Sheet Image Scanner with Organic Transistor Integrated Circuits

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ABSTRACT

A sheet image scanner has been fabricated by integrating high-quality organic transistors with organic photodetectors. Because the sheet scanner requires no mechanical components, it is mechanically flexible, light to transport, shock-resistant and potentially inexpensive to manufacture.

INTRODUCTION

Organic field-effect transistors (FETs) have attracted considerable attention because organic FETs are mechanical flexible, lightweight, shock-resistant, and potentially ultra-low in cost. Those attributes are complementary to silicon-based conventional electronics, which is high-performance, but expensive. Recent studies on organic FETs are motivated by two major applications; flexible displays such as paper-like displays or e-paper and printable wireless tags.

We have recently demonstrated unique applications of organic FETs: the flexible, large-area, pressure sensors. In the new sheet devices, organic FET active matrixes (AM) are used to read out pressure data over wide area.

In another development, we have successfully fabricated a flexible, large-area, lightweight sheet image scanner based on organic semiconductors. In this paper, we report recent progress and future prospect of sheet image scanners and other flexible, large-area sensors and actuators with organic transistors.

MANUFACTURING PROCESS

The sheet scanner is manufactured on transparent poly(ethylene naphthalate) (PEN) films with integrating organic field-effect transistors and organic photodiodes. As shown in Fig. 1, the integrated device is mechanically flexible, very thin, and lightweight. The device structure is schematically illustrated in Fig. 2 along with chemical structure of each layer. Organic FET matrix and photodiode matrix have been manufactured separately on different plastic films and then laminated with each other with silver paste patterned by a microdispenser or anisotropic conductive films.

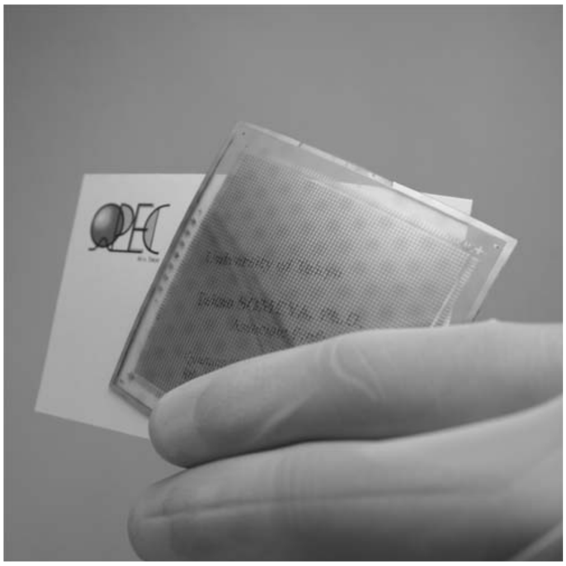

Fig. 1: An image of the manufactured large-area, flexible, and lightweight *sheet image scanner* consisting of organic transistors and organic photodiodes, which is placed on a business card under ambient light for capturing image.

First, a 72 × 72 (~5,184) matrix of pentacene FETs with top contact geometry is manufactured with an ultrafine shadow mask (Athene Co. Ltd., Japan). The surface of the base film, a 125 μm thick PEN, is coated with a 150-nm-thick gold layer with a 5-nm-thick chromium adhesion layer in a vacuum evaporator with shadow masks to form a gate electrode. The polyimide precursors (Kemitite CT4112, Kyocera Chemical) are then spin-coated and cured at 180°C to form 630-nm-thick gate dielectric layers. A 50-nm-thick pentacene is deposited to form a channel layer. A 60-nm-thick gold layer is evaporated through shadow masks to form the source and drain electrodes of the transistors. Figure 3 (a) shows the magnified image of four transistors before integrating with organic diodes. The channel length L and width W are 18 μm and 400 μm, respectively. The periodicity is 700 μm, which corresponds to a resolution of 36 dpi.

