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Printed Flexible Pressure Sensor for Robot Skin

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Abstract

JAPERA (Japan Advanced Printed Electronics Technology Research Association) has developed a basic technology to create OTFT array with all printing. In accordance with the requirements of each component, various printing methods including inkjet are used selectively to realize a high-precision flexible pressure sensor array by full printing. A high resolution active matrix type pressure sensor was made on the film base material and the sensor surface was covered with a thin rubber sheet with the same thickness as the sensor pitch. In this research, we apply our printed flexible pressure sensor to robot skins and show examples of tactile judgment and two-way communication at high speed by using obtained pressure distribution.

1. Introduction

It is expected that the manufacturing method of electronic devices using printing technologies is applied to flexible devices since its process at low temperature enable the use of flexible film. JAPERA has successfully developed all printing technologies of organic TFT array, and is also proceeding to develop several prototypes and customer evaluation of its application [1, 2, 3, 4]. TFT backplane made of film are is generally used as a multi-point sensor of FPD, fingerprint sensor and so on, in addition to flexible display application [5, 6]. We have recently developed active matrix multiple-point flexible pressure sensor driven by the all-printed TFT array. It is considered that the active matrix type can output pressure distribution data of high resolution and high sensitivity with lower power consumption compared with the pressure sensor of the passive matrix type [7]. In this study, we implemented an active matrix multiple-point flexible pressure sensor as a robot skin sensor, created an algorithm for instantaneous tactile judgment of the pressure distribution data obtained, and applied to the robot successfully. It was found that printing technologies have great potential to develop sensor devices such as industrial robots and service robots that will expand in the future.

2. Background

We have supposed that the sensors used as robot skins and processing system must satisfy the following three requirements.

(1) The sensor can be fitted smoothly to the objects and have mechanical and electrical durability even if they are repeatedly bent.

(2) They can detect the pressure with large area, multiple points, high speed, high sensitivity to identify various tactile senses.

(3) They can process the data which identify the tactile pattern and can transmit the action command at high speed.

3. Approach

To solve the above problem, we have decided to adopt the following approach.

(1) In order to have durability, every layers from the TFT backplane to the pressure sensitive layer and protective film was prepared on the PEN film base material by printing method suitable for low temperature treatment. We used our all-printed electronic device manufacturing line to fabricate the TFT backplane. The line is composed of the class 10 clean tunnel in which the main clean robot carries film substrates to printers and other process equipment connected by that clean tunnel as shown in Figure.1 and 2.

***Figure 1**. Substrate transporting robot in clean tunnel of automated print manufacturing line*

***Figure 2.** Clean tunnel connected printers and curing funnels*

The cross sectional view of one pixel area of a multi-point pressure sensor with the top gate structure is shown in Figure 3. We can fabricate bottom gate structure by changing the order of printing process in addition to the top gate structure.

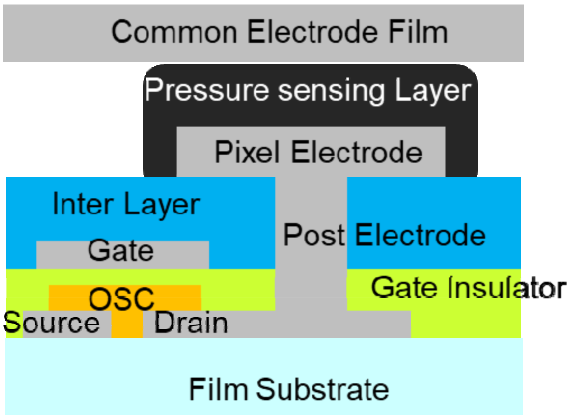

***Figure3.** Cross sectional view of pressure sensor with the top gate structure*

We have developed the process technologies which are suitable for serial printing and the curing without vacuum and photolithography processes. Table 1 shows the fabrication processes and materials used for flexible robot skin sensor. Customized Ag nano particle ink for each source/drain electrode and gate electrode, highly purified polymer ink for the gate insulator and interlayer insulator, special Ag nano particle ink with large surface tension for post electrode (interlayer-connection pillar), Ag paste for pixel electrode and connecting electrode, and organic polymer semiconductor ink for the TFT have been used after fine tuning of developed and formulated inks.

We have operated the offset printer for the source/drain and gate electrode patterns, digital inkjet printer for the organic semiconductor layer and post electrode (interlayer-connection pillar), slit-die coater for the gate insulator layer and interlayer insulator, and screen printer for the pixel electrode and protective layer which prevent damage to TFTs. The maximum process temperature was less than 180degree C.

