Recent progress of organic TFT active matrices for large-area electronics applications

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Abstract

We describe the recent progress of organic TFTs from the viewpoint of large-area sensors and actuators such as artificial electronic skins, sheet scanners, and sheet Braille displays. We report ultra-flexible pentacene TFTs that are functional at a bending radius of 0.5 mm. These transistors are manufactured on a 13-μm-thick polyimide film and encapsulated by a 13-mm-thick parylene layer in order to embed them in a neutral position. The TFTs exhibit no significant change after 60,000 bending cycles. Then, we describe the control of the threshold voltage of the pentacene TFTs with novel double gate structures in which the top and bottom gate electrodes can apply bias voltages to channel layers independently. Finally, we report organic TFTs that exhibit a very small degradation in performance under a continuous DC bias stress. When the pentacene TFTs are annealed at 140 ºC for a duration of 12 h in a nitrogen environment, the change in I_{DS} *is 1% even after the application of continuous DC voltage biases of* $V_{DS} = V_{GS} = -40$ *V for 45 h.*

Introduction

In the past several years, intensive research and development have been made in order to realize flexible electronics. In particular, organic thin film transistors (TFTs) and their integrated circuits have attracted considerable attention (1–4) since organic TFTs possess attributes that complement high-performance silicon-based LSI devices, which are expensive. Organic TFTs can be manufactured on plastic films at ambient temperatures; therefore, they are mechanically flexible and potentially inexpensive to manufacture. Recent studies organic transistors are based on two major applications. The first application includes flexible displays, such as paper-like displays or e-paper, in which electronic inks or other media are driven by matrices of organic transistors. The other is radio frequency identification (RFID) tags. The printable features of organic transistors should facilitate the implementation of RFID tags on packages.

As the third application, flexible, large-area pressure sensors and actuators are proposed and demonstrated: The active matrices of organic TFTs integrated circuits are used for data readout from area-type sensors or to drive large-area actuators. In this paper, we report the recent progress and future prospects of organic TFT active matrix technologies for flexible, large-area sensors and actuators.

Robot skins

The earliest application of large-area sensors is a flexible pressure sensor (5), which is suitable for electronic artificial skin (Fig. 1), which will be used in next-generation robots. 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 the drawbacks of organic transistors, while taking advantage of their mechanical flexibility, large area, low cost, and relative ease of fabrication.

A 16 × 16 active matrix of organic transistors, row decoder, and column selector are assembled by a physical cut-and-paste procedure to develop integrated circuits 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 sensors can be bent to a radius of 0.5 mm, which is sufficiently small for the fabrication of human-sized robot fingers.

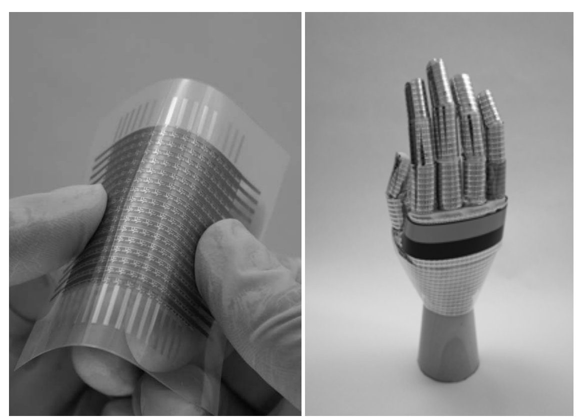

Fig. 1: A picture of an electronic artificial skin (E-skin) for a robot in the next generations. Organic transistors are used to read out pressure distributions. Since all the components except electrodes are made of soft materials and manufactured on a plastic film, it is lightweight, thin and mechanically flexible.

Based on an organic semiconductor, 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. Moreover, a similar network of thermal sensors was developed using organic semiconductors. A possible implementation of both pressure and thermal sensors on various surfaces is presented. By using laminated sensor networks, the distributions of pressure and temperature are simultaneously obtained.

