A sheet image scanner based on 3D organic transistor integrated circuits

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We have fabricated a large-area, flexible, and lightweight sheet image scanner on a plastic film by integrating high-quality organic transistors and organic photodetectors. The effective sensing area of the integrated device is 5x5 cm^2. The periodicity of sensor cells is 700 μm, which corresponds to the spatial resolution of 36 dots per inch (dpi). The total number of sensor cells is 5,184. The pentacene transistors with top contact geometry have channel length of 18 μm, and mobility of 0.7 cm^2/Vs. Organic photodetectors distinguish black and white from the difference of reflectivity between black and white parts on paper. Because the new sheet scanner has no optics or mechanical components, it is mechanically flexible, light to carry, shock-resistant and potentially inexpensive to manufacture, and therefore suitable for human-friendly mobile electronics.

I. Introduction

Organic field-effect transistors (FETs) have attracted much attention due to their excellent properties such as mechanical flexibility, lightweight, and low cost features. Those are complementary to silicon-based conventional electronics, which is high-performance, but expensive. Recent studies on organic transistors are motivated by two major applications, namely, flexible displays [1,2] such as paper-like displays or e-paper and radio frequency identification (RFID) tags [3,4].

On the other hand, we have demonstrated recently the new categories of application, that is, a large-area, flexible sensor. The first example of organic transistor-based large-area sensors is a pressure sensor matrix, where organic transistor active matrixes are used to read out pressure data from sensors. The new pressure sensor could be ideal for electronic artificial skin applications for future generations of robots [5-7]. In another new development of large-area electronics, we have recently successfully demonstrated the large-area, flexible, and lightweight sheet image scanner based on organic semiconductors [8,9]. In this paper, we report recent progress and future prospect of sheet image scanners with organic transistors.

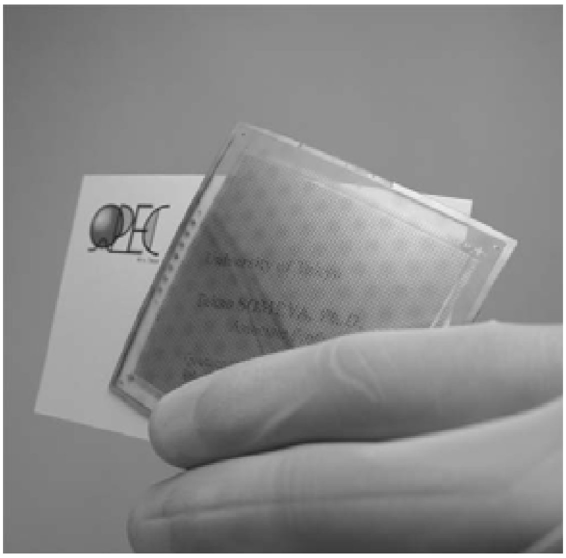

Fig. 1: An image of the manufactured large-area, flexible, and lightweight *sheet image scanner* consisting of organic transistors and organic photodiodes, which is placed on a business card under ambient light for capturing image.

II. Manufacturing process

The device 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 circuit diagram of the core part is shown in Fig. 2. The device structure is schematically illustrated in Fig. 3 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.

The transistor film has a 72x72 (~5,184) matrix of pentacene FETs with top contact geometry, which is manufactured with shadow mask technique. The photodiode array consisting of 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) is separately manufactured on the different PEN film coated with ITO.

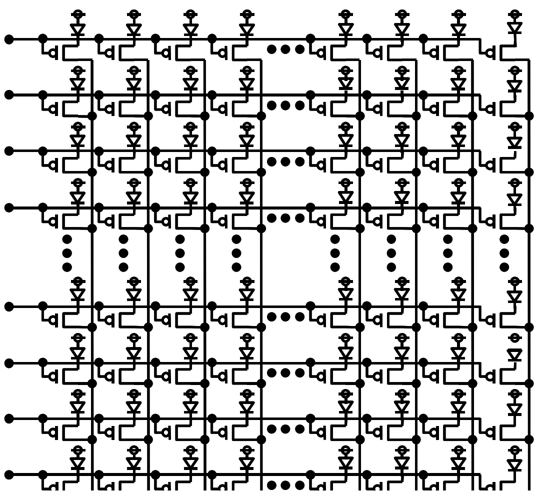

Fig. 2: A circuit diagram of the core part of the sheet image scanner. Each sensor cell consists of one transistor and one photodiode

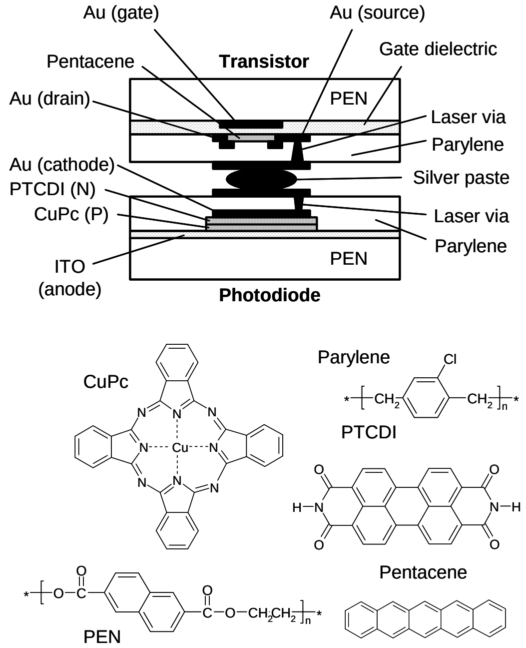

Fig. 3: The cross-sectional view of the device structure is schematically shown. Organic transistor matrix and organic photodiode matrix are separately manufactured on different PEN films and then laminated with each other with silver paste patented by ultra fine printing technique. The chemical structure of each layer is also shown.

