Large-Area Optical Fingerprint Sensors for Next Generation Smartphones

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Keywords: Large area flexible fingerprint sensor, 4-fingers recognition, flexible collimator

ABSTRACT

Printing-based organic photodiodes have demonstrated cost effective process and compatibility with Flat Panel industry equipment making large area optical fingerprint sensors viable for volume production. Large area thin film-based optical collimator enables simple behind display integration. Advantages of this technology are high security level for fingerprint, enhanced ease of use and slim module.

1 INTRODUCTION

The usage of mobile phone in today's life has increased the needs of accurate, reliable and fast security methods to ensure correct identification of the device owner. Nowadays mobile phone applications allow to access bank account, transfer money, control cars and even operate home alarm system; it is a key component to manage IOT objects such as household appliances. Therefore, adapted biometric system embedded in smartphones is essential to prevent any impostor usage and protect the data information of the owner. When we speak about biometric there are different type of sensors (see description below) which have different level of security, practicality and cost.

Face recognition: 2D or 3D	Fingerprint recognition	Iris recognition	Voice recognition

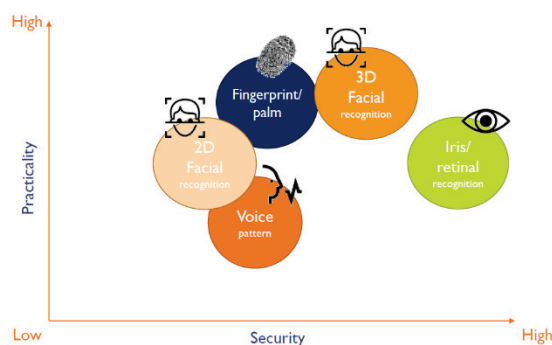**Table 1 Type of sensors**

Fig. 1 Type of recognition: practically vs security
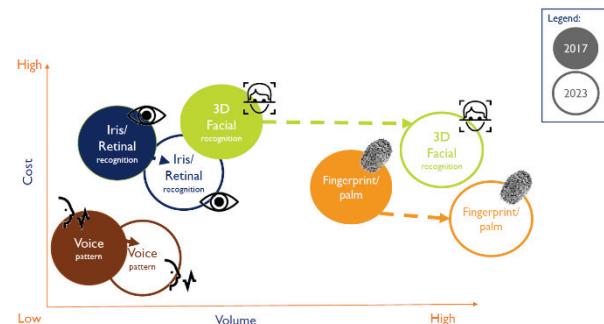

Fig. 2 Type of recognition: cost vs volume
(Courtesy of Yole)

Based on those factors two methods have been preferred by the mobile phone makers: 3D facial and Fingerprint recognition. Indeed, enrolment time and analysis time are key parameters for a smooth use and processing is light especially for the fingerprint solution compared to all other solutions.

Algorithm security level is defined by the relation of the number of rejected attempts of the right user (FRR) and the number of accepted attempts of the wrong user (FAR).
Apple allowed only with those security level

$$\text{Face ID: } FAR = \frac{1}{1,000,000} \text{ for FRR} \leq 2\%$$
$$\text{Touch ID: } FAR = \frac{1}{500,000} \text{ for FRR} \leq 2\%$$

Most fingerprint sensors (optical and capacitive, CMOS based) are usually around
$$FAR = \frac{1}{50,000} \text{ for FRR} \leq 2\%.$$

We have been developing an optical fingerprint biometry solution based on our proprietary Organic PhotoDiode (OPD) technology which is able to be integrated under a smartphone display and which can be covering the entire dimension of the display. This gives the ability to capture 4 fingerprints which considerably increases the security level of identification compare to the current optical or capacitive sensors used in current smartphone on the market.
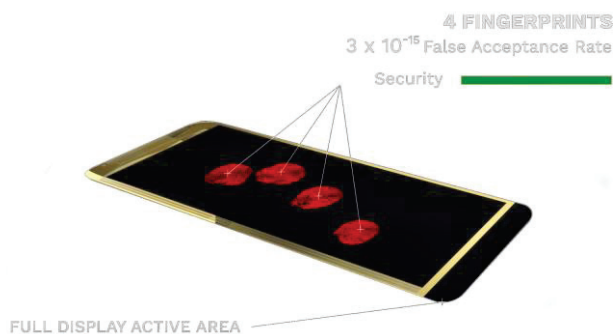
Fig. 3 Full display fingers recognition

2 ORGANIC PHOTODIODE

ISORG has been developing and industrializing Organic Photodiode (OPD) technology to address different markets such as medical applications (x-ray imager, oximetry) or object detection (inventory control). This ground-breaking technology on image sensor based on organic semiconductor materials

The following schematic represents the cross-section of the OPD construction.
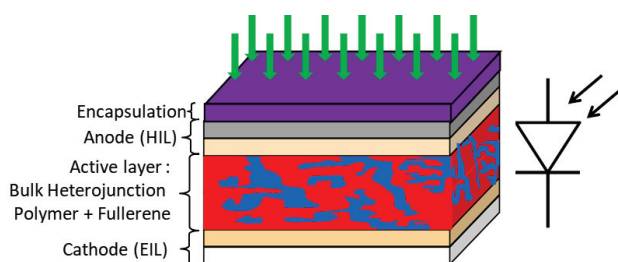

Fig. 4 Organic Photodiode construction

The OPD consists of successive layers deposited:
- a Cathode (or EIL: Electron Injection Layer) which can be a metal oxide (i.e. ITO, ZnO, TiO2, TiN)
- an active layer (or a bulk Heterojunction) containing a π conjugated polymer and a fullerene blended instead of stacked on top of each other
- an anode (HIL: Hole Injection Layer) which can be a doped polymer or metal oxide (i.e. WO3, MoO3)
- an encapsulation to avoid air and moisture to penetrate the layer and degrade the active layer.