Sheet-type Braille displays

Organic transistors are also suitable for applications to large-area plastic actuators. We have fabricated a novel, flexible, lightweight *Braille sheet display* that is fabricated on a plastic film by integrating high-quality organic TFTs with plastic actuators (7). A small hemisphere that projects upwards from the rubber-like surface of the display is attached to the tip of each rectangular actuator (Fig. 2).

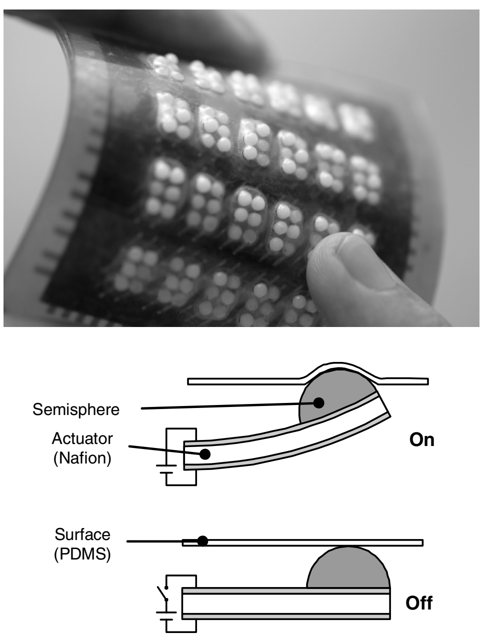

Fig. 2: An image of a pocket *Braille sheet display*. It was manufactured on a plastic film by integrating the active matrix of organic TFTs with a plastic sheet actuator array based on a perfluorinated polymer electrolyte membrane. The device is mechanically flexible, very thin, and lightweight. One character is displayed by a 3 × 2 array of rectangular actuators (4 mm in length and 1 mm in width). A semisphere is attached to each actuator, which bends and lifts the semisphere. Principle of Braille motion is also shown.

Mechanical flexibility

We describe the recent progress of organic transistors from the viewpoint of large-area electronics (8). First, we report ultra-flexible pentacene TFTs that are functional at a bending radius of less than 1 mm. These transistors are manufactured on a 13-µm-thick polyimide film and encapsulated by a 13-µm-thick parylene layer in order to embed them in a neutral position. The TFTs exhibit no significant change after 60,000 bending cycles.

DC bias stress

We report organic TFTs that exhibit a very small degradation in performance under a continuous DC bias stress (9). When the pentacene TFTs are annealed at 140 ^{o}C for a duration of 12 h in a nitrogen environment, the change in I_{DS} is 1% even after the application of continuous DC voltage biases of $V_{DS} = V_{GS} = -40$ V for 45 h.

Future prospect

Organic transistor-based integrated circuits play an important role in large-area electronics wherein the manufacturing cost per area must be very low. Undoubtedly, one of the most important directions for future electronics is ambient intelligence or wireless sensor networks. In order to realize such networks, one of the key technologies is a sensor to detect physical or chemical information distributed over a large area. We believe that the large-area features of the organic transistors would be instrumental in realizing such large-area sensors. A new class of applications that require large-area detections has gained importance in future electronics. It is important for the organic transistors to compete with silicon in terms of the cost per function. However, they are suitable for applications that require low-cost features in a large area. Therefore, organic transistors are appropriate for large-area electronics.

Acknowledgements

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Author Biography

Takao Someya received the PhD in EE from the University of Tokyo in 1997. Since 2003, he has been an associate professor of Department of Applied Physics, University of Tokyo. From 2001 to 2003, he worked on organic electronics in the Columbia University and Bell Labs as a Visiting Scholar. His current research focus is on organic TFTs and flexible electronics. He is an IEEE/EDS Distinguished Lecturer since 2004 and a recipient of 2004 IEEE/ISSCC Takuo Sugano Award.