HIGH PERFORMANCE FLEXIBLE CAPACITIVE PRESSURE SENSOR FOR WEARABLE TECHNOLOGIES

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Abstract

Flexible capacitive pressure sensors have applications in a wide variety of fields, especially soft robotics, bioelectronics, wearable devices and healthcare applications. In this study, a capacitive pressure sensor has been designed and fabricated using silver, nickel, and carbon nanoparticle conductive inks. Pad printing method was used to print nanoparticle inks on a polyamide-based taffeta label fabric. Capacitive pressure sensor underwent testing through three methodologies; these are pressing different fingers on the sensor surface, dropping water on the sensor and applying bending-relaxation process to the pressure sensor to determine sensor performance measuring capacitance variations. The capacitance of the fabricated pressure sensor changed according to the type of finger pressed and the number of water droplets dropped. As the amount of water droplets and the force of the pressed finger increase, the capacitance changes in the printed sensor also increase. On the other hand, there was no significant change in the capacitance values of the sensor after the bending-relaxation application. This shows that the proposed flexible pressure sensor can be used in wearable electronics, human-robot interactions, pressure mapping or detection of finger touch.

Keywords: Pad printing, pressure sensor, conductive ink, flexible, capacitance measurement

1. INTRODUCTION

Flexible pressure sensors with various sensing mechanisms, especially piezoelectric [1], triboelectric [2], resistive [3] and capacitive [4], have become widely used in robotics, bioelectronics, human motion and wearable health monitoring applications. Compared to traditional and rigid pressure sensors, flexible sensors are distinguished by their ability to be bent and deformed, as well as their high sensitivity at low pressures and rapid response times [5], [6]. Furthermore, the stable and straightforward structure of capacitive pressure sensors, coupled with their low power consumption and cost-effective manufacturing, are reasons for their frequent preference [7], [8]. Flexible pressure sensors are essentially capacitors composed of two electrodes and a dielectric layer interposed between them. The application of pressure causes variations in the thickness of the dielectric layer and the distance between the electrodes, resulting in changes in the sensor's capacitance [5], [9].

In the production of capacitive pressure sensors, structures such as fibers, fluids, microstructured or porous elastomers, foam, composites are used as dielectric materials, and the sensitivity of these sensors is proportional to the compressibility of these dielectric materials [5], [7], [10]. A high sensitivity capacitive pressure sensor fabricated using double layer polydimethylsiloxane (PDMS) coated with silver nanowire electrodes was proposed in the study by Wang et al [11]. In another study, a capacitive pressure sensor obtained using hemispherical porous PDMS and carbon nanotube (CNT) used in monitoring pulse and joint movement was presented [12]. Qiu et al. produced a high-sensitivity, capacitive, and flexible tactile sensor from a 3D porous conductive composite using a polyurethane sponge substrate by dip-coating method [13]. The most critical parameters in sensor manufacturing processes are the ease of operation and low-cost. Additionally, possessing high sensitivity and being thin and miniature are also sought-after characteristics of sensors.

In this work, we report on the development of a high sensitivity printed flexible capacitive pressure sensor fabricated through pad printing method utilizing silver/carbon/nickel conductive ink. We evaluated the performance of the pressure sensors by measuring the capacitance variations of sensors produced without an elastic dielectric layer. Based on the obtained results, we believe that the proposed capacitive and flexible pressure sensor holds significant potential across various applications, ranging from wearable technologies to robotic implementations and human-robot interactions.

2. EXPERIMENTAL STUDY

2.1 Chemicals and Materials

In this study, silver, carbon, and nickel nanoparticle conductive inks were used for producing the electrodes of the pressure sensor. Silver, carbon, and nickel nanoparticle inks were mixed in a magnetic stirrer at a weight ratio of 1:1:1 until it becomes homogeneous. A polyamide-based taffeta label fabric was selected as a substrate. Waterproof polyurethane welding tape was used to cover the capacitive pressure sensor. The thickness of the welding tape is 44 µm.

