A High-Resolution In-Cell Fingerprint Display with New Isolation Structure

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Abstract

A new isolation structure was developed without increasing the number of photolithography process for suppressing electrical crosstalk between OLED and organic photodiode (OPD) pixels, one of the biggest issues for high-resolution in-cell fingerprint sensing display. Using the isolation structure and highly efficient broadband OPD, we demonstrated a 6.2-inch 360 ppi prototype and verified that FAR and FRR reached as low as 0.002% and 0.3%, respectively while the display performance remained excellent.

Author Keywords

Organic photo diode; Fingerprint; Isolation structure; Photoelectric

1. Introduction

In the past few decades, mobile phone technology has made significant progress. Early mobile phones were very bulky and had almost single function. Currently, they are compact and sophisticated with some even being foldable [1]. Moreover, they are becoming multi-functional, and more and more powerful, which has greatly facilitated people's lives and work. Artificial intelligence (AI) technology will open up new possibilities for mobile phones while also presenting new demands for our displays.

Firstly, reducing power consumption of display is essential. As we all know, AI requires a large amount of energy. Therefore, mobile phone displays need to be more energy-efficient to allocate more energy to the chips. Therefore, new display technologies for power reduction such as low-temperature polycrystalline oxides (LTPO) [2], CF on encapsulation (COE) [3], and micro lens array (MLA) [4] are being employed in high-end AMOLED displays.

Secondly, there should be more interfaces for perceiving information than before. Touch, microphone, and camera are traditional input interfaces. Among them, touch has been already integrated into the display. Are there any other input interfaces that can be integrated into the display? Multi-functional display having various input interfaces was proposed [5]. We have been developing a-Si pin photodiodes and organic photodiodes (OPDs) as photo detectors for the integration into AMOLED displays. The OPD has a sensitivity not only in visible light but also in near infrared region, enabling a wider variety of biometrics and healthcare monitoring such as fingerprint, vein image, heart rate, blood oxygen saturation, and blood pressure. Coupled with AI technology, the mobile phone can better understand its user's status. The integrated OPD does not conflict with the power reduction technologies as mentioned above, and moreover, can complement each other.

The AMOLED display integrated with OPD was first demonstrated in 2019 [6]. The size and resolution of the display were 3.07 inch and 212 ppi, respectively. Recently a prototype having 7.46 inch and 374 ppi was demonstrated in 2023 [5] and 2024 [7]. However, the resolution of OPD sensor was 262 dpi that cannot meet a security requirement of 300 dpi for fingerprint sensing in mobile devices [8]. Measures against electrical crosstalk was taken using reverse-tapered separator, increasing a photolithography process [7]. A prototype with a size of 5.76 inch and a resolution of 513 ppi was also reported in 2024 [9]. However, it employed 3T1C as a pixel circuit for OLED and used photolithography process for patterning OLED and OPD instead of conventional fine metal mask (FMM) process.

In this paper we demonstrated our prototype with a resolution of 360 ppi for both of OLED display and OPD sensor meeting security requirement. An isolation structure suppressing electrical crosstalk and enabling high performance fingerprint sensing was newly developed without increasing the number of photolithography process. The process using FMM is compatible with current production lines. Moreover, our broadband OPD has high efficiency with EQE of 25% for green and of 45% for red allowing biometrics and healthcare monitoring.

2. Results and Discussion

2.1. Design Concept and Fabrication

2.1.1. Resolution

The fingerprint recognition feature in mobile phones is primarily utilized for unlocking and making payments. To meet the payment standards, a fingerprint resolution of 300 dpi is required [8], while current AMOLED display resolutions typically range around 400 ppi. In order to integrate OPD into the display, we have developed a 360 ppi AMOLED display with 360 dpi fingerprint, in which the number of OPD sub-pixels is equal to the number of green sub-pixels. Through the implementation of innovative design methods and enhancements in manufacturing capabilities, it is possible to further increase the resolution beyond 400 ppi.

2.1.2. Pixel Circuit

For pixel driving circuitry in the display, we have chosen a configuration consisting of seven transistors and one capacitor (7TIC), as depicted in Figure 1 a). In this circuit schematic, some transistors have been replaced with IGZO TFTs due to their low leakage current characteristics. This enables the display to operate at lower frequencies, thereby reducing noise caused by data line charging and discharging processes. Figure 1 b) shows a three-transistor active pixel sensor (APS) pixel driving circuit schematic. All three TFTs are made using IGZO. M1 functions as a source follower while M2 and M3 serve as voltage switches. The array fabrication process remains consistent with traditional LTPO techniques.