The key to obtain good photodiode performance is to ensure the level of energy of each layer is optimised for good charge transfer as describes on the schematic below.
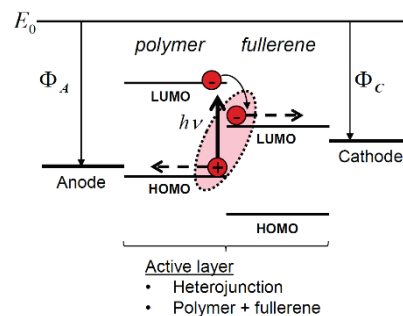

Fig. 5 OPD charge transfer

All the OPD layers are deposited by wet coating, which needs lower capex compare to conventional Si factory as there is no need for vacuum deposition system. The low curing temperature (maximum 120°C) makes the OPD process compatible with plastic substrate such as PET.

In term of performance, OPD devices have demonstrated high linearity, high dynamic range, low dark currents and good temperature stability of dark current; those performances make OPD very competitive compared to conventional a-Si photodiode.

The spectral sensitivity can be adjusted depending on the application by adapting the OPD materials.

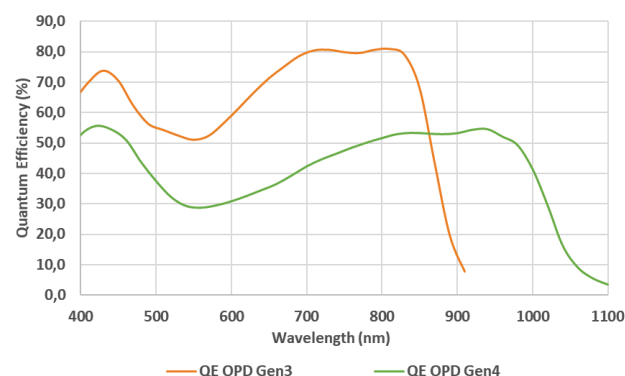An example of External Quantum Efficiency is shown below for reference:

Fig. 6 EQE vs wavelength

In this case the OPD Gen3 material gives good sensitivity in visible wavelengths between 400nm and 800nm which makes it suitable for fingerprint sensors whereas OPD Gen4 gives optimum sensitivity in NIR light: @940nm QE_{OPD}=54%; this is material is more suitable for face recognition.

3 HIGH RESOLUTION IMAGER FOR FINGERPRINT MATCHING

In order to obtain an imager, we have integrated OPD layers on top of TFT backplane. This is necessary to produce a high-resolution sensor for fingerprint imaging. The FBI specification require a sensor of at least 500

pixel per inch (this corresponds to 50.8µm pixel pitch) to ensure good fingerprint matching.

OPD layers have been coated onto a pixelated TFT array without need for fine patterning as shown in the schematic below.
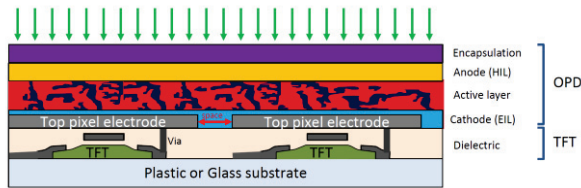

Fig. 7 Construction of organic image sensor

It has been proven that OPD is compatible with all existing TFT backplane technologies available on the market (a-Si, IGZO, LTPS or OTFT). OPD imagers have also been produced using backplane with polyimide-based substrate to ensure that optimized mechanical integration in smartphone can be achieved. Such demonstrator is shown below:
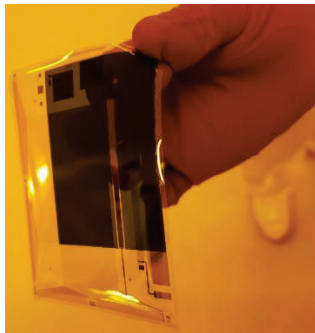

Fig. 8 Flexible PI-based image sensor

4 OPTICAL FILTER

The constrains of integrating an image sensor behind conventional OLED display are the low transmittance of the full stack and the distance between the object (the fingerprint) and the sensor.

The optical collimator needs to allow perpendicular visible light transmission, to limit the angular transmission (this to allow only the light reflected from the finger to reach the sensor) and with limited thickness (under 100µm) to ensure optimized integration within smartphone.

