Novel In-Cell Fingerprint Sensor with High EQE Photodiode Applied in OLED Display

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Abstract

We propose a novel in-cell sensor display panel design to minimize the thickness of OLED module device, in which the fingerprint (FP) optical sensor driver circuit array and high EQE a-Si photodiode devices is fabricated together with the LTPO array of OLED panel on PI substrate forming a super integrated in-cell optical sensor display with full screen fingerprint identification.

Author Keywords

In-cell optical sensor display integration; fingerprint in display; FP; Organic Light Emitting Diodes (OLED); LTPO OLED; a-Si photodiode;

1. Introduction and Motivations

As we all know with the development of smart mobile devices technology, the more powerful the mobile phone functions the more sensors are required, which will inevitably increase the thickness and complexity of mobile phone modules. This situation is inconsistent with the desire of thinner mobile phone modules. Display and mobile phone manufacturers have been cooperating to make efforts to try various methods to slim down the module recent years. One of the effective methods is CFOT procedure, however, it should be noted that an unfavorable consequence with CFOT technology is the degradation of out-cell optical sensor devices performance that caused by the almost 0% transmittance, thus high-end fingerprint optical sensors are sought to compensate the situation which indirectly increase the cost of mobile phones [1] [2]. To overcome the transmittance limitation, one possible attempt is ultrasonic fingerprint, the other is to integrate the fingerprint optical sensor into display. Optical fingerprinting technology does not require complex module manufacturing processes and special piezoelectric materials like ultrasonic fingerprinting which is more preferred. Among various types of photodiode, OPD and a-Si are both reasonable options for fingerprint photodiodes, we chose a-Si as our choice due to its better stability and dark current advantages. After integrated into the mobile phone display, large area biological detection can be realized, which is suitable for future digital payment application scenarios such as full-screen palm print recognition or multi-finger recognition. Based on the above considerations, we consider the development of optical fingerprint sensors embedded in the OLED display, this is not limited by the low transmittance, not only simplify the mobile phone module, but also realize the application of glass based low-cost full-screen optical sensing.

2. Panel Architecture:

In this article, a 6.51-inch AMOLED sensor display is used to verify the feasibility of the proposed in-cell sensor display design. Different from the normal out-cell sensor display as shown in Figure 1(a) the reflection light of the fingerprint go through whole TFT backplane reach to the sensor that add on the substrate, the in-cell sensor as shown in Figure 1(b) is fabricated insert into the TFT array and CFOT layers that the light reach the sensor without much signal loss as shown in Table 1 without passing through the PI substrate. In addition to transmittance and thickness properties of in-cell sensor display, Table 1 also shows the delta reflection is negligible between normal area and sensor area which conducive to achieving the all black off screen visual effects.

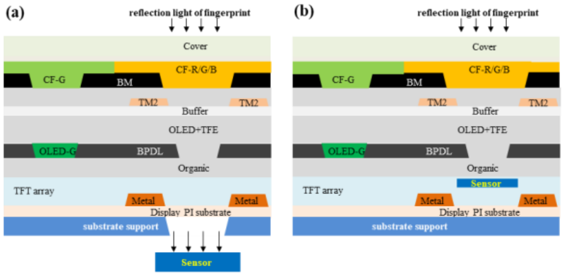

Figure 1. (a) Out-cell FP sensor (b) In-cell FP sensor display structure.

Table 1. Properties comparison of in-cell and out-cell sensor display

Item	Out-cell sensor	In-cell sensor
Display Transmittance/%	<2%	>20%
ΔRefection/% (black visual-effects)	>1.5%	<0.2%
Extra thickness/mm	~0.2	/

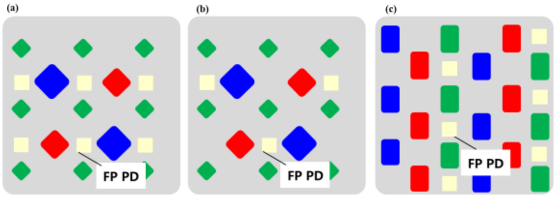

Figure 2. Various kinds of FP PD pixel arrangements for pixel design. (a) Diamond pentile:FP=1:1 (b) Diamond pentile:FP=1:2 (c)Real RGB delta:FP=1:1

Table 2. In-cell sensor display specification

Item	Specification
display size	6.51 inch
resolution	1072x2368
color pixel arrangement	Windmill rendering
Display pixel : FP pixel	1:1

This 6.51-inch fingerprint (FP) recognition area is located throughout the whole display AA area. Fingerprint channel design is strongly related to display pixel arrangement as shown in Figure 2, for example the Figure 2 (a) (b)diamond pentile:FP

ISSN 0097-996X/25/5603-2083-$1.00 © 2025

=1:1 or 1:2, Figure 2 (c) RGB delta pentile:FP=3:2, it is necessary to comprehensively consider the influence of RGB space and fingerprint resolution to determine the FP pixel design. The in-cell sensor display specification is shown in Table 2.