2.1.3. Broadband OPD

Generally, the longer the wavelength of light, the greater its ability to penetrate the skin. The fingerprint recognition function only requires surface morphology of the skin. Therefore, green light is suitable for fingerprint recognition, while health monitoring requires a longer wavelength of light. Considering AMOLED layout limitations, it is necessary to minimize sub-pixels. Based on

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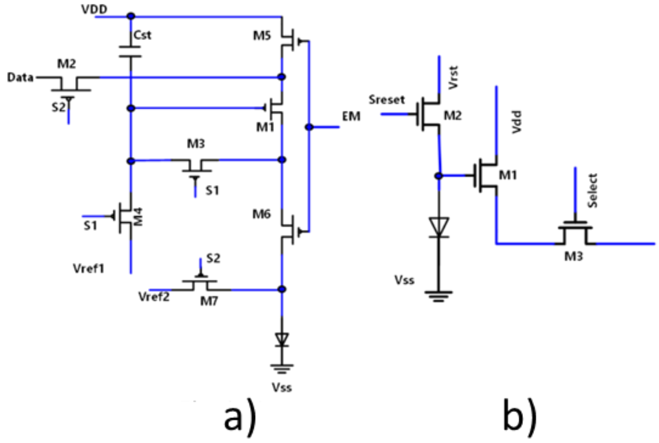

Figure 1. Circuit diagram of a) OLED and b) OPD pixels.

this, we developed an OPD device that can detect both green light and red light, which can be used for fingerprint recognition and health monitoring respectively. OPD device consists of a mixed active layer composed of a donor material and an acceptor material, to further improve device efficiency and be compatible with OLED devices, electron extraction layers can be added. Finally, the external quantum efficiency (EQE) of the OPD device reached 45% near the wavelength of 620nm, and at the wavelength of 530nm, the EQE also reached 25%, the 620nm and 530nm wavelength correspond to the red and green light emission wavelengths of the screen, respectively. Figure 2 Shows the EQE spectrum of the OPD and the normalized emission spectrum of OLED.

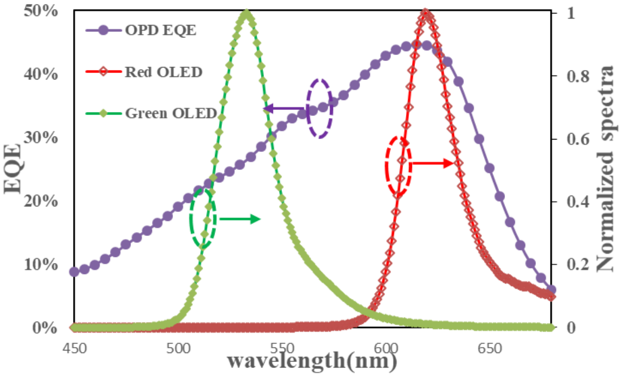

Figure 2. Normalized emission spectrum of the green and red OLED and EQE spectrum of the broadband OPD Device.

In order to integrate OPD devices and OLED devices onto the same substrate using the evaporation process, OPD and OLED adopt a common hole injection layer (HIL)/hole transport layer (HTL) / electron transport layer (ETL)/electron injection layer (EIL). To mitigate the risk of color mixing issues caused by high OPD evaporation temperature, we have arranged the OPD process after the OLED process.

2.2.Crosstalk Problem and Measures

By adopting novel design schemes and process integration, we have successfully fabricated a high-resolution in-cell fingerprint display. The panel can display normally and capture fingerprint images in ambient light environment. While the fingerprint images are very blurry, and the Signal-to-noise ratio (SNR) (a key parameter indicating the quality of a fingerprint image) is much lower than the PIN (an inorganic photosensitive diode) sensor we reported in 2022. Additionally, several other parameters used to characterize sensing performance differ from those of the PIN device. For example the sensitivity curve under green light shows a nonlinear curve, as shown in Figure 3(Blue line), sensitivity is higher in low-illumination environments than in high-illumination ones. According to our experience in developing high-resolution AMOLED and report from other authors [10], charge crosstalk occurs when the distance between pixels is small enough. Although OLED and OPD have separate electrode, they have HIL / HTL/ ETL /EIL/ Cathode in common. Figure 4 illustrates the mechanism of the crosstalk between OLED and OPD devices. Under forward bias, holes and electrons are injected into the light-emitting layer of the OLED device from the anode and cathode. Exciting separate in the active layer of the OPD to produce holes and electrons, which move to the anode and cathode of the OPD respectively under reverse bias. Therefore, the voltage of the OLED anode is higher than that of the OPD anode, and the holes move along the voltage direction and are collected by the anode of the OPD.

