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Keywords:

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Printed organic photodetector arrays and their use in palmprint scanners

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ABSTRACT

Using flat-panel compatible processes we realized 6x8 cm, 200-ppi active-matrix imagers with solution-processed, ultrathin organic photodiodes and demonstrate its performance in a biometric palmprint detector.

Keywords: Large-area photodetector arrays; printed Organic photodetectors. Biometric authentication

1. OBJECTIVE AND BACKGROUND

Most high-end smartphone and tablet displays feature some kind of biometric identification, mostly in the form of fingerprint sensors. With identity protection becoming an ever more serious device feature, cost-effective integration of user identification components becomes crucial. Flat panel display (FPD) technology platform in most fabs offers a possibility of fabricating not only display components, but also image sensors, when the emitting active layer is substituted by an absorbing one – and often with much more relaxed circuit specifications (e.g. for large area x-ray detectors). A similar technology can be used for manufacturing fingerprint and palm sensors, provided a sufficiently high resolution is granted – at least 200 ppi for basic user identification and 500 ppi for FBI compliant standard. In this work we discuss the fabrication and characterization of an organic photodetector on an amorphous IGZO thin-film transistor backplane and demonstrate its use as optical scanners, more precisely a 6x8 cm, 200-ppi palmprint scanner.

Organic photodetectors (OPDs) have recently attracted a lot of attention for large-area light detection applications. They combine effective light absorption in the region of the spectrum from ultraviolet to near-infrared with good photogeneration yield, sensitivity and response time. As organic semiconductor materials have low dielectric constants and rather high exciton binding energies (0.1-1.4 eV), OPDs are preferably based on the concept of

bulk heterojunction (BHJ) structure. In a typical BHJ, electron donating semiconducting polymers and electron accepting fullerene derivatives are coated from a common solution. Upon evaporation of the solvent, phase separation at micro- and nanometer length scale occurs, and junctions with a large interface area are formed, *i.e.* the bulk heterojunction. Photo-generated electron-hole pairs are effectively formed at this junction, leading to a photocurrent. The materials can be processed from solution over large area, making them attractive for photovoltaics but also photo-imaging applications where area is key. Furthermore, their low processing temperature also allows the use of non-glass substrates such as flexible polyester films [1].

Fig. 1. Cross section of the photodetector array, consisting of a IGZO TFT backplane and a solution processed bulk heterojunction photodetector (D denotes the p-type polymer donor. A denotes the fullerene acceptor material.)

Fig. 2. Photograph of imagers of different sizes on glass. The active area with slot die coated OPD is the brown rectangle. All imagers are made on 320x352mm substrates.

2. RESULTS AND DISCUSSION

2.1 Detector fabrication

The photoactive layer is a 300-nm thick blend of a p-type polymer and n-type small molecule, [6,6]-phenyl C61 butyric acid methyl ester (PCBM). The polymer is a donor-acceptor copolymer with a band gap of ~1.9 eV (HOMO ~5.4 eV, LUMO ~3.5 eV). The blend is slot-die coated, and encapsulated with a transparent anode and a thin film moisture barrier.

We combined our organic photodetector with a low temperature Indium-Gallium-Zinc Oxide (IGZO) thin-film transistor backplane. The TFT technology was previously used to realize mechanically flexible OLED displays [2]. IGZO was used as active channel material in a so-called etch stop layer (ESL) device architecture. The linear mobility of these transistors is ~12 cm²/Vs and the off current is < 10⁻¹² A. The high mobility and low leakage current aid in improving the sensitivity and robustness of the final detector array.

Not shown in the cross section in Figure 1 are the thin-film moisture barriers on top of the OPD stack and below the oxide TFT backplane. The thin-film encapsulation technology was originally developed for encapsulation of OLEDs. The technology performance of the thin-film encapsulation is described in more detail elsewhere [3]. The moisture barrier consists of a multilayer stack of two PECVD SiN films, the actual thin-film moisture barriers decoupled by organic planarization layer(s). The final quality of the full barrier stack is dependent on the intrinsic WVTR of the inorganic SiN, the number of pinholes in the inorganic SiN together with rate of lateral diffusion of water and oxygen within the interlayer material. The final temperature stability of the complete stack is determined by the temperature stability of the organic interlayers. The SiN/OCP/SiN barrier stack has a water vapor transmission rate (WVTR) of < 10⁻⁶ g/m²/day. When applied on top of our OPD pixels, we estimate the lifetime of the detector to be at least 5 years.

For top encapsulation, a maximum process temperature is

imposed by the stability of OLED/OPD materials, commonly ca. 100°C, but it is important that it is optically transparent. For flexible, monolithically integrated thin-film barriers under the oxide TFT backplane, the required barrier temperature stability is determined by the maximum processing temperature of the oxide TFT.

Figure 2 shows finished photodetector arrays of various sizes, all fabricated on 320x352mm substrate size with the described technology. All building blocks described above are monolithically integrated using deposition and patterning equipment available in today's display fabs. We have previously shown the technology can be applied on polyimide films as well, but polyimide was not used in this work.

2.2 Organic photodetector characterization

To quantify the OPD frontplane, discrete test devices were measured. Typically, our OPDs have a leakage current density of 0.5-1 pA/mm² at -2 V. This value is comparable to dark current densities of a-Si p-i-n photodiode devices (1 pA/mm² [4,5]). It represents one of the lowest reported dark current densities for BHJ based OPDs, notably with ~300 nm thick active layer and without any specific blocking layer.