The photodiodes are separately manufactured on the different films. The base film of photodiodes is a PEN film coated with ITO. The surface of ITO

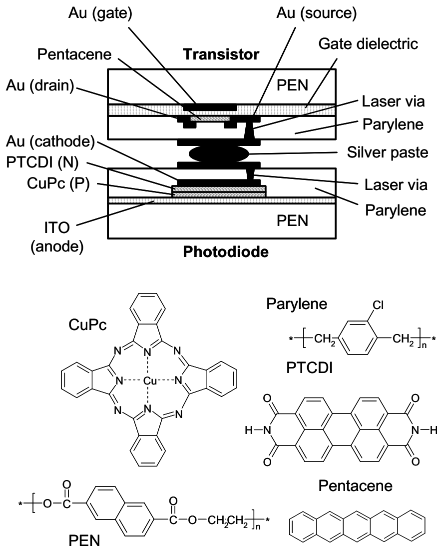

Fig. 2: The cross-sectional view of the device structure is schematically shown. The chemical structure of each layer is also shown.

coated films is cleaned with an organic solvent and, subsequently, a UV-ozone cleaner. A 30-nm-thick p-type semiconductor of copper phthalocyanine (CuPc) and a 50-nm-thick n-type semiconductor of 3,4,9,10-perylene-tetracarboxylic-diimide (PTCDI) are deposited in a vacuum sublimation system. A 150-nm-thick gold layer was deposited as cathode electrodes. The optical transparency of the 150-nm-thick gold layer is small enough and this layer works as a light-shielding layer. We choose Au as the cathode electrode to manufacture the final structures because Au electrodes enable us to obtain a reliable interconnection by the laser via process. The size of cathode electrodes and the periodicity of photodiodes used to integrate with organic transistors are 450 × 450 μm^2 and 700 × 700 μm^2, respectively.

Both films with organic FETs and photodiodes are transferred to the vacuum chamber without exposing them to air after the manufacturing process; further, they are uniformly coated by a 2-μm-thick poly-monochloro-para-xylylene (parylene) passivation layer. Parylene spots on electrodes are removed by a CO_2 laser drilling machine for electronic interconnections.

Please note in Fig. 2 that organic semiconductor layers of transistors are sandwiched between two electrodes: the gate electrode and the contact pad to integrated with sensors. Although organic transistors are photosensitive, the light-shielding layers cover the channel layers in the present design. As a result, effects of light on transistors are negligibly small.

Further, these films are laminated with each

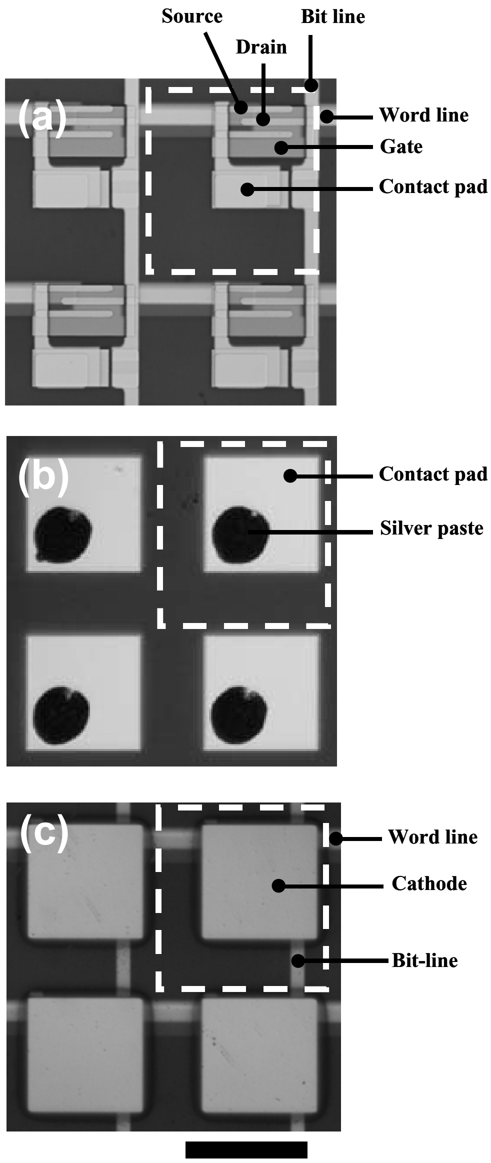

Fig. 3: (a) A magnified image of four transistors before integrating with organic diodes. The channel length L and width W are 18 μm and 400 μm, respectively. (b) A magnified image of four contact pads with silver paste islands before laminating organic transistor films and organic diode films. (c) A magnified image of four sensor cells integrating organic transistors and organic photodiodes. Scale bar is 500 μm.

other. Silver paste islands were patterned by a microdispenser (Musashi Engineering) for vertical interconnections. Alternatively, anisotropic conductive films (Anisolm, Hitachi Chemical) are also used. Figure 3 (b) shows the magnified image of four contact pads with silver paste islands before the lamination of organic transistor and organic diode films. Figure 3 (c) shows the magnified image of four sensor cells integrating organic transistors and organic photodiodes. The entire transistor regions are covered by photodiodes.

