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An Ionic Liquid Based Sensor Using Coplanar Electrode Design for Pressure Measurement

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Abstract: ***These paper report the development of an ionic liquid based sensor for pressure measurement. Enhancement of the sensor design with complex fabrication techniques, due to changes in the geometry layer will affect the mechanical properties of the sensor. Due to this problem, the ionic liquid based capacitive pressure sensor using Polydimethylsilaxone fluidic systems is proposed. The proposed sensor consists of membrane, microchannel and coplanar electrodes. Polydimethylsiloxane (PDMS) material is chosen for main material based on its potential properties in fluidic systems and the soft lithography technique is used to form a PDMS structure. The fluid mechanism inside the microchannel sensor is validated between the experiment and analytical result. Ethanol is chosen as an ionic liquid due to its property that has low kinematic viscosity. The characterization process including pressure measurement, sensitivity, and linearity were carried out. From the experimental results, the sensor sensitivity is 0.072 pF/kPa.***

Keywords: ionic, liquid, pdms, pressure

1. Introduction

In recent years, the capacitive type sensors have found wide applications in medical, aerospace , industrial and others[1-3]. By utilizing the capacitive effect, the capacitive type sensors measure the external type of forces including acoustic [4], pressure [5] and other physical quantities [6]. It has been developed by researchers many years ago due to the advantages of the capacitive type sensor that has high resolution, high robustness and lower power consumption compared to the piezoresistive type sensor [7].

Generally, the capacitive pressure sensor consists two electrodes in parallel with the gap between both of it. One electrode is positive and other one is negative. Both of them is attach to a membrane channel. When the pressure is applied, the membrane is deforming and displaces the liquid [8]. The capacitance is change depending on the distance and the gap of the surface area of the both electrode and the movable electrode is sensed. The development of capacitive pressure sensors is still ongoing and various designs have been proposed. The combination of silicon micro-machining techniques and the advent of high expertise in silicon integrated circuit have opened up the opportunity for development. However, evolvement of fabrication process such as micromachining technology involves a complex fabrication technique [9]. Lately, a few researchers have proposed to use new materials and new sensing methods in order to simplify the fabrication complexity, including by using Polydimethylsilaxone microfluidic.

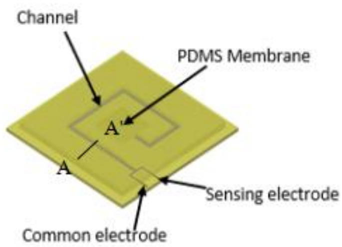
In this paper, the development process of ionic liquid based capacitive pressure sensor using polydimethylsilaxone (PDMS) fluidic systems will be discussed. PDMS offer a simple fabrication technique by using soft lithography process in order to overcome a complexity of fabrication process. In addition, soft lithograph process is one method to able simplify the process with the formation of membrane and body structure. The fabrication process and characterization process including pressure measurement, sensitivity, and linearity also will be carried out.

2. Sensor Design

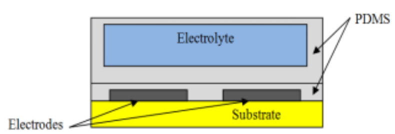
2.1 Proposed Pressure Sensor

A structure of ionic liquid based capacitive pressure sensor with electrode pattern is shown in Figure 1(a). Unlike conventional capacitive pressure sensors, this sensor has one-side-electrode structure and integrated with the PDMS fluidic system. It is consists of a rectangular membrane, microchannel, and two electrodes in parallel side by side inside the microchannel.

The liquid was fill in the cavity to form to act as an ionic liquid as shown in Figure 1(b). According to the previous research, the smallest thickness offering high sensitivity of membrane deflection [8]. Therefore, the thickness of 0.8 mm is chosen and diameter is fixed to 10 mm. The size of electrode is 0.4mm width and the separation gap between the both electrodes are 0.4mm and it is fabricated using printed circuit board process.



