmental light. The simulation employed Monte Carlo methods, fixing the number of incident light rays and rotating the light source to vary angle of incidence, while recording the illuminance at the receiver for each corresponding angle.

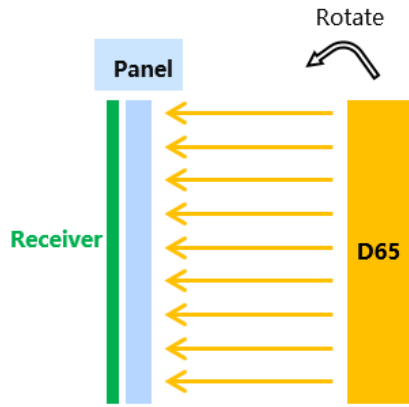


Figure 2. Schematic diagram of the simulation model

3. Results and Discussion

To more intuitively demonstrate the impact of OLED panel on the FOV performance of ALS, an equivalent concept is introduced: the relative transmittance of OLED panel, which can be used to quantify the sensor’s FOV performance. This metric is defined as the ratio of panel’s transmittance at a specific angle of incidence to its transmittance under perpendicular incidence. Specifically, for the same angle of incident light, a higher relative transmittance of the panel indicates a smaller impact on the FOV of ALS. This means that the panel allows more light to penetrate at various angles, thereby ensuring the sensor can more accurately capture information about the ambient light.

3.1 Results of Simulation

Based on the aforementioned three-dimensional simulation model, the relative transmittance of three OLED panels (A, B, and C), each featuring a different underlying array design, was simulated at the same incident angle (as shown in Figure 3). The simulation results indicate that, both in the X direction (horizontal) and the Y direction (vertical), the simulated outcomes closely match the measured results. This demonstrates that the simulation model can accurately replicate the impact of OLED panel on the FOV of ALS.

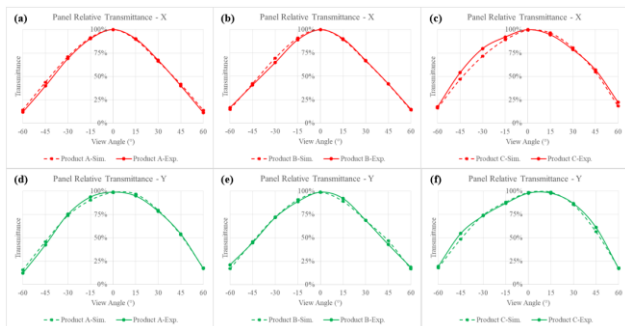


Figure 3. Simulated and measured relative transmittance of different OLED panels

Comparing the relative transmittance of the three panels at a 45° view angle, it was observed that the transmittance ranking is C > A > B, indicating that panel C exhibits the best FOV performance, while panel B performs the worst. In simulation model of the three products, organic and inorganic film stack and optical parameters are consistent; the primary difference lies in the shape of metal layer in the underlying pixel array. To further investigate how the pixel design of OLED panel influences FOV performance, and considering that panel A represents the current mainstream underlying array design, the following analysis will be based on the simulation model of panel A.

3.2 Mechanism of the Influence of OLED Panel on FOV Performance

In the above simulation process, the same optical parameters for organic/inorganic thin film layers were set across different products to more accurately focus on the impact of metal film layer’s wiring shape on FOV performance. By progressively removing the metal film layers in panel A and conducting one-factor simulations, we found that the active layer SD3 had the most significant effect on relative transmittance. To further investigate the specific influence of the metal layer’s wiring shape in SD3 layer on relative transmittance, three sets of different SD3 layer metal wiring shapes were designed as part of a Design of Experiments (DOE), and simulations were performed at 45° view angle, with the results shown in Table 1.