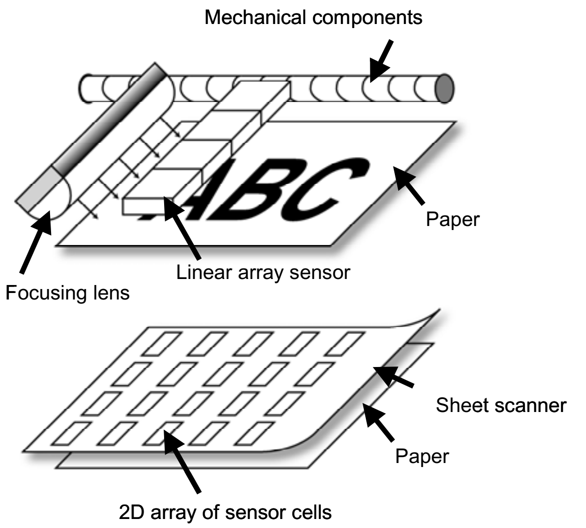

Fig. 4: Schematic illustrations of a conventional scanner and the present sheet image scanner. A conventional scanner consists of a linear array of sensors and that of light sources. The new scanner consists of a two-dimensional array of organic photodiodes coupled with organic transistors, which can be read out electrically by the organic transistors.

The effective sensing area of the prototype is 5x5 cm2; the resolution is 36 dots per inch (dpi), and the total number of sensor cells is 5,184. The pentacene FETs with top contact geometry have channel length of 18 mm, and mobility of 0.7 cm2/Vs. The total thickness and the weight of the whole device are 0.4 mm and 1 g, respectively.

PRINCIPLE

Figure 4 shows the difference between the conventional and present scanning method, which does not require any mechanical or optical component. In conventional scanners, a linear array sensor is moved from the top of a page to its bottom to capture images. The new design employs a two-dimensional array of organic photodiodes coupled with organic transistors. Instead of a mechanical scanning procedure, the signal of the photodiodes is read out electrically by the organic transistors, avoiding the need to use any movable part. As a result, the device is thin, lightweight, and mechanically flexible.

The principle of imaging with the present sheet image scanner can be described as follows. As can be observed from Fig. 5, if all incident light directly reaches the active layers, photodetectors cannot distinguish between black and white. Therefore, we prepared light-shielding layers to prevent photodetectors from being exposed to direct incident light. Direct light cannot reach the active layers. In this case, the incident light passing

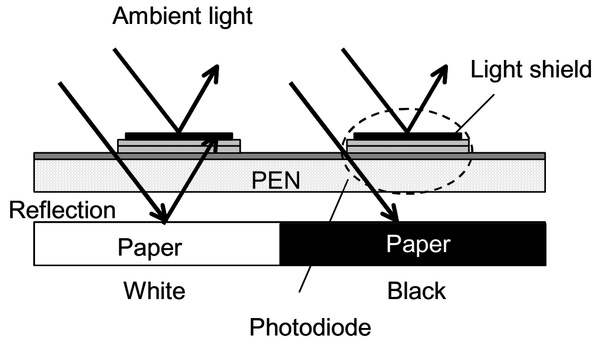

Fig. 5: A principle of imaging with the present sheet image scanner, which is placed onto paper with white and black regions.

though transparent regions is reflected on the white part of paper and reaches the active layers, while that on black does not reach the active layers. In this manner, the new scanner can distinguish between black and white.

Please note here that this principle does not rely on the size of the total sensing area. The size of the prototype is 5 × 5 cm^2. However, if the devices are manufactured by printing technologies, similar structures with a large effective sensing area will be feasible and those can be functional in the same principle.