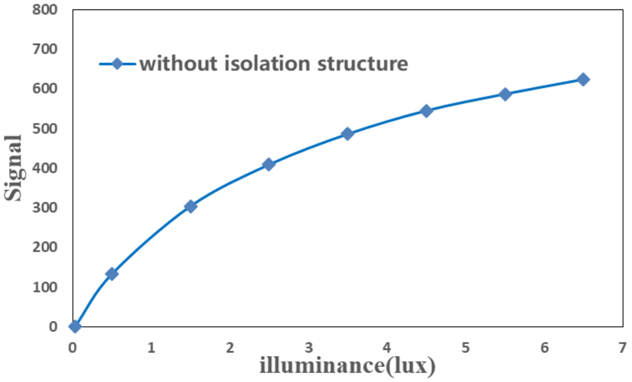

Figure 3. Sensitivity curves without isolation structure.

In order to solve this problem, a physical separator structure is necessary, and the reverse-tapered separator formed by negative photoresist is usually used, but this structure needs to increase the number of photolithography process and the reliability of the photoresist material is also relatively high.

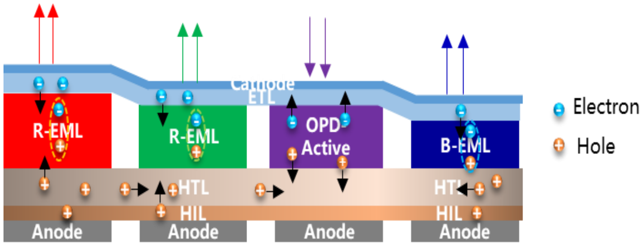

Figure 4. Stacked structure of OLED and OPD pixels, and electrical crosstalk pathway between them.

The new undercut structure was fabricated by sputtering a sacrificial layer on top of the PDL, followed by creating a normal spacer layer using photolithography process. The shape of the spacer layer was modified from square to C shape and O shape, as depicted in Figure 5 a). Subsequently, the exposed sacrificial layer underwent wet etch process for etching, as illustrated in Figure 5(b), outlining the process flow of our novel isolation structure. Upon completion of evaporation and encapsulation processes, FIB test was conducted. The cross-section view of the isolation structure is presented in Figure 6.

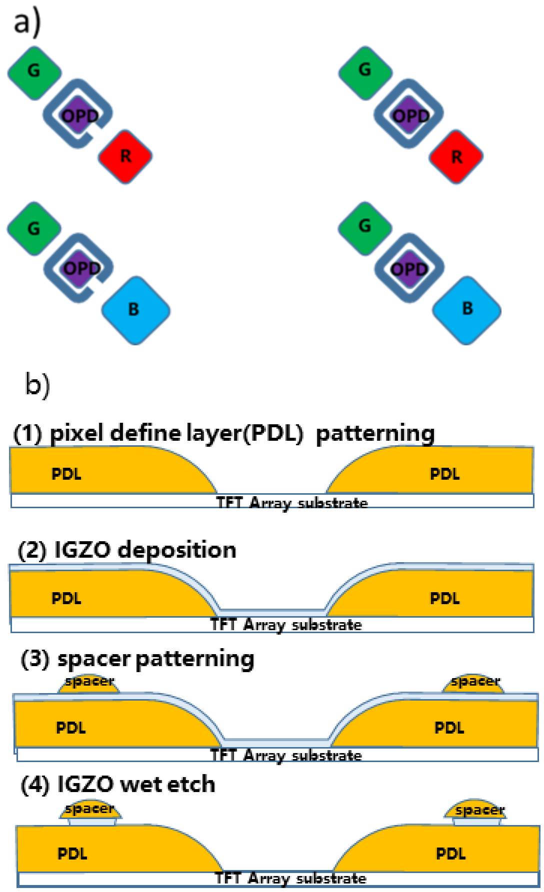

Figure 5. Pixel structure of in-cell fingerprint sensing display with new isolation structure. (a)Top view image, (b) Cross-sectional view image of isolation structure at each process step.

