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An integrated organic passive pixel sensor

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ABSTRACT

We demonstrate an imaging passive pixel sensor circuit consisting of a bottom-gate, top-contact pentacene organic thin-film transistor (OTFT) integrated with a top-illuminated, inverted subphthalocyanine/C_{60} organic photodetector (OPD). The vacuum-deposited OTFT utilizes parylene as the gate insulator, achieving a drain current ON/OFF ratio of 10^5. The transistor hole mobility is 0.09 ± 0.02 cm^2/V s. The inverted OPD has a dark current of 20 pA at a reverse bias of 1.5 V. By integrating the two components, a 12-bit dynamic range passive pixel sensor is achieved, with an OFF current of 31 ± 5 pA and a pixel readout time of 0.4 ± 0.05 ms, limited by the discharge time of the OTFT channel. The integrated pixel has potential for use in large-scale focal plane array imagers.

Organic semiconductors provide a promising pathway to inexpensive and flexible optoelectronic devices. Organic photodetectors (OPDs) have attracted particular interest for use in optical imagers due to their light-weight, broad spectral detectivity and compatibility with flexible or conformal substrates. For example, a passive-matrix OPD imaging array has been demonstrated on a hemispherical substrate [1,2]. However, such an OPD array is limited because the dark current is a function of the size of the array, scaling linearly with the number of rows or columns. Consequently, transistors must be used as switching elements to reduce the total leakage current. An organic passive pixel sensor was recently reported [3] consisting of a bottom-contact (BC) pentacene organic thin-film transistor (OTFT) and a bottom-illuminated subphthalocyanine (SubPc)/C_{60} OPD. This integrated pixel achieved an 8-bit dynamic range, limited mainly by the low ON-drain current and hole mobility ($\mu = 0.0025$ cm^2/V s) of the BC-OTFT. On the other hand, it has been shown that top-contact (TC) OTFTs have superior performance compared with BC-OTFTs owing to improved carrier injection and reduced contact resistance [4–6]. However, the integration of bottom-illuminated OPDs and TC-OTFTs often involves complicated processing, such as photolithography, inkjet printing [7], laser drilling or lamination [8]. Therefore, it is of interest to modify the pixel to include TC-OTFTs while retaining the simple fabrication process of bottom-contact devices.

In this work, a small-molecule organic passive pixel sensor consisting of an inverted SubPc/C_{60} OPD [9] and a bottom-gate, top-contact pentacene OTFT is demonstrated. By using a transparent, sputter-deposited indium-tin-oxide (ITO) anode, the top-illuminated OPD can be integrated with a TC-OTFT via thermal evaporation and shadow-mask patterning. The OTFT achieves a drain current ON/OFF ratio of 10^5 at a drain-source voltage, $V_{DS} = -4$ V, and $\mu = 0.09 \pm 0.02$ cm^2/V s, resulting in a 12-bit dynamic range for the circuit.

The integrated pixels in Fig. 1 were fabricated on high thermal conductivity sapphire substrates to prevent heating during ITO sputtering. Prior to thermal deposition in a vacuum chamber with a base pressure $<4 \times 10^{-7}$ torr, the substrates were cleaned by ultrasonication in acetone followed by immersion in boiling isopropanol. The OTFT gate and OPD cathode consisting of 500 Å-thick Al were simultaneously thermally evaporated. Next, the OPD

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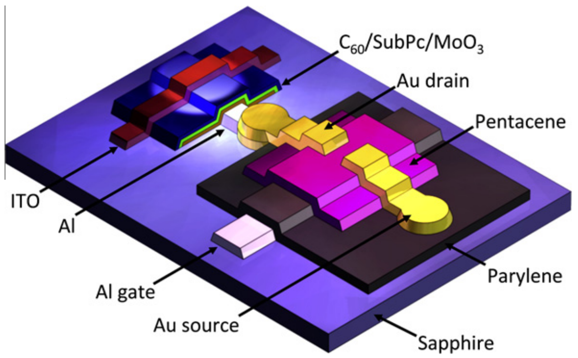

Fig. 1. Schematic diagram of the integrated passive pixel sensor consisting of a top-illuminated organic photodetector with an indium-tin-oxide (ITO) top contact in series with a pentacene organic thin film transistor. Layer compositions are indicated.

structure (500 Å C_{60}/90 Å SubPc/300 Å MoO_3) was thermally evaporated at a rate of 1 Å/s. A 500 Å-thick ITO anode was sputtered at a power of 20 W (rate = 0.1 Å/s) using an Argon plasma at a pressure of 2 mTorr. In Fig. 2c, inset, is a molecular structural formula of the donor, SubPc. After depositing the OPD layers, the samples were loaded into a parylene deposition system where 0.70 g of parylene C (dielectric constant, $\varepsilon_r = 3.15$) was coated onto the OTFT gate contact, forming a 2700 Å-thick insulator. Finally, the 500 Å-thick pentacene channel and the 400 Å-thick Au source and drain contacts were sequentially evaporated at the rates of 0.5 and 0.3 Å/s, respectively, to complete the OTFT. All features were defined using shadow masks attached in a high-purity N_2 ambient (<1 ppm H_2O and O_2), with the exception of a brief exposure to air before and after parylene deposition. The OPD dimensions (100 μm × 800 μm) and OTFT channel width-to-length ratio (W/L = 500 μm/30 μm) were set by shadow-masking during ITO and Au deposition, respectively.