Fig. 3. EQE (A) and spectral response (B) of discrete OPD devices.

Figure 3 shows the external quantum efficiency, EQE, and spectral responsivity, SR, as a function of wavelength in the range of 380-950 nm. The optical absorption onset of ~700 nm is determined by the polymer. The values obtained are given in Table 1.

Table 1: Optical performance OPD		
Wavelength (nm)	EQE (%)	SR (A/W)
620 (red)	25	0.12
530 (green)	45	0.19
460 (blue)	40	0.16

Detectivities D^* (in Jones, where Jones = cmHz^{1/2}/W) were calculated using measured values of photocurrent, dark current, and incident light intensity using

$$D^* = SR / (2qJ_d)^{1/2} \quad \text{Eq. 1.}$$

where q is the absolute value of electron charge (1.6×10⁻¹⁹ C) and J_d is the dark current density. The use of eq. 1 implies that the dark current is the major

contribution to the noise that limits D^* . At -2 V bias, the calculated maximum detectivity is $D^* = 8 \times 10^{13}$ Jones (at ~530 nm). This is amongst the highest values reported so far for OPDs.

2.3 Photodetector array characterization

Figure 4 shows a photograph of an optical image captured using a 640x480 pixels, 126x126 μm^2 array. Each pixel of 126x126 μm^2 consists of an IGZO TFT (channel length and width of 3 and 10 μm , respectively) and an organic photodiode on top. No storage capacitance apart from the intrinsic diode capacitance of about 2 pF is built into the pixel. The effective pixel area is determined by the OPD bottom pixel electrode, as the top electrode is common to all pixels.

Fig. 4. Captured image of our 480x640, 200-ppi imager in reflection mode.

The image in Fig. 4 is captured in reflection mode, *i.e.*, using backside illumination. A graphic print is placed upside down on the imager. Light passes through the imager, and is then reflected by the graphic print. The reflected light is recorded by the detector. Thus, the optical properties of the different layers in the whole imager stack are very important. The top encapsulation stack including a hard coat is only 40 μm thick and enables maximum spatial resolution.

To quantify the spatial resolution of our OPDs we measured the Modulation Transfer Function (MTF), a standard figure of merit for the performance of

optical-imaging systems. The MTF was obtained using the slanted-edge method (ISO 12233 Standard) [6]. The resulting MTF of our detector is plotted versus spatial frequency in Figure 5, showing an MTF50 of 6.3 lp/mm and an MTF10 of 11.5 lp/mm.

Fig. 5. Modulation Transfer Function (MTF) of the 200-ppi imager.

The high MTF numbers imply that there is no substantial optical crosstalk between neighboring pixels, despite the fact that the solution-processed organic bulk heterojunction photodetectors is coated directly on the active matrix backplane and is unpatterned, both the active OPD layer and the transparent top electrode. Hence, there is no need to fine-pattern these layers. So, a number of costly vacuum deposition and lithography steps are eliminated compared to the case of conventional inorganic (amorphous silicon) detectors. This greatly simplifies the manufacturing process, opening the door to lower-cost compared to today's a-Si p-i-n diodes.

2.4. Palmprint scanner prototype

Because passwords and personal identification numbers can be guessed or forgotten, biometric authentication technology is now increasingly of interest and can distinguish the registered legitimate user from imposters. Among the various biometric characteristics that can be used to recognize a person, the human hand is the oldest, and fingerprint scans are perhaps the most successful form of biometric technology. Typically, an active area of 2-3 cm^2 is scanned in high resolution. Scanning a larger area would allow measurements of other features of the hand, such as hand geometry, palm print, knuckle print (and potentially even vein patterns). These hand properties are stable for adult persons. Each person has a unique set of patterns and features [7].

Figure 6 shows a scan of a human hand, together with a schematic of a human hand. Clearly visible are the alternating creases and troughs on the palmar structure of the hand. The inner part of the hand shows less details. Its shape, however, is formed by the so-called heart line, head line and life line of the hand. All together, the scan contains unique biological information.

Fig. 6. Scan of a human hand, measured in reflection mode.

3. IMPACT

We successfully obtained a large-area (6x8 cm) imager with 200 ppi resolution using an amorphous IGZO TFT backplane and a solution processed (slot die coated) organic photodetector layer. All process steps are known to the flat panel display industry, enabling fast implementation in current fabs.

We believe that the presented technology enables new markets. Previously we reported a 120x160, 200-ppi X-ray detectors that meet medical requirements [1]. Here, we demonstrate a prototype of a palm print scanner. Palmprint is seen as a more secure biometric than fingerprint scanners. Today's palmprint scanners are camera-and-lens based, making the whole system bulky. Our technology has a slim form factor which is beneficial for seamless integration on the surface of doors, security gates etc.

4. OUTLOOK

Further work is in progress to (1) scale the backplane technology to higher resolution (500 ppi) and reduce the thickness of the thin-film encapsulation on top of the detector, with one aim being an optical fingerprint scanner that is integrated within the whole display area in a

(full-face) mobile phone, (2) increase the optical transparency of the top electrode, as it will increase the detector sensitivity, and (3) increase the wavelength sensitivity to the near-infrared so we can include vein detection and also pulse oximetry.

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