Screen Printed Flexible Capacitive Pressure sensor

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Abstract—**A novel flexible fully printed capacitive based pressure sensor was designed and fabricated using screen printing technique. Silver (Ag) ink and polydimethylsiloxane (PDMS) were printed on a flexible polyethylene terephthalate (PET) substrate as metallization and dielectric layers, respectively. The capacitive response of the sensor demonstrated a percentage change of 1 % and 3.6 % for compressive forces of 0.2 MPa and 2.4 MPa, respectively when compared to the base capacitance. The response of the pressure sensor is analyzed and presented in this paper**.

I. Introduction

There has been an emerging interest in the development of flexible electronics, especially sensors and sensing systems, during the last decade [1-8]. Flexible pressure sensors have different applications in the aerospace, automotive, and biomedical engineering fields. Conventional CMOS processes are generally used for the fabrication of pressure sensors which are usually expensive and the devices are typically fabricated on rigid substrates [9-12]. Nowadays, for various sensing applications, especially in health monitoring, flexibility has been an important factor for better interface with body. Most of the fabricated pressure sensors using silicon based technologies are based on hanging structures or cavity based devices [13-17]. The rigidness of these devices renders them unsuitable for applications which require flexibility. The development of cost effective, flexible and conformal pressure sensors using alternate fabrication processes is therefore important to overcome the drawbacks associated with conventional fabrication processes.

In recent years, the fabrication of electronic devices utilizing traditional printing methods has attracted increasing attention [18-22]. Some of the advantages associated with traditional printing methods include improved cost efficiency, reduced wastage of material during fabrication, flexibility and low manufacturing temperatures [23]. Some examples of fabricated devices using printing techniques include substrates for surface enhancement Raman spectroscopy (SERS) [24], electrochemical sensors [25], organic thin film transistors [26], electronic circuit boards [27] and humidity sensors [28]. Recently, polydimethylsiloxane (PDMS), a transparent silicone elastomer, has become a popular dielectric material for the fabrication of sensors and electronic devices [29-31]. There have been some reports that employ PDMS for the fabrication of pressure sensing systems. One of the main advantages of using PDMS is that the dielectric constant of PMDS is 2.65, which is larger than the dielectric constant of air, and this result in a higher base capacitance as well as a greater change in capacitance when pressure is applied [31]. Even though we have reported previously employing of gravure and screen printing for fabrication of pressure sensor [31], there are no reports on fully screen printed PDMS based pressure sensors.

Screen printing is widely used for the deposition of functional electronic materials on different substrates. One of the main advantages of screen printing is the ability to provide thick layers of deposited material which is difficult to achieve using other printing methods. In screen printing technique, the mask (screen) is not in direct contact with the substrate. The main components of a screen printer include squeegee and image carriers or screen. The squeegee is usually made of rubber or polymeric raw materials. The screen consists of a frame and stencil. The typical material used for the frame is aluminum. Metal, fabric, plastic or other similar types of materials, based on different inks and applications of screen, are used for manufacturing the screen fabric. The materials which are used for screen mesh and fabric depend on the solvent and cleaning agent. The ink will be transferred on the screen and then by employing pressure on the squeegee, the ink will be swept through out the screen while the ink will be deposited on the substrate through the screen mesh. Screen printing can be done at room temperature and high viscosity inks (0.5-50 Pa s) are used in this process.

In this work, screen printing method was used for the fabrication of a fully printed flexible pressure sensor. Silver (Ag) ink, as a metallization layer, was deposited on the top and bottom of a PDMS based dielectric layer. The top and bottom electrodes as well as the dielectric layer were screen printedThe ability of the printed device to be used as a pressure sensor was analyzed by tracking the capacitance change of the sensor based on varying applied forces.

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II. EXPRIMENTAL

A. *Chemicals, and Sample Preparation*

A transparent PET (Melinex ST 506) film from DuPont Teijin Films, with average thickness of 130 µm, was used as the substrate. Conductive Ag ink (Electrodag 479SS) from Henkel was used as a metallization layer. PDMS (Sylgard® 184 Silicone Elastomer) was purchased from Dow Corning. The PDMS in liquid form was mixed in a 10:1 (w/w) ratio with the included curing agent and stirred vigorously until well mixed. The mixing introduces bubbles that were removed by setting aside the mixture at room temperature for 30 minutes.

