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Development of A Flexible Temperature Sensor Array System

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Abstract. A flexible temperature sensor array and a scanning system are developed in this paper. A 16×16 temperature sensor array in a 25×20 mm^2 area is fabricated on a flexible copper-PI substrate using MEMS fabrication technology. Platinum is employed as the temperature sensing material, which is often so called the resistance temperature detector (RTD). Copper patterns on both sides of the flexible substrate serve as the row and column interconnects for scanning circuitry. In each element of the temperature sensor array, the resistance of platinum, which is patterned by lift-off process, can be measured by the scanning system.

Introduction

Recently, research on artificial skin for robots has been popular. The main feature of artificial skin is that sensors should be highly arrayed in a requested area on a flexible substrate. Most of the researches were focus on flexible tactile sensor array [1-5]. As for flexible temperature sensor arrays, Takao Someya *et al* [6] used organic diodes. Also, Ji-Song Han *et al* [7] and Gwo-Bin Lee *et al* [8] employed micro thermal resistors made of platinum. In this paper, we present a temperature sensor array with much higher density on a flexible polyimide substrate. The temperature variation is detected by measuring the resistance change of the platinum resistor as the temperature sensing material.

Design

Figure 1 shows the fabricated flexible temperature sensing array. The photograghs of the temperature sensor array are shown in Figure 2. The temperature sensor array is composed of the temperature sensing material and the scanning circuitry. Figure 2(a) shows the column interconnects made of copper layer, and Figure 2(b) shows the other side of the polyimide film. As shown in Figure2(b), the serpentine patterns are the platinum resistors, the temperature sensing elements. The copper layer on both sides of the polyimide film forms the row and column interconnects which are required for 2-D array scanning.

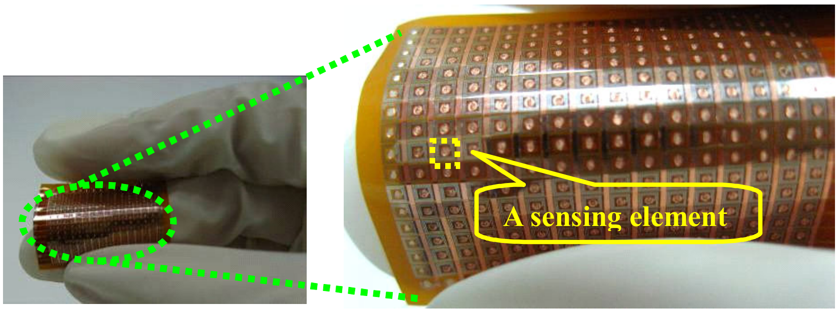


Fig. 1 Overall look of the flexible 16×16 temperature sensor array

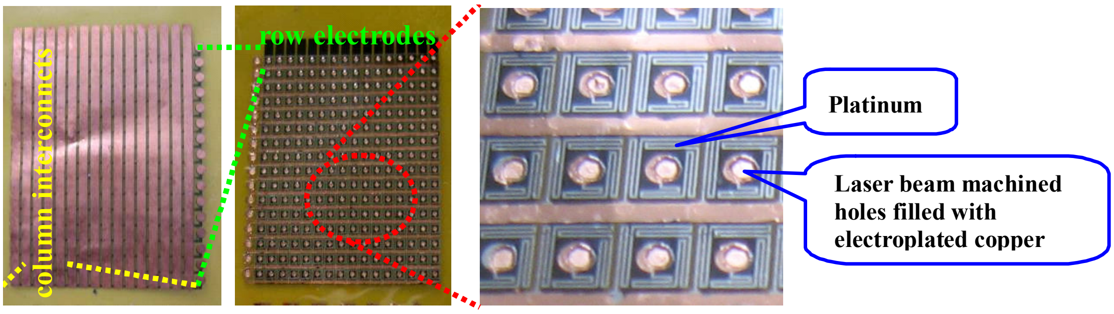


Fig. 2 Illustration of the temperature sensor array

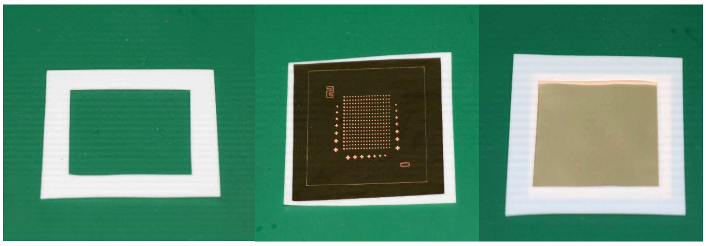
Resistance of a uniform slab of conducting material can be expressed as

