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Organic Transistors: towards Ambient Electronics

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Introduction

In view of the tremendous technical challenges for realizing next-generation information technology, organic semiconductors have attracted significant attention since the emerging electronics based on them have features that are complimentary to main stream electronics based on silicon. Thanks to the recent advent of organic transistors, the emergence of a new class of electronics makes full use of the unique features of organic semiconductors, such as the ultralow cost, low weight, and flexibility, is becoming more realistic. With this background, our group discerned that large-area circuits could be easily fabricated using organic transistors, which are essential for certain applications, and has developed large-area sensors and actuators using organic transistors. More accurately, we have integrated various types of sheet-type sensors and sheet-type actuators with organic transistors on plastic films and have demonstrated the world's first electronic artificial skins (Eskins), sheet-type Braille displays, and many other sheet-type devices.

In the forthcoming ambient electronics era, multiple electronic objects are scattered on walls, ceilings or in imaginative locations and interact each other to enhance safety, security and convenience. For implementation of many electronic objects in our daily life, large-area sheet-type devices are needed and organic transistors (1-4) are expected to play an important role.

In this paper, I will describe recent progress and future prospects of organic transistor-based flexible, large-area sensors and actuators. Moreover, the issues and the future prospect of organic transistors will be addressed from the view point of ambient electronics.

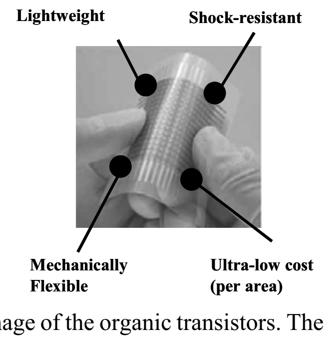

Fig. 1: An image of the organic transistors. The devices are mechanically flexible, very thin, lightweight, shock-resistant, and potentially ultra-low in cost.

An electronic artificial skin (E-skin)

As one of the large-area sensors, we first describe a flexible pressure sensor (5-8), which is suitable for an electronic artificial skin. Although the mobility of organic semiconductors is approximately two or three orders of magnitude less than that of poly- and single-crystalline silicon, the slower speed is tolerable for most applications of large-area sensors. In particular, for the fabrication of E-skins, the integration of pressure sensors and organic peripheral electronics avoids such drawbacks of organic transistors, while taking advantage of their mechanical flexibility, large area, low cost, and relative ease of fabrication.

An active matrix of organic transistors, row decoder, and column selector are assembled by a physical cut-and-paste procedure to develop integrated circuits (ICs) for data readout. Three functional films — an interconnection layer, a pressure-sensitive rubber sheet, and a top electrode for power supply— are then laminated together with the organic ICs. Pressure images were obtained by a flexible active matrix of organic transistors whose mobility is as high as 1.4 cm^2/Vs. These transistor films can be bent to a radius of 0.5 mm, which is sufficiently small for the fabrication of human-sized robot fingers.

Furthermore, we have developed conformable, flexible, wide-area networks of thermal and pressure sensors. A plastic film with organic transistor-based electronic circuits was processed to form a net-shaped structure that allows the E-skin films to be stretched by 25%. The net-shaped pressure sensor matrix was attached to the surface of an egg and pressure images were successfully obtained in this configuration.

In the above prototypes of E-skins, spin coating has been utilized to form thin and uniform polyimide gate dielectric layers, but it is preferable to use printing methods in order to minimize the consumption of materials and avoid additional patterning processes. We have fabricated 23×23 cm^2-flexible pressure sensors with active matrices comprising 2025 pentacene FETs. Polyimide precursors and silver nanoparticles are patterned on a polyimide film by using an inkjet printing system to form organic FETs. Pentacene deposited in the vacuum system is used as the channel layer. We have obtained the spatial distribution of pressure by using flexible pressure sensors, in which our organic FET active matrices are used for data readout.

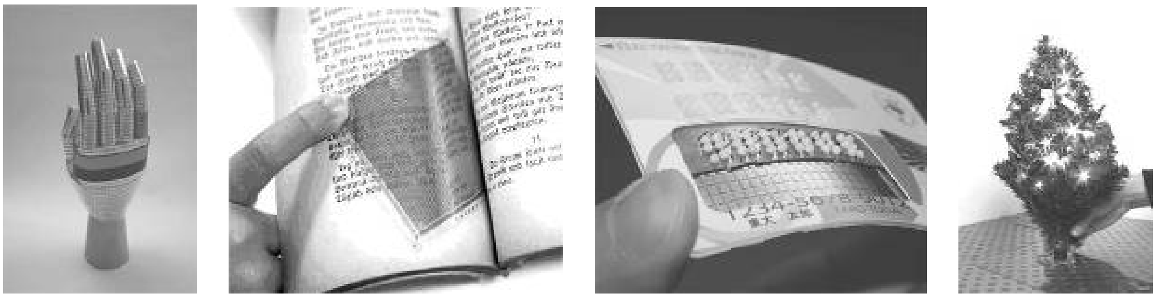

Fig2: Images of unique large-area, flexible electronics devices using organic transistors; an Eskin, a pocket scanner, a Braille e-paper, and a power sheet.