B. *Sensor Fabrication*

The fabrication process was done at Center for the Advancement of Printed Electronics (CAPE). The schematic of the design is shown in Fig. 1. Initially, the bottom metal electrode with an area of 144 mm^2 was screen printed on PET using HMI 485 semi-automatic screen printing press. The thickness of printed layer was measured to be 14.3 µm using a Bruker vertical scanning interferometer microscope (CounterGT), as shown in Fig. 2. A 196 mm^2 PDMS dielectric layer was then printed on top of the bottom electrode. Finally, the 81 mm^2 top electrode was screen printed on the PDMS, with a grid structure. The thickness of the top layer was measured to be 17.9 µm (Fig. 3). The thickness of the final device was measured to be 48.2 µm. The photograph of the final device consisting of the three printed layers is shown in Fig. 4.

C. *Experiment Procedure*

The experimental setup is shown in Fig. 5. A vertically movable platform and force gauge (Mark-10 M5-200) was used to apply varying compressive forces to the sensor and the capacitive response of the printed sensor was measured. The sensor was placed between the force gauge and movable platform. Test wires were connected to the sensor using silver epoxy from Circuit Works (CW 2400). An Agilent E4980A LCR meter along with a custom built LabVIEW™ program was used for measuring the capacitive change. The sensor was connected to the LCR meter through the attached test wires.

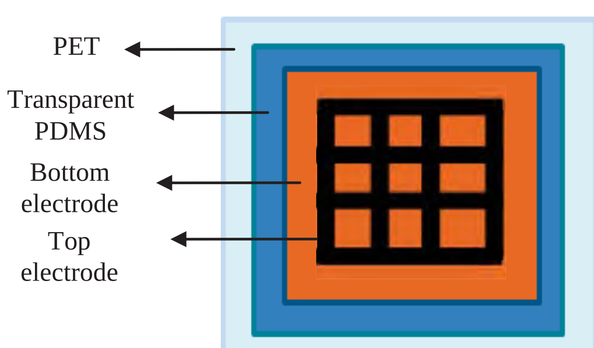

Figure 1. Schematic of the sensor.

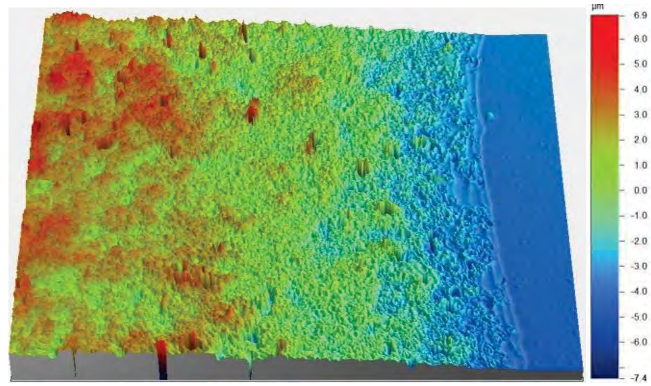

Figure 2. Vertical scanning interferometry of bottom electrode

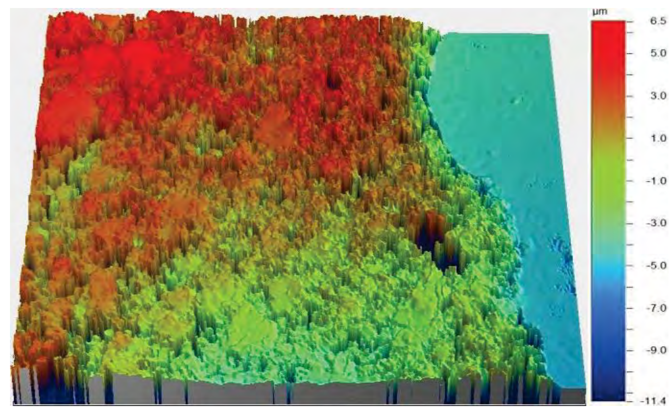

Figure 3. Vertical scanning interferometry of top electrode.

Figure 4. Photograph of fully screen printed pressure sensor

Figure 5. Experimental setup.

III. RESULTS AND DISCUSSION

The printed sensor was subjected to different compressive forces. Figure 6 shows the percentage change of the capacitance towards the varying forces. It was observed that the minimum detected force was 0.2 MPa. A 1 %, 2 %, 2.2 %, 2.7 % and 3.6 % change in capacitance was observed as the pressure was increased from 0.2 MPa to 0.4 MPa to 0.8 MPa to 1.8 MPa to 2.4 MPa, respectively when compared with the base capacitance.