$$R = \left(\frac{\rho}{t}\right)\left(\frac{l}{w}\right) \tag{1}$$

where ρ is the resistivity of the resistor material, t is the thickness, l is the length and w represents the width of the conductor. The resistance is proportional to length and inversely proportional to cross-sectional area. The pattern of the platinum layer is designed to be long and narrow, while copper is relatively wide, in order to ensure that the resistance change is caused by the meandering platinum patterns. Besides, the thickness of copper layer was designed to be 10 times larger than platinum. The resistivity is 10.6μΩ-cm for platinum and 1.68μΩ-cm for copper. The estimated resistance of the platinum patterns is about 200 times larger than that of the copper interconnects. Therefore, The temperature-dependent resistance of the copper layer can be negligible during the temperature measurement.

Fabrication

Rather than spinning flexible polymer material, such as PI, on a handling wafer during the fabrication process as the most common way to fabricate a flexible MEMS device [1][2][9], the fabrication process in this work starts with a flexible copper-polyimide film. We chose the film which is composed of an 18μm-thick copper layer and a 20μm-thick polyimide (PI) layer. In order to hold the copper-PI thin film during the double-sided fabrication MEMS process, the copper-PI film is glued on a Teflon frame prior to the fabrication process. Photographs of the Teflon frames (with copper-PI substrates) are shown in Figure 3.



(a) (b) (c)

Fig. 3 (a) Teflon frame before fixing a copper-PI film; (b) polyimide side; (c) copper side

Figure 4 shows the fabrication process. Firstly, laser-beam machining is operated on the polyimide layer of the copper-PI film to form a 16×17 array of through-holes (Figure 4(b-2)), in which 16×16 through-holes are made for the 16x16 sensing elements and the other 16 through-holes in one column (16×1) is designed to connect the electrodes to the copper layer side of the copper-PI substrate. The copper-PI film which is attached to the steel frame carrier right after the laser beam machining. Then, the through-holes are filled with copper by electroplating from the copper layers to the polyimide top surface (Figure 4(b-3)). After electroplating, column interconnects on the backside of the flexible substrate are created by wet etching the copper layer using HCl: $FeCl_3$: H_2O = 8:5:5 (Figure 4(b-4) and (b-5)). Copper in through-holes is protected from the copper etchants by spinning photo-resist on the polyimide surface. On the polyimide side, a platinum layer of 0.1μm in thickness with a 0.01μm titanium layer is deposited by e-beam evaporation and patterned by lift-off process (Figure 4(b-6) to (b-8)). Similarly, on the same side, row interconnect copper layer is deposited and patterned by the same way (Figure 4(b-9) to (b-11)). Finally, the film could be cut off from the frame carrier and the fabrication process is completed (Figure 4(b-12)).