(a)



(b)

Figure 1: (a) Structure of ionic liquid based capacitive pressure sensor (b) Cross sectional area of A-A'

2.2 Sensing Principle

When input pressure is applied to the membrane ($P_i > P_o$), deflection occurs which then will push the electrolyte inside the microchannel. Figure 2 shows a sensor pattern for a no-load condition and for applied pressure. The displacement of the electrolyte inside the microchannel ΔL depends on the applied pressure. An electrode will sense the movement of the electrolyte inside the microchannel and create capacitance. Capacitance increases as the liquid displacement inside the microchannel increases. The relationship between changes in capacitance ΔC and changes of liquid displaced ΔL is given in Equation (3.2)

$$\Delta C = C - C_o = \frac{\varepsilon w(\Delta L)}{d} \quad (1)$$

where C_o, ε_r, ε_o, w and d are initial capacitance, dielectric constant of insulator, vacuum permittivity, width of microchannel and thickness of insulator, respectively.

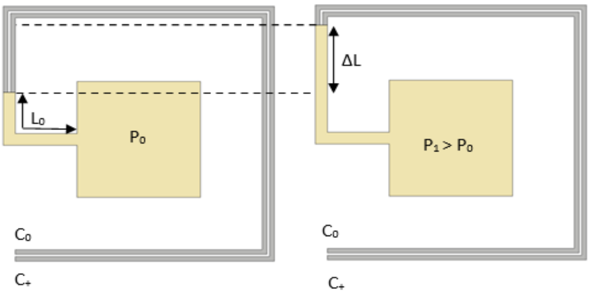


Figure 2: Sensor pattern for no load and applied pressure condition

2.3 Fluid Mechanism

In this sensor, an ionic liquid movement inside microchannel is acting as the mechanism based on the membrane deflection. The equation (2) shows the relation between pressure, P and liquid displacement, L movement where it is depends on the width, w and thickness, t of microchannel.

$$L = \frac{3\pi}{32}\frac{R^6(1-v^2)}{Ewt_c t_m^3}\left(1+ \frac{3}{256}\frac{R^6(1-v^2)^2}{E^2 t_m^6}P^2\right) \quad (2)$$

where $w, t_m, t_c, L, R, v, E,$ and P are the width of channel, thickness of membrane, thickness of channel, liquid displacement, the radius of membrane, Poisson's number, elastic modulus and the pressure applied. Two different types of ionic liquids are chosen including ethanol and water.

3. Sensor Fabrication

Sensor fabrication involves 3 stages including electrode fabrication process, the PDMS container fabrication process and sealing process. For electrode fabrication process, the coplanar electrode which located side by side is design using the software Autodesk EAGLE 8.4.1 and printed it on the top of compound site (FR4) using print circuit board (PCB) process is shown in Figure 3(a-b). It consists of two electrodes; make sure both of these electrodes are not connected to each other. The width is 0.4mm for both electrodes and the gap is 0.4mm. After that, the electrode is coated on the top of electrode with PDMS solvent by using the spin coating at the uniform rotation until the requirement thickness is obtained (Figure 3(c)). The thickness layer of PDMS on the top the electrode is about 50µm.

For the container process, this process is using soft lithography process. The PDMS material is selected as a membrane. The PDMS is easy to handle, easy to fabricate and also easy to create any geometry. The PDMS solvent is make by mixing the elastomer base and the curing agent at the ratio 10:1 and stirring well. Prior to that, the mold is fabricated by using the rapid prototyping machine with the base container as shown in Figure 3(d). The size of mold is 1 mm for height and width and the radius is 5 mm. After that, the PDMS solvent is poured in the base container as shown in Figure 3(e). Then, the base container is baked in the oven at temperature 100 for 15 minutes for hardened PDMS. After the PDMS is became harder, the PDMS container is peel off slowly from the base container to make sure it does not break or failure. Figure 3(f) is shows the hardened PDMS.