The effective sensing area of the prototype is 5x5 cm^2; 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 μm, and mobility of 0.7 cm^2/Vs. The total thickness and the weight of the whole device are 0.4 mm and 1 g, respectively.

III. Principle of imaging

Figure 4 shows the difference between the conventional and the present scanning method, which does not require any mechanical or optical component. In conventional scanners, a linear array sensor are moved from the top to the bottom of a page to capture images. In the new design, 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

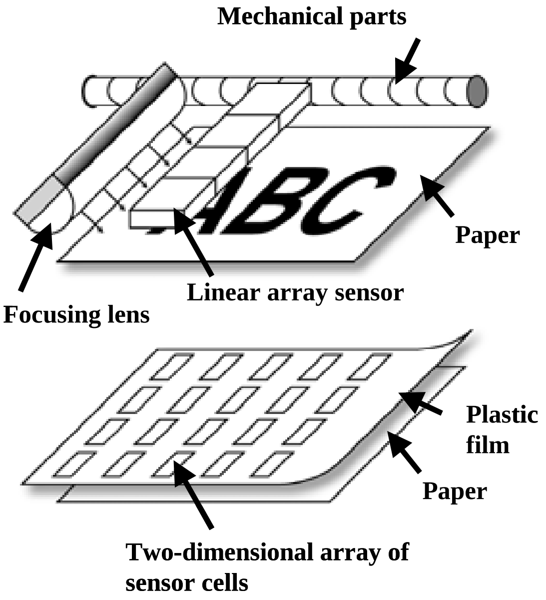

Fig. 4: A schematic illustration of a conventional scanner and the present sheet-type scanner. The new scanner consists of a two-dimensional array of organic photodiodes coupled with organic transistors.

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.

We describe the principle of imaging with the present sheet image scanner. As shown in Fig. 5, if all incident light reaches directly to the active layers, photodetectors can't distinguish black and white. Thus, light-shielding layers are prepared to prevent photodetectors from being exposed to direct incident light. Now direct light can't reach to the active layers. Then the incident light passing though transparent regions is reflected on white part of paper and reaches to the active layers, while that on black doesn't go to active layers. In this way, the scanner can distinguish black and white.

IV. Remaining issues

We would like to address three remaining issues. The first issue is reliability and stability of organic transistors and diodes. Indeed, the performance of our un-encapsulated device changes over a couple of days. This should be the most stringent problem related to organic FETs,

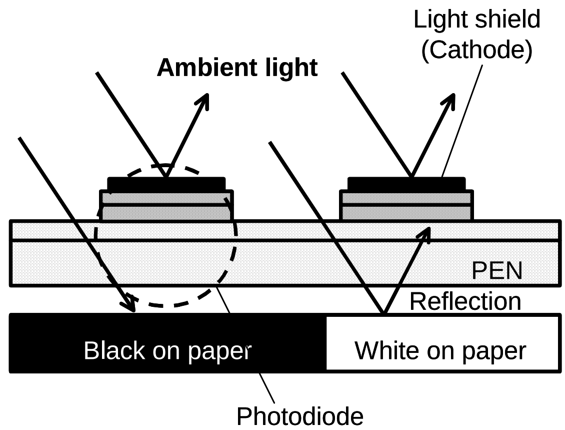

Fig. 5: Image capturing with photodiode matrix sheet in the reflection geometry. Organic photodiodes distinguish between black and white from the difference of reflectivity between black and white parts on paper.

but it should be overcome by introducing adequate encapsulations similar to electroluminescent devices.

The second issue is the high operation voltage. Lowering the operation voltage is not very difficult by introducing the thinner gate dielectric layer or the use of high-k materials.

The third issue is the spatial resolution. Although the present resolution is 36 dpi with organic transistors, many practical applications require 250 dpi for the spatial resolution. The resolution is currently limited by size of via interconnections, but we expect to reduce the diameter of via holes, when we use the lasers with shorter wavelengths such as excimer lasers or YAG lasers.

V. 3D organic integrated circuits

The drawback of organic transistors is a slow speed. We can overcome this problem by using a new circuit concept called "double word-line and bit-line structure" which reduces the time delay by a factor of 5 and the power consumption by a factor of 7. To manufacture a new circuit, two different films with organic transistors are stacked along with the photo detector film [9].

VI. Conclusions

We have demonstrated a sheet image scanner integrating organic transistors and organic photo detectors. The device with light shielding layers can distinguish black and white in the reflection geometry. Because the new image-capturing device has no optical or mechanical component, it is lightweight, shock-resistant, flexible, and is suitable for human-friendly mobile application.

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