2.2 Capacitive Pressure Sensor Fabrication

Interdigital electrodes were used for the design of the capacitive pressure sensor. The electrodes, which can be designed in many different shapes according to different gap patterns, have a square wave air gap [5]. The silver/carbon/nickel ink mixture prepared for the fabriation of pressure sensor was printed on polyamide taffeta label fabric using a pad printing machine, which has a fast and easy application. The image of the pressure sensor, which was printed 5 times to increase conductivity, is shown in **Figure 1**. Since the conductivity of nanoparticles increases with heat treatment, the printed sensor was subjected to a sintering process in an oven at 150°C for 30 minutes after the printing process. Except for the uncoated sensor, the sensor printed was covered with polyurethane welding tape using a hot press machine in order to find out whether the coating of the sensor surface has an effect on the capacitance performance of the sensor. The important point here is the softening temperature of the welding tape. Based on the datasheet of the welding tape, the hot press machine was operated at 90°C. Another important point is that while the sensor is being coated, the ends of the sensor are left open in order to take measurements with the multimeter.

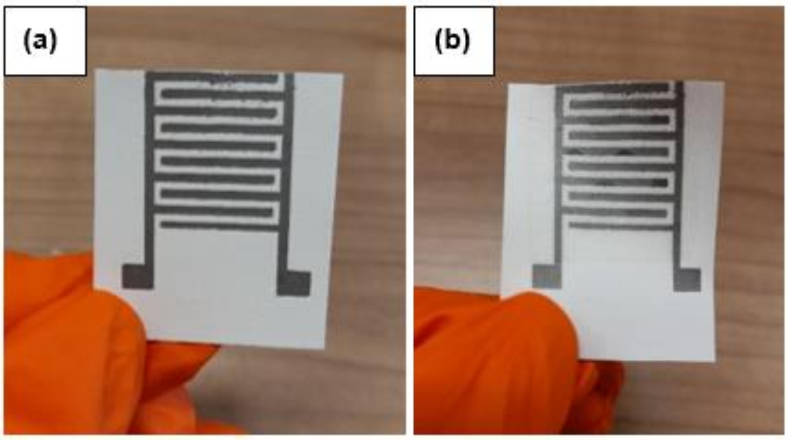

Figure 1 (a) Printed pressure sensor without coating, (b) Printed pressure sensor coated with welding tape

2.3 Capacitance Measurement

To evaluate the performance of coated and uncoated silver/carbon/nickel printed sensors, tests including finger pressing, water droplet application, and bending were conducted. Capacitance measurements were performed by direct contact of the probe tips of the Fluke 17B+ digital multimeter to the pressure sensor.

3. RESULTS AND DISCUSSION

Finger pressing was first applied to coated and uncoated silver/carbon/nickel printed sensors. Higher finger pressing force increases the relative capacitance. Increasing finger pressing force increases the contact angle between the finger and the sensor and creates a smaller parallel contact resistance in the circuit, thus producing a larger capacitance [5]. In this study, since fingers have different pressing forces, the middle finger, index finger and thumb were pressed separately on the pressure sensors and the capacitance changes were measured with a multimeter. The capacitance response graph of uncoated and coated sensors when pressed with three different fingers is given in **Figure 2**. Based on the capacitance changes shown in **Figure 2**, the highest capacitance change in both sensors according to finger pressing force and finger areas was obtained when the thumb was pressed, while the lowest capacitance change was obtained when the index finger was pressed. At the same time, the capacitance change in the uncoated pressure sensor is higher than the coated sensor. This shows that the uncoated sensor is more sensitive to the pressing force.

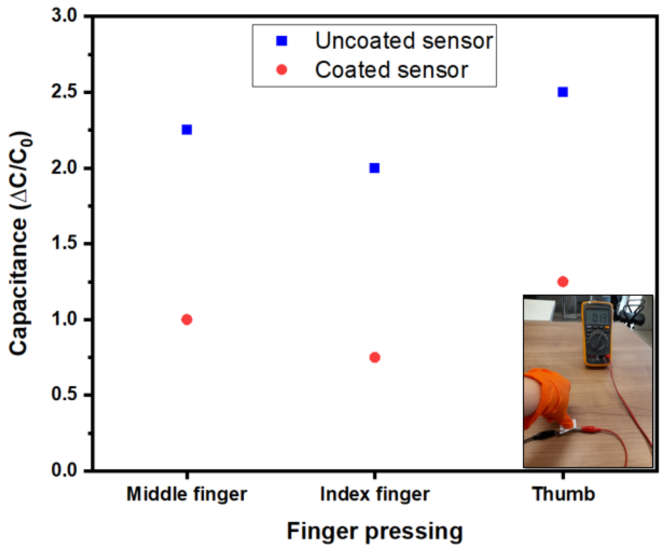

Figure 2 Capacitance response of the uncoated and coated sensors when pressing middle finger, index finger and thumb