MEASUREMENTS

One of the sensor cells consisting of one transistor and photodetector is measured under illumination of various intensities of light up to 70

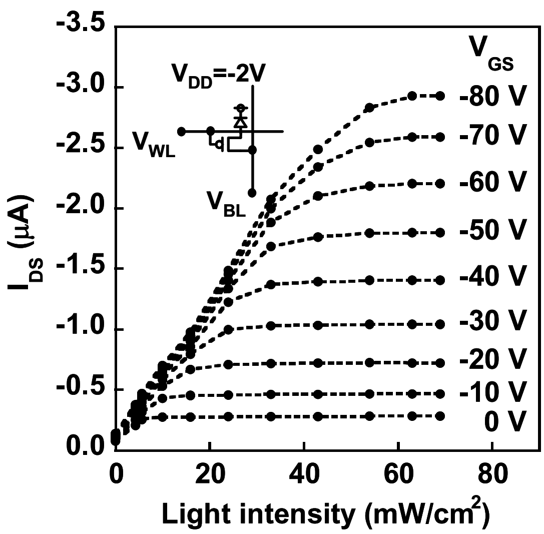

Fig. 6: I_{DS} vs. light intensity is measured for one sensor cell of the 36-dpi integrated devices with a different V_{GS} bias. The power supply V_{DD} is –2 V.

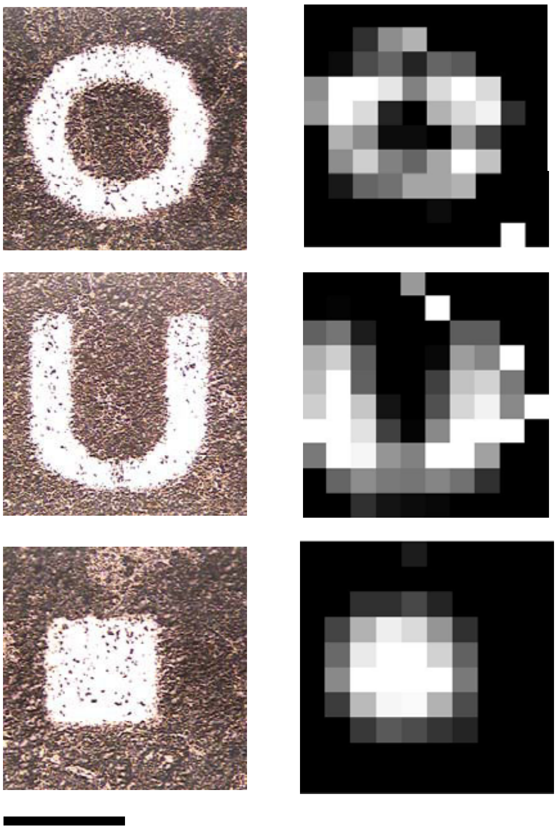

Fig. 7: White capital letters "O", "U", and a square printed by a laser printer on a paper are placed on the 250-dpi organic photodetector matrix without organic transistors. The photocurrent of each detector is measured under light (80 mW/cm^2). The mapping of normalized photocurrents is compared with an image taken by a commercial 250-dpi scanner. The size of each image is 0.8 × 0.8 mm^2.

mW/cm^2. Figure 6 shows I_{DS} retraced as a function of light intensity for the sensor cell. When V_{GS} = –80V is applied, I_{DS} is proportional to a light intensity of up to 40 mW/cm^2 and then saturates around a light intensity of 60 mW/cm^2.

We prepared a 250-dpi 10 × 10 organic photodiode matrix without organic transistors. The effective sensing area of each sensor cell is 50 × 50 µm2, while the periodicity is 100 µm. We have positioned a sheet of paper with white capital letters "O," "U," and a square printed on it by a laser printer underneath the photodiode matrix and measured the photocurrent of each detector with light illumination (80 mW/cm^2). The mappings of photocurrents are shown in Fig. 7.

CONCLUSIONS

We have demonstrated a sheet image scanner integrating organic transistors and organic photo detectors. The device with light shielding layers can distinguish between black and white in the reflection geometry.

The present scanning method does not require any mechanical or optical components; a two-dimensional array of organic photodiodes coupled with organic transistors is used. Instead of a mechanical scanning procedure, the signal of the photodiodes is read out electrically by the organic transistors, avoiding the need to use any movable part. As a result, the device is thin, lightweight, and mechanically flexible. The total thickness of the device is approximately 0.4 mm and its weight is approximately 1 g.

The present scanner is suitable for mobile electronics and can be easily carried in a pocket. The new scanner would have unique applications beyond the portability feature. It can be bended such that it can entirely cover at once the folded page of a thick open book. It would be also suitable for the recording of fragile, historically invaluable documents. A label affixed to a bottle of wine could also be accurately and conveniently scanned.

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