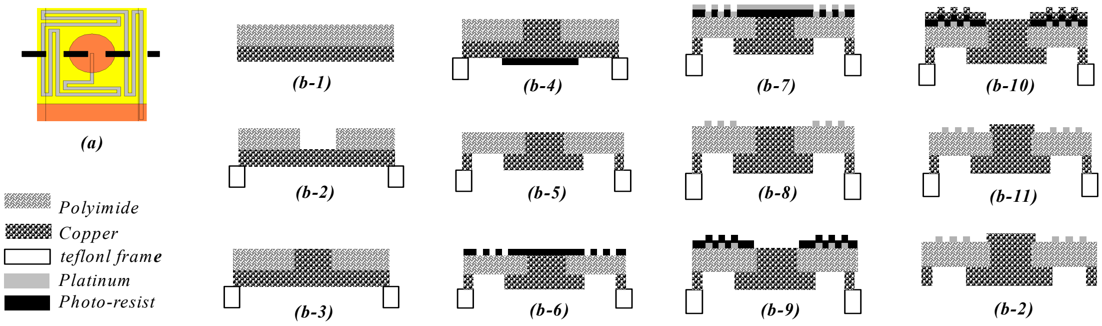


Fig. 4 Illustration of the fabrication process

Results

Temperature is detected by measuring the resistance of platinum using a scanning circuit. The scanning system is connected to the row and column interconnects of temperature sensor array. Figure 5 shows the schematic of the sensing system. The row-electrode selecting multiplexer gives a small constant bias to the row interconnects, and the column-electrode selecting multiplexer recieves the output voltage, which is converted from the output current of each scaned resistor. The relation between resistance and temperature of a material can be written as

$$R = R_0\left(1 + \alpha\left(T - T_0\right)\right), \qquad (2)$$

where T_o is the ambient temperature, R_o is the resistance at T_o, and α is the temperature coefficient of resistance (TCR) of platinum. The measured relationship between temperature and normalized resistance change of platinum for a single sensing element is shown in Figure 6, and the measured temperature coefficient of resistance (TCR) is 0.0033 K^{-1}.

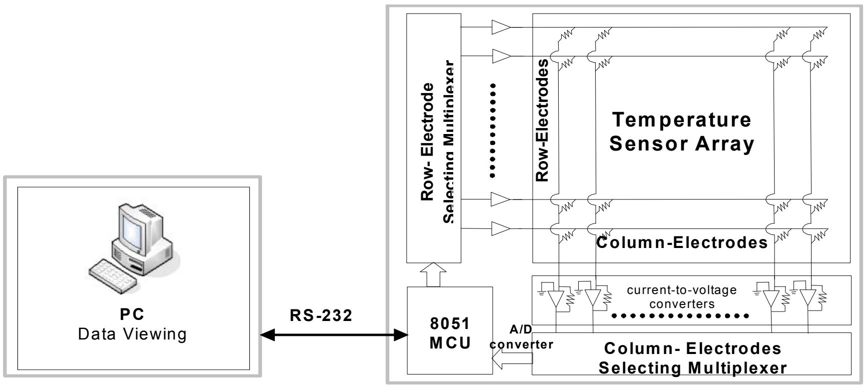


Fig. 5 Skeleton of the scanning system connected to the temperature sensor array

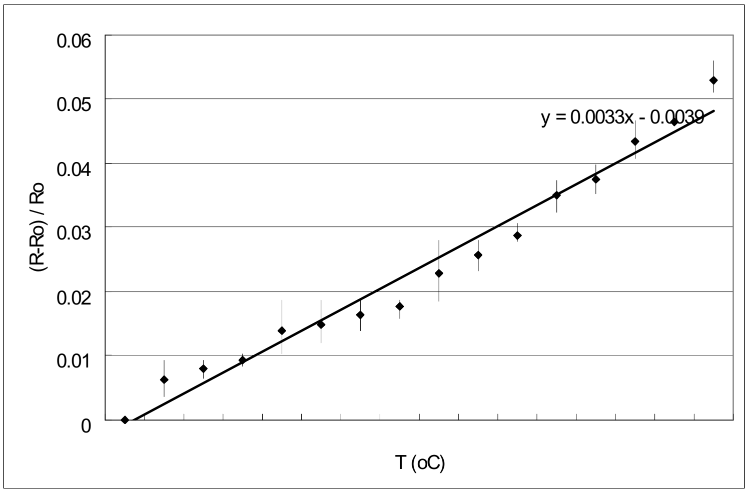


Fig. 6 The measured relationship between temperature and normalized resistance change

Conclusions

A 16×16 temperature sensor array on a 28×20 mm^2 area is fabricated on a flexible copper-PI substrate using MEMS fabrication technology. Platinum is employed as the RTD (resistance temperature detector) for sensing temperature. Fabrication process on both sides of the copper-PI film, which is essential for the interconnects of scanning circuitry, is also implemented for measuring each sensing element in the two-dimensional array. Furthermore, a scanning system is developed to get the temperature sensing information from the sensor array.

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