STRETCHABLE ARRAY OF RESISTIVE PRESSURE SENSORS IGNORING THE EFFECT OF STRAIN-INDUCED DEFORMATION

Ryosuke Matsuda, Satoru Mizuguchi, Fumika Nakamura, Takuma Endo, Go Inamori, Yutaka Isoda, and Hiroki Ota

Department of Engineering Yokohama National University, Kanagawa, JAPAN

ABSTRACT

In this study, a stretchable array of resistive pressure sensors which could ignore the effect of stretch deformation was demonstrated. In terms of stretchable pressure sensors composed of elastic materials, pressure sensors itself are deformed during strain of the devices, which becomes large error of the pressure measurement. Our resistive sensors in a array are based on patterned porous conductive silicone (Ecoflex). The substrate consists of hetero-silicone rubbers of two different elastic silicones. In addition, resistances of column and row electrodes in the matrix of mapping are much lower than the pressure sensors. This substrate and control of electrode resistances can prevent stretch deformation of the device from affecting the sensing of pressure. The error of the pressure sensor in our device during 150 % strain was one sixth less than the one by conventional elastic pressure sensor composed of organic materials. This result suggests possibility to apply stretchable pressure sensor on largely deformed area of body, and soft robots.

INTRODUCTION

Stretchable electronics, the next step beyond flexible electronics, are driven by advanced organic materials and microfabrication techniques. In particular, the array of physical sensors such as pressure mapping are highly demanded for robotics, display, and wearable electronics. Therefore, a lot of stretchable array of pressure sensors have been developed using carbon nanotubes [1], PEDOT: PSS [2], and Polyaniline nanofibers [3]. However, large error in pressure sensors using elastic materials occurs during stretch deformation of the device, because the sensor itself deforms at that time. Here, we propose a stretchable array of resistive pressure sensor which can ignore the effect of stretch deformation using hetero-silicone substrate and resistance control of electrodes and sensors (Fig. 1a).

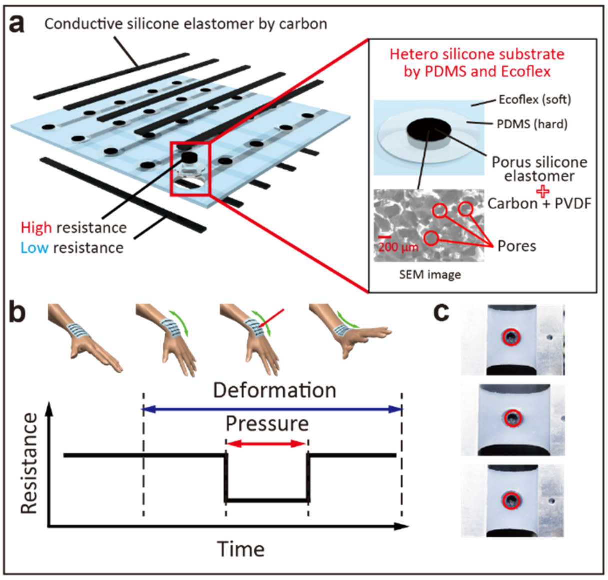

Figure 1: Stretchable array of resistive pressure sensor ignoring the effect of strain-induced deformation. a. The schematic of the array. The pressure sensor is composed of a porous silicone elastomer with carbon nano particle for conductivity. b. Sensing elements in this array sensor are surrounded by harder silicone to avoid drastic deformation. c. Porous silicone elastomer for the pressure sensor (red circle) does not deform under stretch deformation.

METHOD

In this study, the device is made by conductive carbon paste and conductive porous silicone elastomer. This section is aimed at describing the fabrication procedure of these materials.

Fabrication of conductive materials

The preparation method of the low resistance conductive paste is shown below. First, 220 mg of Super P carbon black was added to 5 mL of chloroform and stir at 500 rpm for 30 minutes with stirrer. After ultrasonic treatment for 30 minutes, stir again for 15 minutes. Then, 2 g of Ecoflex 00-10 A and 1 g of B were added to this solution. After stirring for 15 minutes again, the low resistance carbon paste was prepared. (Fig. 2a)

The high resistance conductive carbon solution was made as follows: first, 10 mg of Super P carbon black and 60 mg of PVDF (PolyVinylidene DiFluoride) were added to 1 mL of NMP (N-methylpyrrolidone). After stirring at 500 rpm for 30 min with a stirrer, the solution can be prepared by sonication for 30 minutes. (Fig. 2b)

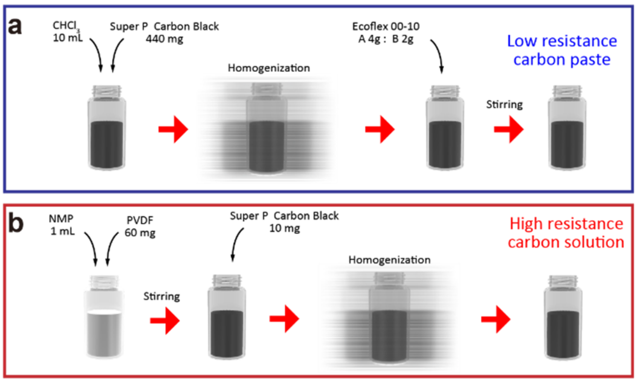

Figure 2: Fabrication of conductive materials. a. fabrication method of low resistance carbon paste. b. fabrication method of high resistance carbon solution.