Table 1. Relative transmittance variation at 45° view angle under different SD3 patterns

Item	POR	DOE1	DOE2	DOE3	
Δ Tr. @45°	X+	0.00%	1.52%	6.50%	1.83%
	X-	0.00%	1.22%	8.24%	1.32%
	Y+	0.00%	0.06%	1.48%	-3.36%
	Y-	0.00%	1.96%	2.56%	1.08%
Normal Tr. Area%	51.89%	59.64%	59.91%	77.90%	
Pattern*					

* In the binarized representation of normal projection for SD3 layer, the metal wiring was considered opaque.

Compared to the control group POR, both DOE1 and DOE2 exhibited a significant increase in the normal projected light-transmitting area of SD3 layer, and the light-transmitting areas of the two were similar. However, the relative transmittance in X direction for DOE2 was significantly higher than that for DOE1, indicating a strong correlation between relative transmittance and the position of metal wiring. Further comparison revealed that the normal projected light-transmitting area of DOE3 was much larger than that of DOE1, yet its relative transmittance in X direction showed only a modest increase, with a deterioration in Y direction; in contrast, DOE2 had a normal light-transmitting area comparable to DOE1, while

its relative transmittance in all four orientations was superior to that of DOE3. This result suggests that relative transmittance has a low correlation with the normal projected light-transmitting area of SD3 layer. To comprehensively evaluate FOV performance of panel, it is necessary to consider the overall impact of multiple metal film layers.

Utilizing the three-dimensional model of panel A, combined with simulation ray tracing, an analysis of the multilayer metal film stack reveals that the light passing through SD3 layer can be categorized into four types (as shown in Figure 4): Type A involves only SD3 layer, with no SD1/SD2 layers beneath it, meaning that the light is obstructed by SD3 layer; removing this SD3 layer results in an increase in relative transmittance. Type B includes SD3 layer with SD1/SD2 layers below it, where light can be blocked by both the SD3 layer and the underlying metal layers; removing this SD3 layer does not enhance relative transmittance. Type C has SD1/SD2 layers beneath the SD3 layer, where light is not obstructed by SD3 layer but is blocked by SD1/SD2 layers. Type D describes a scenario where light is completely unobstructed by any metal layers during its propagation, allowing it to pass directly through.

Comparing the pixel design differences between DOE1 and DOE2, it is noted that the removed SD3 wiring in DOE2 fall under light path Type A, while those in DOE1 are categorized under light path Type B. This leads to a significantly higher relative transmittance in X direction for DOE2 compared to DOE1. In DOE3, large portions of SD3 metal wiring were removed, substantially increasing the normal projected light-transmitting area of the single film layer; however, since it is positioned in light path Type B, the underlying SD2 metal still blocks the light, contributing minimally to relative transmittance.

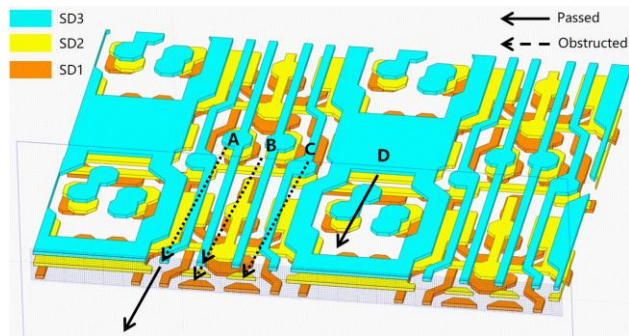


Figure 4. Schematic diagram of the optical paths (Type A/B/C/D) inside OLED panel

In summary, for incident light at different angles, the key factor determining FOV performance of OLED panel is whether there are metal film layers obstructing the light path at specific internal locations of panel. To enhance FOV performance, it is essential to increase the light-transmitting area of metal film layers in their oblique projection, thereby increasing the proportion of light path Type D (no metal obstruction, allowing direct light transmission). To achieve this goal, two approaches can be considered:

Adjusting the Pixel Array Design: By optimizing the layout of metal layers (including their paths, shapes, and spacing), the proportion of metal obstruction to oblique incident light can be reduced, ensuring that light is minimally obstructed by metal wiring as it passes through the OLED panel.