Additionally, distilled water was dropped onto coated and uncoated sensors to measure the effect of the weight of water drops on capacitance changes in the sensors. Distilled water was dropped onto the sensors from 1 to 10 drops, each drop volume being 0.01 mL. Following the application of each water drop, the capacitance response of the sensors was measured with the help of a multimeter. Capacitance measurements were first started with the uncoated sensor. The capacitance change on the uncoated sensor could not be measured with the multimeter after the second drop of water. It is estimated that this situation is due to the absence of any dielectric layer between the electrodes.Therefore, in the continuation of the study, water droplets were dropped only onto pressure sensors coated with polyurethane welding tape. The capacitance change graph obtained when distilled water droplets were dropped onto the coated sensor is presented in **Figure 3**. The capacitance values read from the multimeter when each water droplet falls onto the sensor surface are also given in the figure. According to the capacitance responses in **Figure 3**, as the number of water droplets on the sensor surface increases, both the capacitance and the capacitance change in the sensor increases.

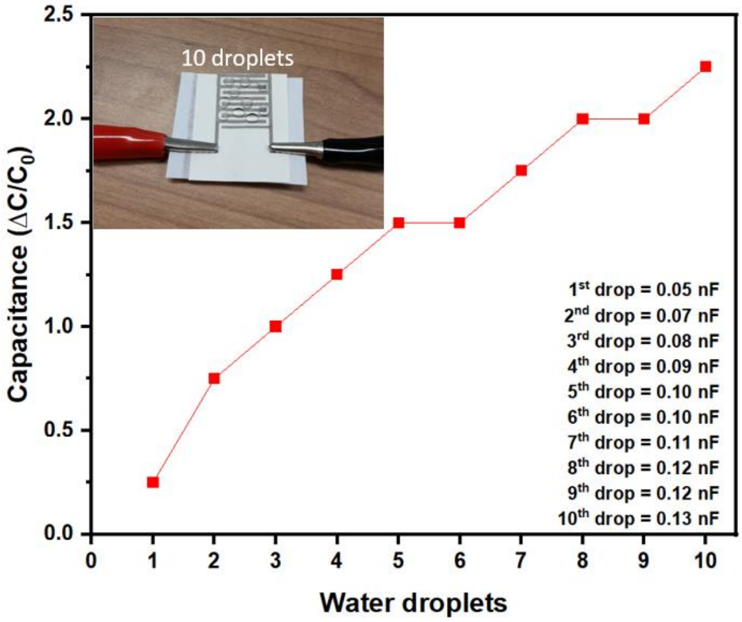

Figure 3 Capacitance response of the coated sensor when dropping distilled water

In addition to the water dropping and finger pressing tests, a bending test was applied to the printed sensor to test the suitability of the proposed pressure sensor especially for wearable technologies. To measure the stability and performance of the sensor against bending, the sensor was bent and released 10 times. The capacitance measurements were made by finger pressing the sensor before and after bending and compared these values in order to understand the performance of the sensor. **Figure 4** shows the capacitance change after applying force with the thumb to the coated pressure sensor before bending, while **Figure 5** indicates the capacitance results after the same application after bending process. When the graphs in **Figure 4** and **Figure 5** are examined, the values of the capacitance changes of the pressure sensor before bending and after the bending-relaxation application vary between 0.9 and 1.3. When the graphs are compared, the capacitance changes after the bending-relaxation process are quite similar to the capacitance changes of the sensor before bending. Therefore, the proposed flexible pressure sensor shows high resistance to bending.