The working principle of the fully printed sensor is similar to that of parallel plate capacitors. The capacitance of a parallel-plate capacitor, which can be mathematically calculated using Eq. (1), is inversely proportional to the thickness of the dielectric (d).

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \tag{1}$$

where A is the overlapping plate area, d is the distance between the parallel plates (or thickness of the dielectric), ε_0 is the permittivity of free space, and ε_r is the relative permittivity of the dielectric material. The change in capacitance can be attributed to the fact that when a force is applied on the sensor, the distance between the top and bottom layers will decrease, which results in an increase in capacitance.

Fig. 7 demonstrates the dynamic response of the printed pressure sensor when varying compressive forces were applied. The base capacitance of the sensor, which was 57.2 pF, was recorded for two minutes when no force was applied. Then, 0.2 MPa was applied for two minutes and it was observed that the capacitance increased to 57.7 pF. After releasing the applied force, it was observed that the capacitance returned to its original base value of 57.2 pF, which was recorded again for two minutes. This cycle was continued for varying forces up to 2.4 MPa, which was the maximum detectable force. It was seen that the capacitance of the sensor would always back to its base capacitance, thereby demonstrating the reproducibility of the printed sensor response toward varying applied forces.

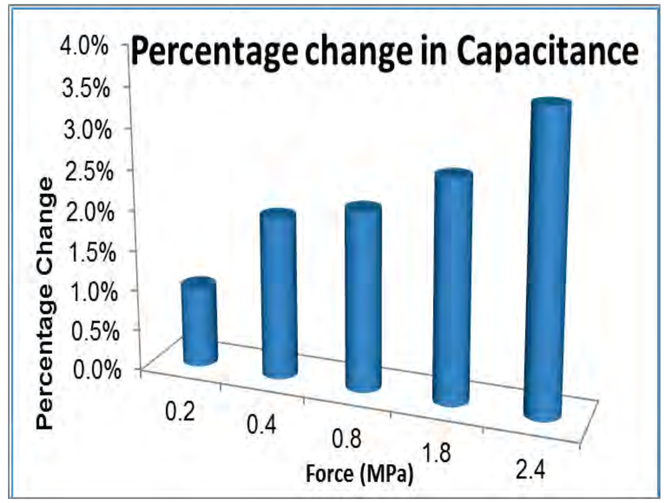

Figure 6. Percentage change in the capacitance of the printed sensor when varying compressive force were applied.

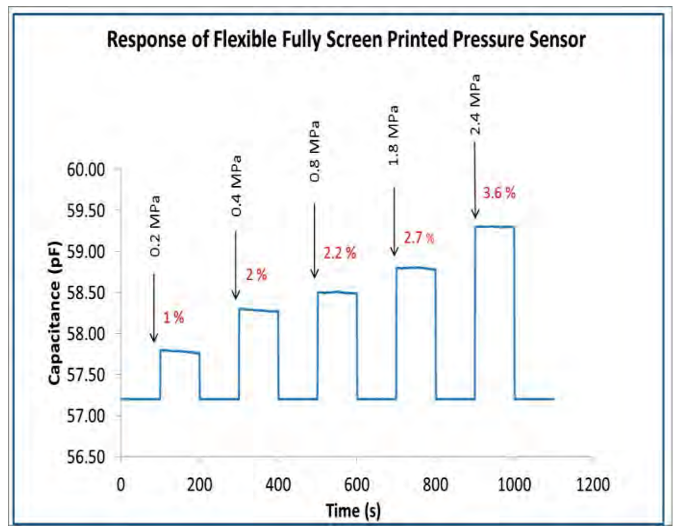

Figure 7. Capacitive response of fully screen printed pressure sensor towards different compressive forces and percentage change when compared to base capacitance.

IV CONCLUSION

Screen printing method was successfully employed for the fabrication of a fully printed pressure sensor on PET. Ag ink was used as a metallization layer for top and bottom electrode layers. PDMS was also screen printed to be used as a dielectric layer. The dimension of the final device was 144 mm^2 and the overall thickness was measured to be 42.2 µm. The capability of the sensor for detecting pressure changes was tested by subjecting it to different compressive forces. The sensor was able to detect minimum and maximum forces of 0.2 MPa and 2.4 MPa, respectively which corresponds to 1 % and 3.6 % change in the base capacitance of the sensor. The results obtained indicate the feasibility of the sensor to be used in various pressure sensing applications. Further study is underway to improve the sensitivity of the sensor and fabricate a fully printed sensing system including the sensor and readout electronic circuit board.

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