Adjusting the Thickness of Organic Layers: Organic layers are typically used to flatten the surfaces between metal film layers. By slightly increasing the thickness of these organic layers, the spacing between metal film layers can be enlarged, thereby reducing the obstruction of oblique incident light by metal wiring (as shown in Figure 5, the obstruction of oblique incident rays by metal film layers varies with different organic layer thicknesses).

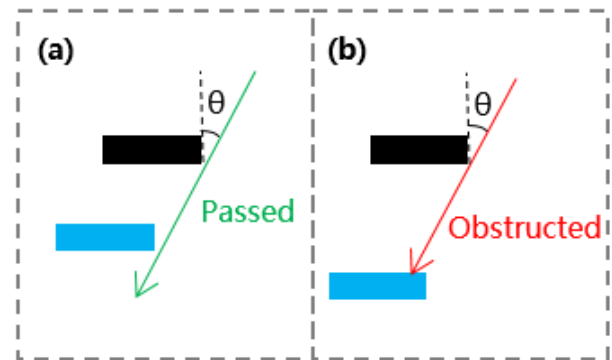


Figure 5. Effect of organic flatness layer thickness on oblique incident rays

3.3 Method for Evaluating OLED Panel's FOV Performance

Based on the mechanisms explored above, we propose a novel method to evaluate the impact of OLED display panels on FOV performance. First, using the geometric data from three-dimensional model of OLED panel, we extract the projection images at both normal (perpendicular) and oblique incident angles (Figures 6a and 6b) and apply binarization to these projection images. This allows us to calculate the ratio of white pixels, resulting in the determination of the transparent areas for both normal and oblique incident angles. The ratio of oblique to normal transparent areas is adopted as the evaluation criterion: a higher ratio indicates greater relative transmittance and improved FOV performance for the corresponding angle. The fitting relationship between the ratio of oblique to normal transparent areas at 45° view angle and the panel's relative transmittance under different pixel designs is shown in Figure 6c, revealing a significant positive correlation between the two.

It is important to note that, due to the microstructural nature of OLED panel, where the gap sizes between microstructures are close to the wavelength of visible light, diffraction effects are significant. Additionally, factors such as scattering at the interfaces of thin film layers may introduce some errors into this evaluation method. However, based on the comparison between simulation and experimental results, our method can accurately reflect the corresponding FOV capability of OLED panel to a certain extent. This approach provides valuable insights and guidance for the design and optimization of OLED panels.

Furthermore, we optimized the pixel array design of existing products based on the simulation results. The FOV capability of optimized samples closely matched with simulation predictions, thereby validating the accuracy of our simulation model and method.

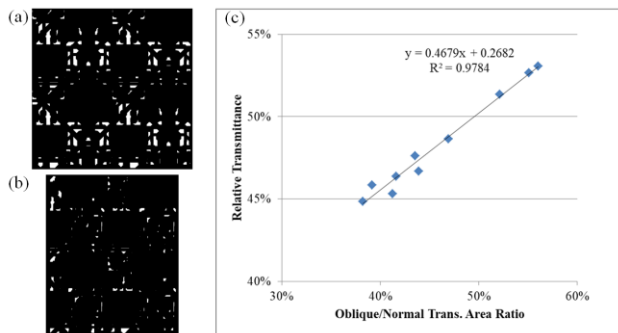


Figure 6. Projection of view angle 0° (a) and 45° (b), Linear fit plot of oblique (45°)/normal transmittance area ratio to relative transmittance of panel (c)

4. Conclusion

We established a comprehensive three-dimensional model geometry of OLED panel based on its pixel layout and actual film thickness, and developed a simulation model for Panel-ALS FOV using geometric optical simulation software. The simulation results for multiple products showed good agreement

with experimental data, demonstrating high accuracy. This simulation model was used to investigate the key factors influencing panel FOV performance and to propose effective optimization and evaluation methods. These findings hold significant guiding importance and practical value for advancing the design of OLED panels.

5. References

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