Fabrication of single pixel test device

Using these two conductive materials, a single pixel sensor test device was fabricated. This resistive sensor array was based on conductive carbon paste and patterned porous silicone with conductive carbon solution. Figure 3a shows the fabrication process of a single pixel test device. First, liquid Ecoflex 00-20 was poured into 3D printed mold (Fig. 3a-i). After curing and peeling off, liquid PDMS was poured into the hole center of the Ecoflex sheet (Fig. 3a-ii). After curing, a smaller hole was made on the center of PDMS (Fig. 3a-iii) and small amount of sugar was put into the hole (Fig. 3a-iv). Then, liquid Ecoflex was poured onto the sugar. Ecoflex penetrated sugar by Vacuuming (Fig. 3a-vi). After penetration, sugar was dissolved using ultrasonication.

Using this method, porous Ecoflex was fabricated in the hetero-silicone substrate. After this, super P carbon black and PVDF mixture solution was penetrated this porous silicone (Fig. 3a-vi). The resistance of this conductive porous silicone is made higher using PVDF with carbon powder. Finally, the column and row electrodes in the passive matrix for sensor mapping was formed by conductive Ecoflex containing carbon black paste (Fig. 3a-vii).

Figure 3b ~ 3e shows SEM images and EDS results of the surface of porous silicone with carbon and PVDF mixture solution.

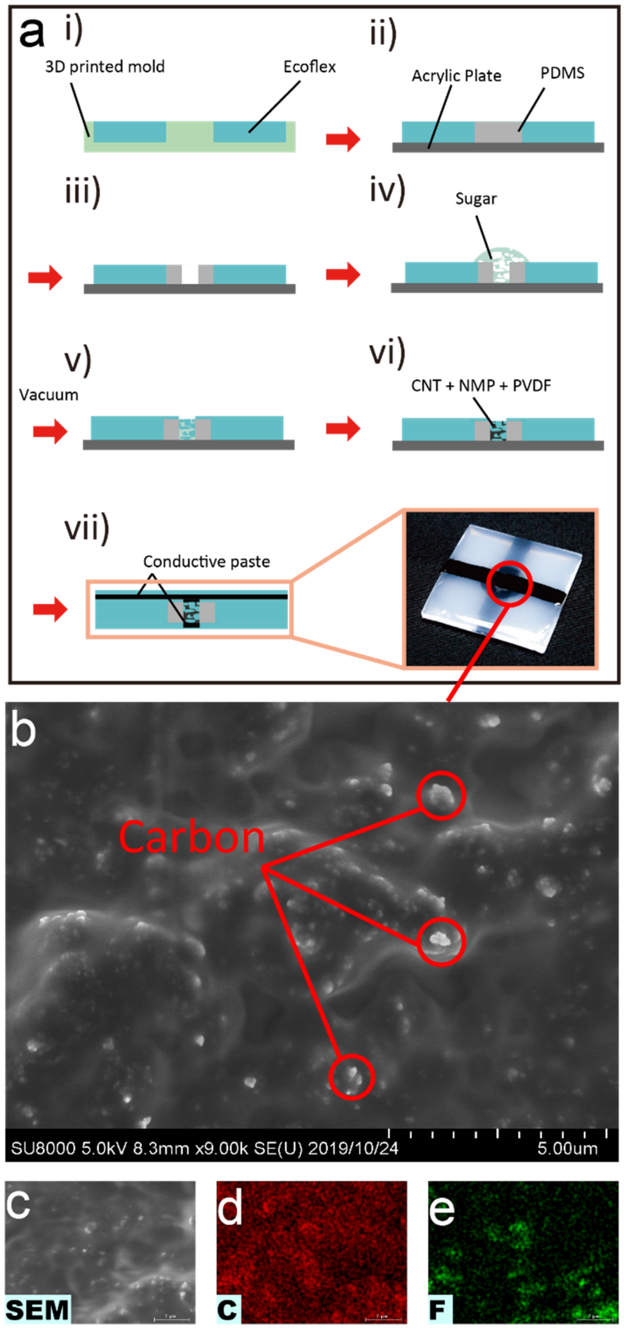

Figure 3: Fabrication method of single pixel test device and SEM images. a. fabrication method of single pixel test device using porous silicone and hetero silicone substrate. b. SEM image of the surface of the porous silicone with high resistance liquid by carbon and PVDF mixture. c~e. SEM and EDS images of carbon and fluorine at the same spot on the sensing element.