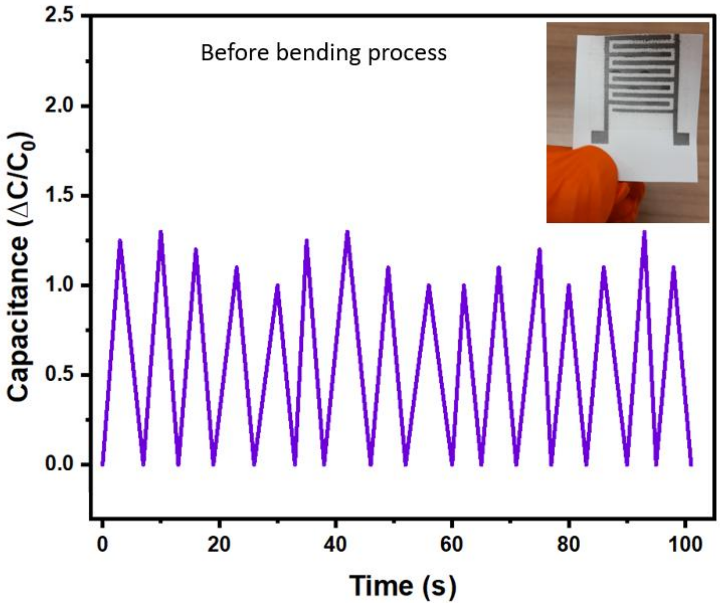

Figure 4 Capacitance change of the sensor before bending process

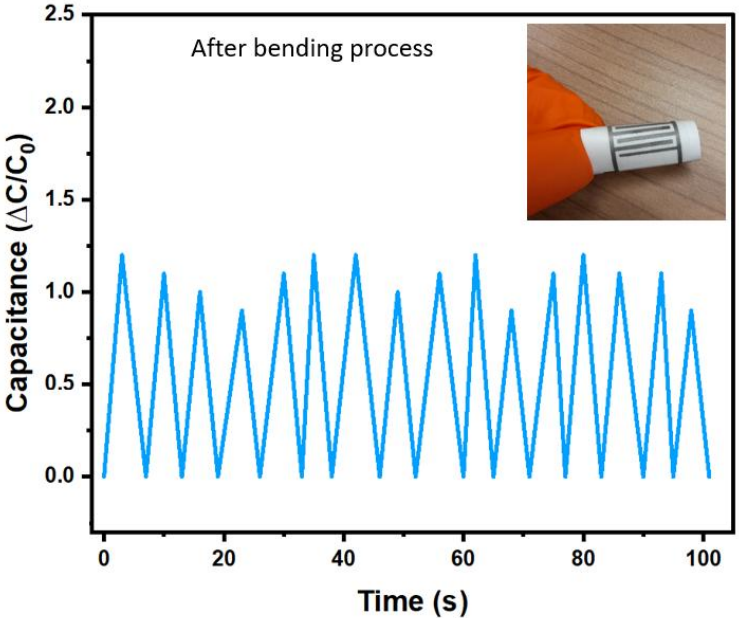

Figure 5 Capacitance change of the sensor after bending-relaxation process.

4. CONCLUSION

As a result, in this study, a flexible capacitive pressure sensor was fabricated by pad printing machine using silver/carbon/nickel mixture ink, especially targeting wearable technologies and robotic applications. To investigate the performance characteristics of the sensors, capacitance responses were examined using a multimeter by applying force with three different fingers on sensors coated with polyurethane welding tape and those without any coating. Since the capacitance change in the uncoated pressure sensor is greater as a result of finger pressing, the sensitivity of the uncoated sensor to pressure was found to be better. On the other hand, no meaningful results were obtained in the capacitance values of the uncoated sensor in the capacitance changes measured for the pressure formed by the weight of the water droplets. This situation highlighted the advantage of the coated sensor. Repeated bending-release process was applied to demonstrate the flexibility of the proposed sensor. The capacitance changes of the sensor after bending give very close results to the capacitance changes before bending. As a result, it is foreseen that the capacitive printed pressure sensor is flexible, bendable, highly sensitive and will be advantageous in areas such as human monitoring systems, robotics, wearable technologies, and bioelectronics.

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