3. A-Si Photodiode Device

The development of photo diode devices with high external quantum efficiency(EQE) take great significance to the realization and optimization of sensor functions, as we all know the higher the conversion efficiency means that the more light signal can be absorbed and converted into voltage output, which is easier for the ROIC sampling. We have made efforts to optimize the PD devices performance by adjusting the thickness of photosensitive layers and p-layer and optimizing the n-layer materials film quality, as can be seen from the Figure 3.(a)~(c), as shown in Figure 3(a), p-layer thickness is a key factor affecting the band response of PD devices which is controlled by adjusting the P dose density from thicker DOE3 to thinner DOE1 to achieve the increase of the photocurrent of the PIN device, we think that the thinner P-layer is conducive to the absorption of light at shorter wavelengths bands. The thickness of photosensitive layer is also a factor affecting the photocurrent response. As shown in Figure 3(b), the photocurrent increases continuously as the thickness of photosensitive layer increases from DOE4 and DOE5 which benefit from more light absorption. However, the photocurrent decreases with the further increase from DOE5 to DOE6 thickness may be caused by the longer carrier path. In addition, we discover that the n-layer surface defect state can affect the dark current of the device by affecting the surface leakage current under large voltage bias as shown in the figure 3(c), the surface leakage current is reduced by improving the quality of film formation from DOE7 to DOE8. Based on the above analysis, we applied all the optimized factors to the DOEC which indeed showing better optical performance as shown in Figure 4(a), a significant EQE improvement in the short wavelength bands is achieved in DOEC (p-layer/n-layer/photosensitive layer optimized doe) compared to DOEA(base doe) and DOEB (p-layer/n-layer optimized doe). The PD sensor shows excellent photoelectric conversion efficiency, such as 20% of the 435nm blue band and 63% of 550nm green band and 50% of 620nm respectively. In addition, its dark current is low to 5nA/cm2 and shows great light response as shown in the Figure 4(b).

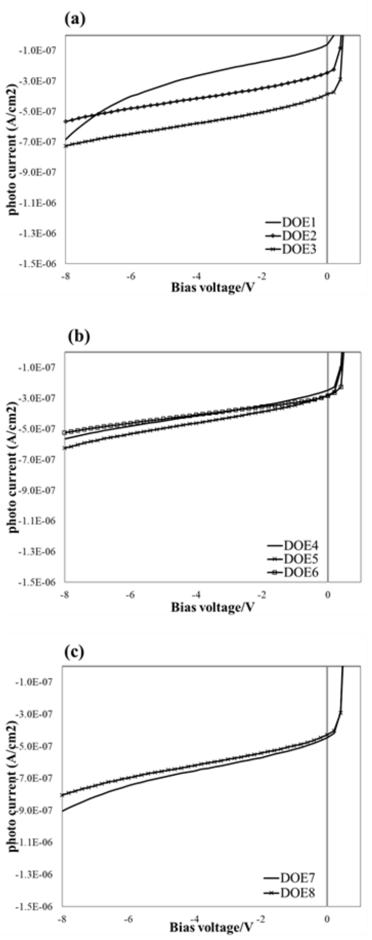

Figure 3. Blue bands I-V curve of PD. Three factors that affect the photocurrent (a) p-layer thickness (b) photosensitive layer thickness (c) n-layer material