Device performance was measured in air using a semiconductor parameter analyzer. Incident light for measuring the circuit dynamic range (*DR*) was provided by a mercury lamp with a spectral bandpass filter at a center wavelength of $\lambda = 580 \pm 2$ nm, matching a Hg emission peak as well as the absorption maximum of SubPc. The illumination intensity was varied using neutral density filters and measured using a calibrated Si photodetector. External quantum efficiency (*EQE*) was measured using a lock-in amplifier and monochromated light from a tungsten-halogen lamp chopped at ~200 Hz. Voltage was applied to the detector with a current amplifier at the input to the lock-in for biased *EQE* measurement. The circuit

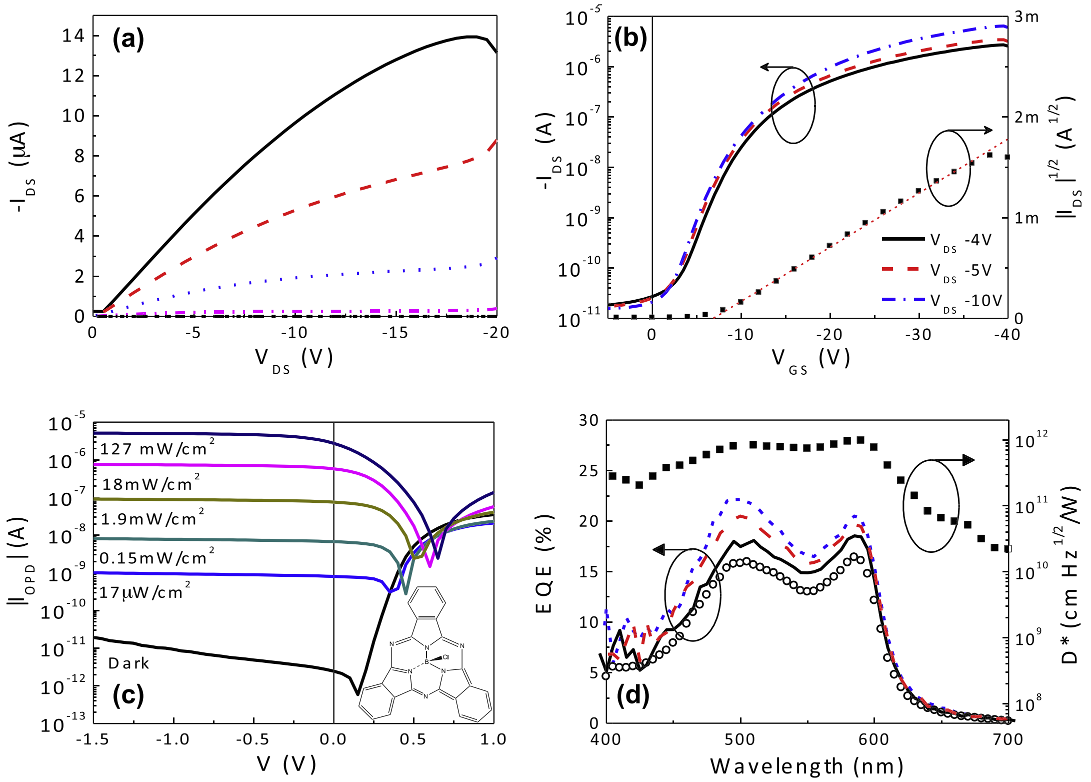

Fig. 2. Performance of discrete components comprising the integrated passive pixel sensor. (a) Output characteristics of the pentacene OTFT for $V_{GS} = 0$ V (short-dashed line), −10 V (dash-dotted line), −20 V (dotted line), −30 V (dashed line), and −40 V (solid line). (b) Transfer characteristics of drain current (I_{DS}) vs. gate-source voltage (V_{GS}) of the organic thin film transistor (OTFT) at a drain-source voltage of $V_{DS} = -4$ V (solid line), −5 V (dashed line), and −10 V (dash-dotted line). The square-root of the drain-source current (squares) and the fit (short-dashed line) are shown on the right-hand axis. (c) Current–voltage characteristics (I_{OPD}–V) of the organic photodetector (OPD) in the dark and under illumination at several different intensities. The incident wavelength is $\lambda = 580 \pm 2$ nm. *Inset*: Molecular structural formula of SubPc. (d) External quantum efficiency (*EQE*) of the integrated SubPc/C_{60} OPD under 0 V bias (solid line), −1 V (dashed line), and −2 V reverse bias (short-dashed line), compared to that of a control inverted OPD (open circles). The specific detectivity (D^*) at −1.5 V is shown on the right-hand axis (squares).