Table 1. Fabrication Process for Flexible Robot Skin Sensor

**NISSHA CO., Ltd.*

	Layer	Materials	Process
Common Electrode Film	Common Electrode	Confidential*	Confidential* (Printing)
TFTs array Sensor Film	Pressure sensitive resistance	Confidential*	Confidential* (Printing)
	Protective Layer	Polymer	Screen
	Pixcel Electrode	Ag paste	Screen
	Inter Layer	Polymer	Slit Die Coating
	Gate Electrode	Nano-Ag	Offset
	Semi Conductor	Organic	Inkjet
	Gate Insulator	Polymer	Slit Die Coating
	Inter Layer Connection	Nano-Ag	Inkjet
	Source / Drain Electrode	Nano-Ag	Offset

(2) We have designed active matrix type pressure sensor with 1.2 mm pitch, 5760 pixels (sensor area is 4.8 cm x 17.3 cm), measurement pressure range of 300 kPa, 256 gradations, sampling frequency of 100 Hz. Figure 4 shows the surface view of TFT elements after the pressure sensitive layer process represent. The black dots are the pressure sensitive patterns and the horizontal lines represent gate lines or common electrode lines. Figure 5 illustrates the equivalent circuit of the sheet sensor. The circuit consists of the gate lines, source lines, common power supplies and transistors. By using the switching function of TFTs, a resistance value of each variable resistor is measured. Since the active matrix driving has very little current leakage between each line, it features high sensitivity, low power consumption and high resolution. The photograph of our flexible pressure sensor is shown in Figure 6.

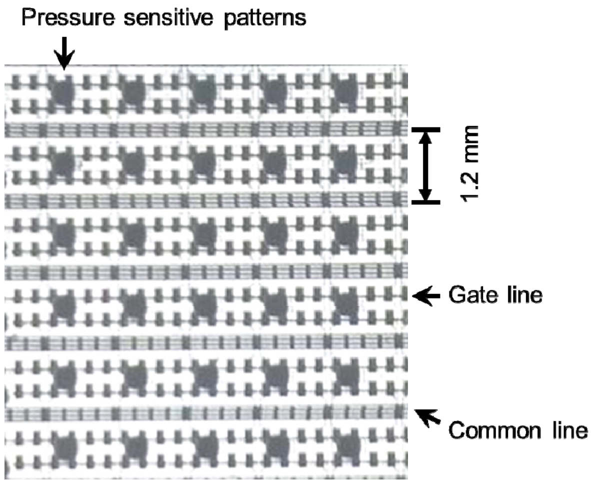

***Figure 4.** Surface view of pressure sensor elements.*

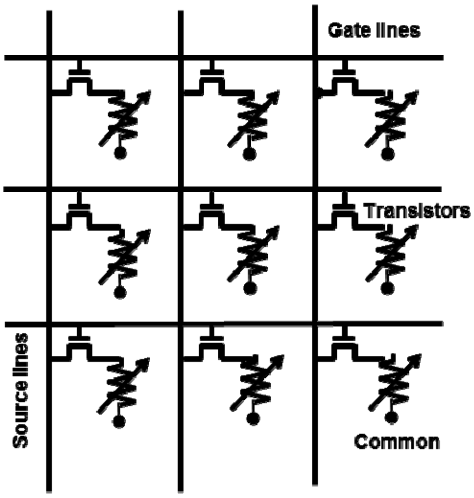

***Figure 5.** Equivalent circuit of pressure sensitive sensor*

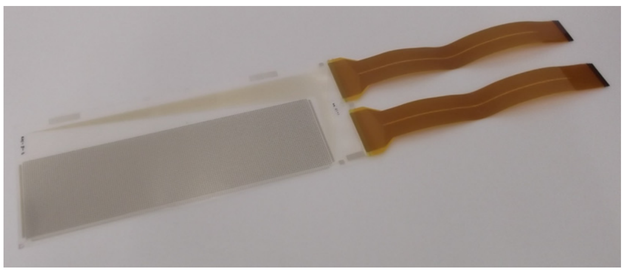

***Figure 6.** Flexible pressure sensor with 1.2 mm pitch, 5760 pixels (sensor area is 4.8 cm x 17.3 cm)*

(3) The obtained pressure distribution data, can be used to make a system to identify the tactile pattern and let the robot react as seen Figure 7. The sensor was attached to both shoulders of the robot. Touching the shoulder of the robot, we can obtain the pressure distribution data as the palm images in figure 7. An expert system, which is a kind of artificial intelligence (AI), analyzes the tactile pattern and immediately identifies the contact action as “stick”, “stroke”, “tickle”, “scratch”, “brush” and so on. Robot reacts in accordance with the action command which is determined by the system.

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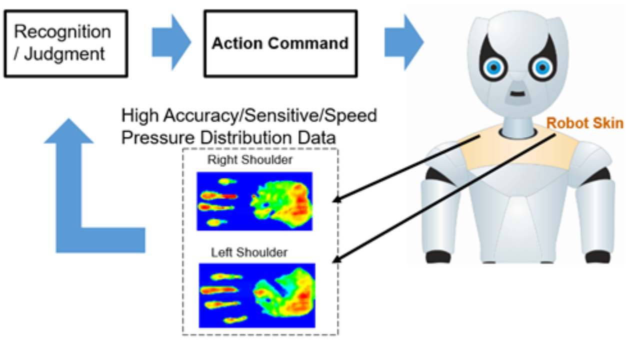

Figure 7. *Robotic skin tactile identification system*

4. Result

Appropriate selection and matching of various materials and precise patterning technologies including inkjet, made it possible to obtain a flexible TFT array sheet which was enough to drive a pressure sensor. The electrical properties of TFT array is shown in Figure 8. Average mobility of 48 transistors in the sheet was 0.97 cm2/Vs at saturated region, average Id current was 0.5 mA with less than 5% sigma in the size area, and ON/OFF current ratio was 5 multiplied by ten of order 8.