RESULTS

Characteristics of single pixel test device

Figure 4 shows the characteristics of 1 px test device. Fig. 4a shows the change of pressure sensor's resistance when the device is strained. As shown in this graph, the pressure sensor with hetero-silicone substrate is not sensing the effect of strain-induced deformation comparing sensor made by only Ecoflex without hetero-silicone substrate.

Fig. 4b shows the resistance change of pressure sensor under pressure. As shown in Fig. 4b, the porous structure has higher sensitivity of pressure than regular conductive silicone elastomer.

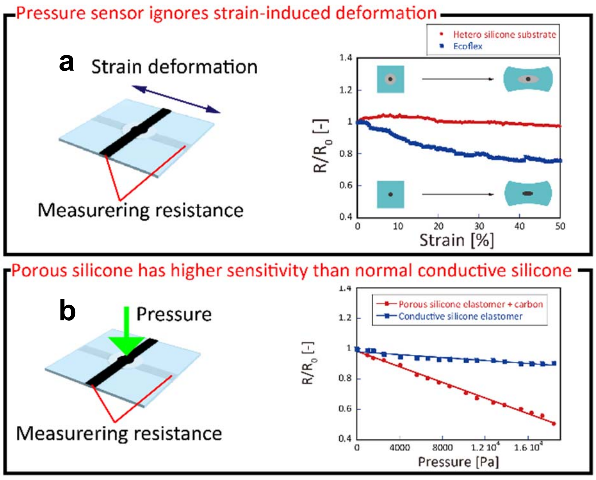

Figure 4: characteristics of single pixel test device. a. Resistance change of the sensor on usual Ecoflex and hetero-substrates under 50 % strain deformation. b. Resistance change of porous and regular conductive silicone with respect to pressure.

Fig. 5 shows the resistance change by 150 % strain was relatively small in comparison with resistance change by 30000 Pa of pressure.

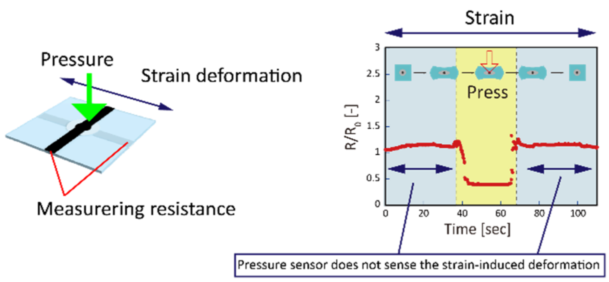

Figure 5: Pressure sensitivity of 30000 Pa under 50 % strain deformation.

Demonstration

As a proof-of-concept, Fig. 6a indicates 9 px pressure mapping worked correctly during 2 dimensional strains. Considering the application for wearable electronics, we demonstrated display control on a wrist by the device consisting of 2 pixel pressure sensors during movement of hands. Figure 6b indicate "Y", "N", "U" on the display based on the pattern of pressing sensors.

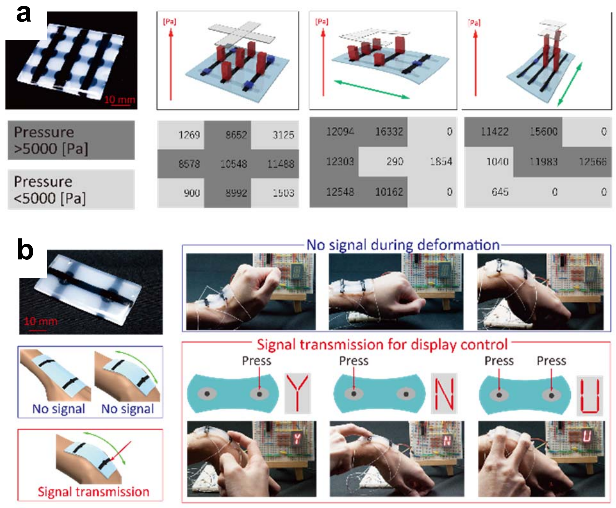

Figure 6: Demonstration of the array of pressure sensors. a. 9px Pressure mapping during stretch deformation. b. Stretchable pressure switch for display control. A signal is not transmitted to the system of the display while the device is strained but transmitted when the sensor elements are pressed.

CONCLUSION

In conclusion, fabrication of stretchable array of resistive pressure sensor was demonstrated in this work. This pressure sensor can ignore the effect of strain induced deformation because of hetero-silicone substrate. Then, this sensor can sense the pressure independently under strain deformation.

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CONTACT

H. Ota, tel,+81-45-339-4330
ota-hiroki-xm@ynu.ac.jp