Therefore, an angular filter is needed to block the oblique rays and collect only the photon from the normal ray. At a given finger-sensor distance, there are 2 main specifications for angular filter both can be characterized with a bar target: the maximum resolution (viewing angle θ) and the contrast on each spatial frequency. The figure below describes the calculation of the viewing angle.
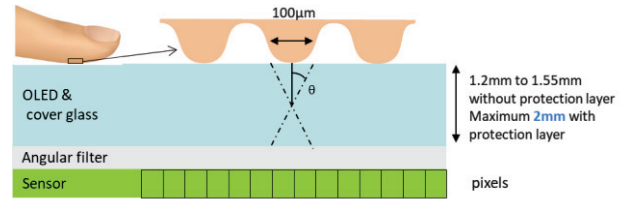
$$\tan(\theta_{2mm}) = \frac{100\ [\mu m]}{2000\ [\mu m]} \rightarrow \theta_{2mm} = \pm 2.8°$$

Fig. 9 Calculation of viewing angle

It is crucial that the transmittance (Tr) is high as the OLED display transmittance is only 2% at 530nm as shown on the next figure.

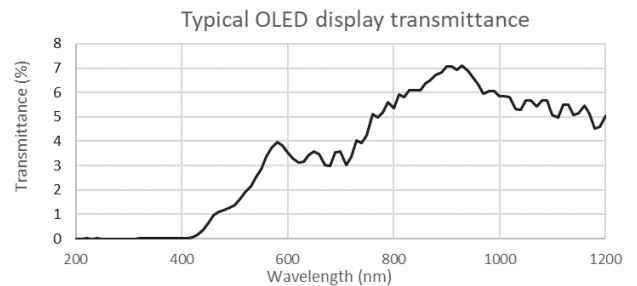**Fig. 10 OLED display transmittance**

This demonstrates that the collimator needs to have a viewing angle $\theta < \pm 2.8°$ and transmittance > 40% (this is not available on the market).

We developed our proprietary Collimator with $\theta < \pm 2.5°$ and Tr = 45% for a thickness < 50µm.

The collimator filter is plastic-based and can be mass produced even for full screen solution which make it compatible with most of OLED displays in the market.

The Modulation Transfer Function (or MTF) is used to characterize the performance of an image sensor with 1 being the perfect contrast and 0 being no contrast. This is measured by imaging a series of transparent and non-transparent line pairs with different line spacings; the slanted-edge-method is used to determine the MTF as a function of spatial frequency in line pairs per mm (lp/mm). The figure 11 shows the MTF performance of fingerprint module imager behind OLED display with and without angular filter; this emphasizes the needs of such layer has no fingerprint could be imaged without integrating such collimator.
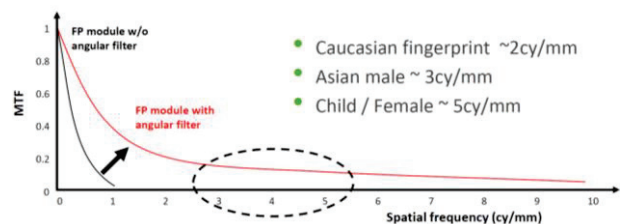

Fig. 11 MTF vs spatial frequency

5 ASSEMBLY IN MOBILE PHONE AND RESULTS

Our construction has been evaluated by assembling our sensor and optical collimator to a commercially available glass-based 6" OLED smartphone display of 1.5mm thick. Figure 12 shows the complete cross-section including the IR filter necessary to remove impact induced by sun light in outdoor condition.
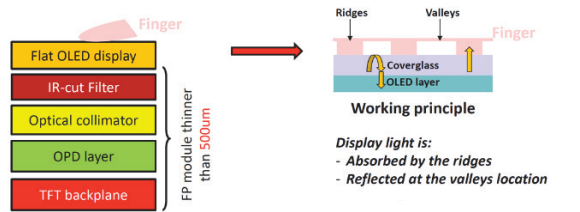

Fig. 12 Cross-section of the fingerprint module

It is important to highlight that from TFT backplane to the IR cut filter the thickness of the module is below 300µm with PI-based TFT backplane and below 500µm with the glass-based ones.

Fig. 13 Large area fingerprint module

Below is a picture of the complete module attached to a mobile phone display.

Fig. 14 Picture of the fingerprint module

A matching algorithm has been used to evaluate the performance of real fingerprint.
Fingerprint were captured through this complete module:

- Organic image sensor - ISORG proprietary - Manufacturing line ready
- Optical filter – ISORG proprietary – Under industrialization
- IR-cut filter – ISORG partner – first samples from factory qualified
- Read-out IC – specifications defined by ISORG – Ready in November 2019
- Matching algorithm – ISORG partner – strong experience in embedded system
- AMOLED display of 1.5mm thick

The result is shown in the figure 15, comparing (a) a raw image and (b) an image after image processing.

Fig. 15 (a) Raw image & (b) after image processing

6 CONCLUSION

A complete solution for large area fingerprint image sensor has been produced by ISORG; such device is meant to be integrated under a smartphone OLED display to allow the function of 4 fingerprint biometry system to increase the level of access security in smartphone.