A sheet-type image scanner

In another new development in large-area sensors, we have demonstrated the large-area, flexible, and lightweight sheet image scanner based on organic semiconductors (9-11). We report the principle of imaging, manufacturing process, and electronic performance. The device is manufactured on plastic films by integrating organic FETs and organic photodiodes. Organic photodetectors distinguish between black and white parts on paper based on the difference in their reflectivity. The effective sensing area of the integrated device is 5×5 cm^2; resolution, 36 dpi; and the total number of sensor cells, 5,184. Furthermore, we have successfully obtained the images of several characters whose size is approximately 1×1 mm^2 by using two-dimensional arrays of a photodiode matrix without organic transistors. The present sheet image scanners are mechanically flexible, lightweight, very thin and, therefore, suitable for human-friendly mobile electronics.

A sheet-type Braille display

Organic transistors are suitable for applications to plastic large-area actuators. We have developed a flexible, lightweight *Braille sheet display* that is fabricated on a plastic film for the first time, by integrating high-quality organic FETs with plastic actuators (12,13). A small semisphere which projects upwards from the rubber-like surface of the display is attached to the tip of each rectangular actuator.

A wireless power transmission sheet

We have also demonstrated the first implementation of a large-area wireless power transmission system (14,15). The sheet-type large-area wireless power transmission system has been manufactured using organic transistors and MEMS switches. The position of electronic objects on this sheet can be contactlessly sensed by electromagnetic coupling using an organic transistor active matrix. Then, power is selectively fed to the objects by an electromagnetic field using a two-dimensional array of copper coils that are driven by a printed plastic switching matrix. The effective power transmission area is 21×21 cm^2. Due to selective power transmission, we achieved a coupling efficiency of power transmission of 81.4%, and a power of 40 W was wirelessly received. The thickness and weight of the entire sheet are 1 mm and 50 g, respectively.

Issues and future prospects

We describe the issues of organic transistors from the viewpoint of ambient electronics. Stability and reliability are the main concerns for the organic transistors. Degradation may be induced by oxygen and/or moisture like electroluminescent (EL) devices; therefore, it can be suppressed drastically by appropriate encapsulation. Although plastic films usually exhibit high gas penetration, applications that require mechanical flexibility, such as electronic skins and sheet image scanners, also require flexible substrates with low gas permeability. Thus, it is very important to develop flexible base films with low gas permeability.

With the development of ubiquitous information technology, there is a demand to realize a seamless connection between objects and humans in real space and the bit in cyberspace. In order to bridge this gap between humans and cyberspace, large-area sensors and actuators with sizes comparable to those of people are required. Our prototypes demonstrate that organic transistors can be used to extend the field of electronics into large areas.

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References

[1] A.Tsumura, et al., APL 49, 1210 (1986).
[2] C. D. Dimitrakopoulos, et al., Adv. Mater. 14, 99 (2002).
[3] A. Dodabalapur, et al., Science 268, 270 (1995).
[4] C. J. Drury, et al., APL 73, 108 (1998).
[5] T. Someya, et. al., PNAS 101, 9966 (2004).
[6] T. Someya, et. al., PNAS 102 (35) (2005).
[7] H. Kawaguchi, et. al., IEEE JSSC 40, 177 (2005).
[8] Y. Noguchi, et al., APL 89, 253507 (2006).
[9] T. Someya, et. al., IEEE T-ED 52, 2502 (2005).
[10] H. Kawaguchi, et. al., IEEE Sensors Journal 6, 1209 (2006).
[11] H. Kawaguchi, et. al., ISSCC, 365 (2005).
[12] Y. Kato, et. al., IEEE T-ED 54, 202 (2007).
[13] M. Takamiya, et al., IEEE JSSC 42, 93 (2007).
[14] M. Takamiya, et al., ISSCC # 20.4 (2007).
[15] T. Sekitani, et al., Nature Materials 6, 413 (2007).