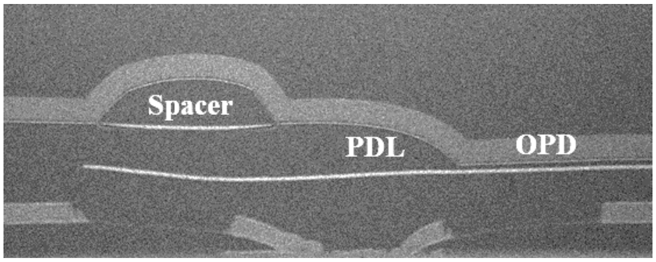

Figure 6. SEM image of the new isolation structure.

2.3.Prototype

The AMOLED display screen was tested with the integration of OPD devices using the new isolation structure. Figure 7 illustrates the panel in its display state. The parameters about the screen are summarized in Table 1.

The sensitivity curve with and without the new isolation structure are compared in Figure 8, the sensitivity cure of the panel with the new isolation structure is very linear. This means that the charge crosstalk between the OLED and OPD is cut off.

Based on 1000 samplings, the FAR and FRR of the panel with an isolation structure reach as low as 0.002% and 0.3%, respectively, meeting security requirements of the fingerprint sensor. When the multi-finger recognition mode is used, the security level can be further improved.

Figure7. Prototype of high-resolution in-cell fingerprint sensing display.

Table 1. Specifications of the prototype.

		Display	Sensor
		OLED	OPD
Panel Size		6.2inch	
Pixels		960*2000	
Substrate		Polyimide	
Process		LTPO	
Measures against Crosstalk		New isolation structure	
Pixel Density		360 ppi	360 dpi
Gray level		8 bit	12 bit
Circuit	Pixel	7T1C	3T
	Gate	GIP	
FAR/FRR *1,000 Samplings		-	0.002%/ 0.3%

Figure 9 demonstrates the fingerprint image captured by the panel, comparing it with and without the isolation structure. With this structure, sensor signal (the code difference between ridge and valley) is significantly higher compared to without it. A higher sensor signal implies a lower False Acceptance Rate (FAR) and False Rejection Rate (FRR).

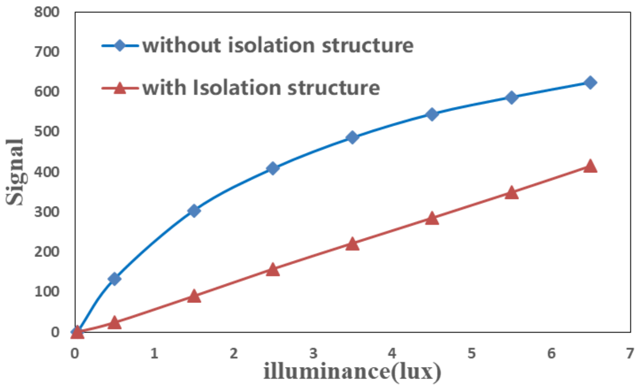

Figure 8. Sensitivity curves with and without isolation structure.

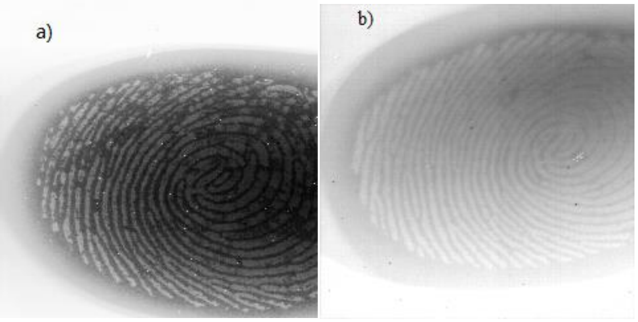

Figure 9. Fingerprint images captured by the prototype (a) with and (b) without new isolation structure.

3. Conclusion

We demonstrated a 6.2-inch 360ppi prototype of high-resolution in-cell fingerprint sensing AMOLED. For the prototype an isolation structure was newly developed without increasing the number of photolithography process, for suppressing electrical crosstalk between OLED and OPD pixels that was one of the biggest issues for high-resolution. Highly efficient broadband OPD with EQE spectrum covering green (25%) and red (45%) light emitted from the OLED was also developed for the prototype allowing biometrics and healthcare monitoring. We verified experimentally that the new isolation structure and the broadband OPD enabled the prototype to capture 360dpi fingerprint image, meeting a security requirement of 300dpi in mobile devices, and to achieve FAR and FRR as low as 0.002% and 0.3%, respectively while the display performance remained excellent.

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