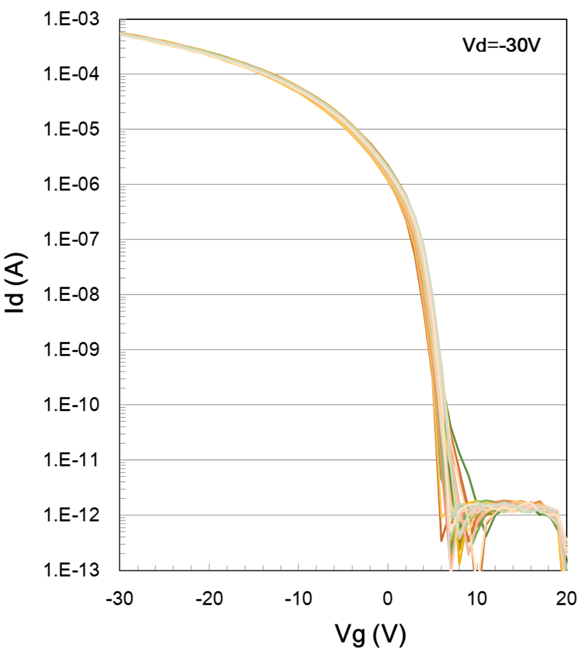

Figure 8. *Electrical properties of TFT elements*

Figure 9 shows the structure of a flexible pressure sensor. By using a flexible rubber sheet with a thickness close to the pixel pitch on the sensor surface, it was possible to obtain highly efficient sensor at the level where the brush tip can be detected. Furthermore, the flexible rubber sheet realize the human skin sensation. Figure 10 shows the relationship between the output current and the applied pressure. We can obtain the wide dynamic range of more than 300 kPa and high sensitivity especially at the range of low pressure. This robot skin maintains the sensor function without being destroyed even when pressed and bent repeatedly. In addition, Tactile discrimination and robot response at the ms order have been attained by identifying the maximum level of the obtained pressure distribution, the number of pressed pixels and their location, and the movement speed of the pressing center of gravity.

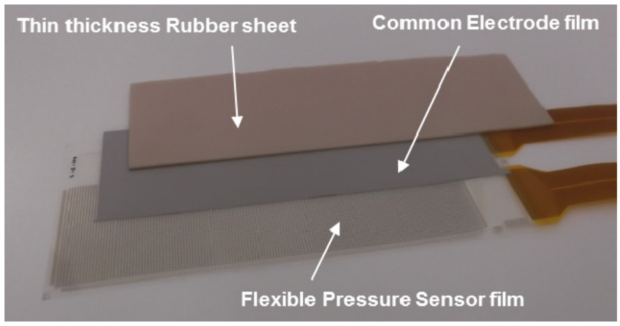

Figure 9. *Structure of Flexible Pressure Sensor*

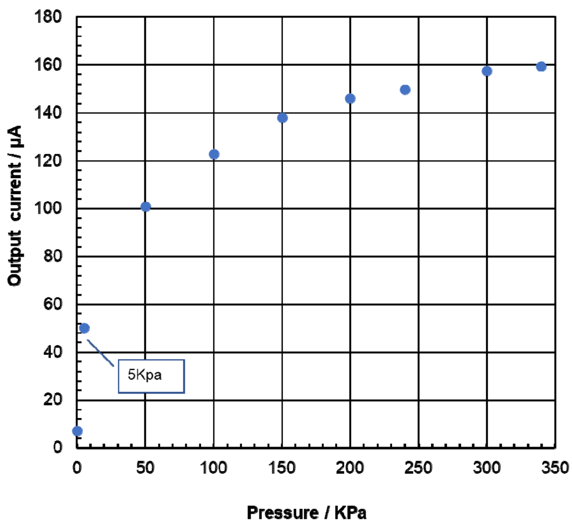

Figure 10. *Structure of Flexible Pressure Sensor*

5. Conclusions

By combining a flexible pressure sensor based on printing methods with the program for tactile discrimination of pressure distribution, it was possible to realize a robot skin that can be fitted to a curved surface like sholders. The active matrix system made it possible to obtain high sensitivity and the realistic sense of touch. A combination of high quality pressure distribution data and machine learning and deep learning will also enable robots to perform more advanced tactile discrimination. There is a high probability that appropriately arrangement of pressure sensitive elements, temperature sensitive elements and moisture sensitive elements in the active matrix sensor will make a tactile sensor close to the human body. [8]

6. Acknowledgment

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Author Biography

Atsushi Nakajima acquired a master's degree in Applied Chemistry from Hokkaido University (Sapporo) in 1988. Since that time, he joined Konica and has been developing recording materials and inkjet printing processes for digital printing machines. Currently he is developing process of printed electronics at Konica Minolta. Since 2011, he has participated in JAPERA and is developing the printing electronics production technology of organic TFT array film and sensor device.