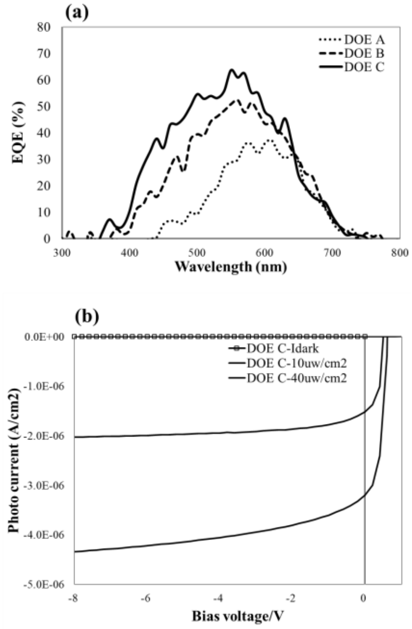

Figure 4. (a) EQE of DOEA/B/C (b) Blue bands I-V curve of PD for DOEC

4. Driving Architecture

In order to improve the efficiency and speed of FP recognition, we divide the full screen into M identify zones, each identify zone could work independently or together which depends on the application scenario requirements. As shown in Figure 5 (a), each identify zone contains m source lines, thus the total output source signals number is M*m. Meanwhile, we use multiplexer to reduce the output source lines, each identify zone shares the same multiplexer signal so that the source could reduce from M*m to m lines. When it comes to the specific identification, we propose that when the finger touch on certain identify zone screen, only the circuit in this zone is triggered, otherwise when the finger touch on the area that between two adjacent zones, the circuit in both zones all need to be triggered. This design uses shift register circuit to drive large area fingerprint recognition. The sensor circuit works short pulse width to quickly skip during the non-fingerprint recognition zones, and the data is not sampled, the circuit of the fingerprint recognition zone is driven by a long pulse width, and the signal data is sampled and collected during this time. As shown in Figure 5 (b), the fingerprint point position is located according to TP function. For example, the first line of the fingerprint falls on the j behavior, the long pulse width scan is carried out from the j line by adjusting the timing of CK. After the long pulse width scanning, adjust the timing of CK, and continue to scan to the last line of fingerprint functional area with short pulse width to complete the working time of one frame. To collect data, the mux gate of vertical partition should be opened accordingly, and the data should be processed in the terminal to obtain the fingerprint image.

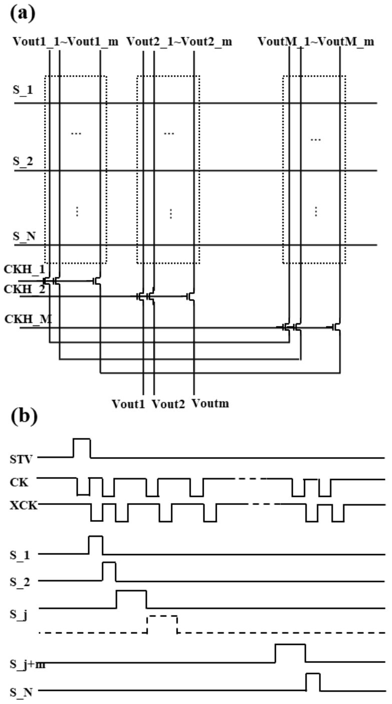

Figure 5. (a) FP sensor driver architecture (b) Fast and slow sweep timing design

5. Optical System

One challenge of integrating the FP sensor into the panel is how to avoid the display stray light including TP reflected light. As shown in Figure 6(a), OLED emitted light is reflected by TP metal and irradiated to the fingerprint sensor. The presence of stray light reduces the gap between valley and ridge signals, resulting in blurred or even hard to distinguish the fingerprint images because of the intensity of stray light reflected by TP metal is assignable. In order to eliminate the disadvantage of display stray light, TP metal line is suggested to set away from the PDL hole boundary. As shown in Figure 6(b), the distance a between TP metal line and BM pattern boundary on the sensor side is smaller than the distance b that between TP metal line and BM pattern boundary on the PDL side (a<b), which can prevent most of the display stray light from irradiating on the sensor. The gap between valley and ridge optical signals before and after TP optimization is simulated. As shown in Figure 6(c), in the case of TP line is close to the display pixel, the difference between valley and ridge optical signals is small (about 1.5 times) due to the introduction of display stray light, when TP is far away from the display pixel, the amount of stray light is reduced, and the difference between valley and ridge optical signals is dramatically increased. It can also be seen from the true color images in Figure 6(d) that after TP optimization, the stray light signals of Red and Blue decreased. This conclusion is meaningful for us to do the TP design and sensor design.

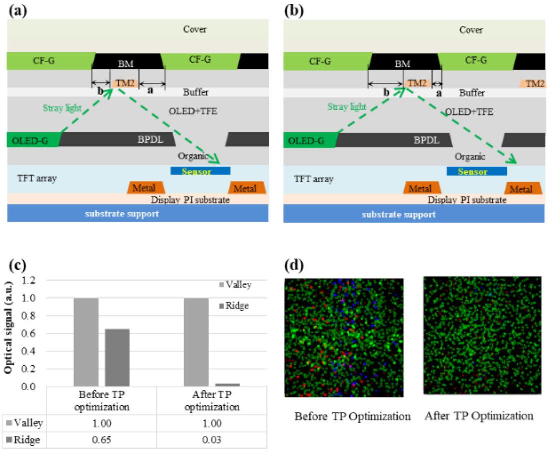

Figure 6. (a) Before TP optimization (b) After TP optimization (c) signal gap of valley and ridge (d) True color images

6. In-cell Sensor Display with high EQE PD

With above improvement on photo diode device and discussion on driver architecture and optical system, we designed a 6.51 inch 400ppi CFOT OLED module with in-cell full screen fingerprint scanning. Since the project is in the backplane process, we will further verify the sensor performance as soon as the module is ready before 2025 March. The contribution of EQE enhancement to the fingerprint exposure time was simulated. The single finger exposure time is expected to be only 45ms using our high-performance sensor.

Table 3. The simulation result of FP exposure time with high EQE PD devices

Item	EQE(550nm)	Signal Gap /V	Exposure Time /ms
DOEC	63%	0.3	45
DOEB	50%	0.3	55
DOEA	28%	0.3	95

7. Conclusions

This work presents in-cell fingerprint sensor with high EQE (up to 63% in 550nm) photodiode that applied in OLED Display. It provides the possibility of large-area fingerprint recognition with ultra-thin display module.

8. References

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