Lastly, the sealing process. In this stage, the electrode and the PDMS container is sealed together with the PDMS solvent as shown in Figure 3(g). Prior to that, the PDMS container need to adjust properly to ensure the microchannel and electrode is linearly aligned. After that, that sample is baked in the oven at room temperature 25 for 48 hours to seal the sensor. Lastly, wire bonding is performed using single core wire for the measurement that the sensor is enable to connected to the LCR meter. Figure 4 is shows the final fabricated sensor.

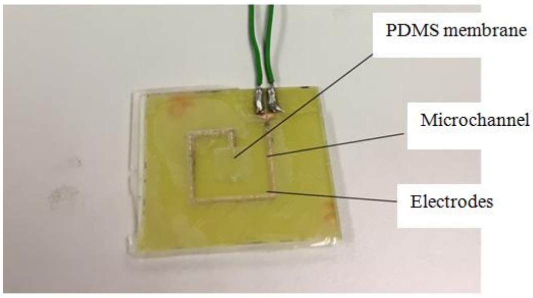


Figure 4: The ionic liquid based capacitive pressure sensor

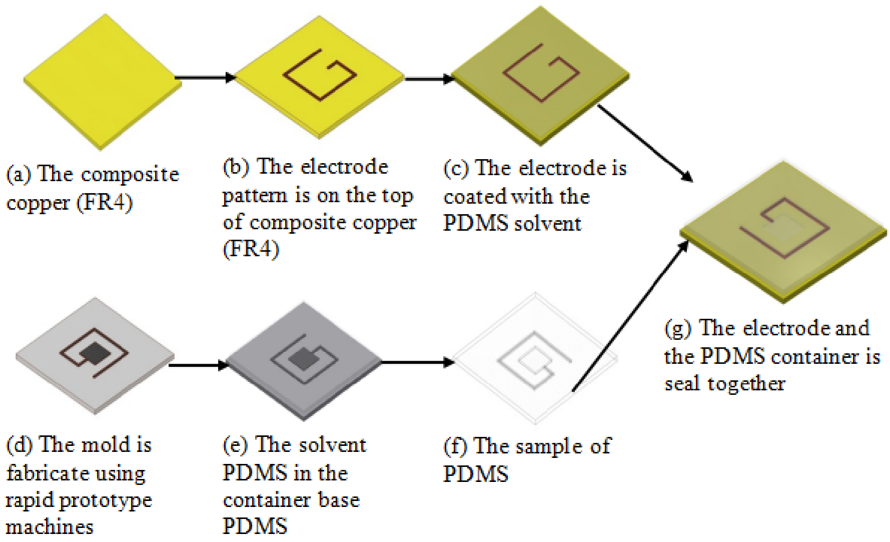


Figure 3: fabrication process (a-g)

4. Result and Discussion

The ionic liquid is injected manually using the syringe at the thickest area of membrane. For experimental setup, both wires of electrodes were connected to the LCR meter (Applent AT826). This LCR meter allows us to record the measurement of raw data in real time. A picture for measurement pressure setup is shows in Figure 5. The input pressure was applied by using uniform load to the membrane and the result were given in capacitance. The input range was from 1 kPa to 9 kPa. Two parameters were observed, including the liquid displacement inside the microchannel and capacitance response for different types of liquid. The sensor was also characterized for linearity, hysteresis and sensitivity.

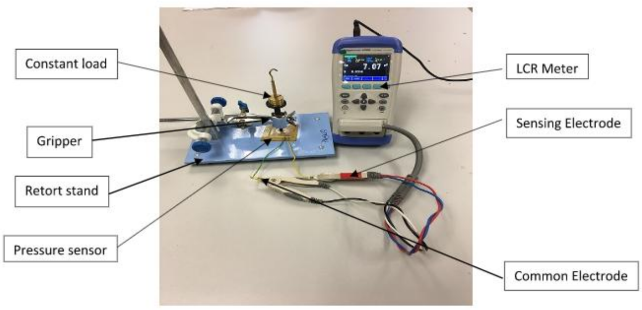


Figure 5: The picture for measurement setup.

4.1 Liquid Selection

For the selection of liquid, there are a two different liquids is selected based on their different properties. The important parameter such as dielectric constant, kinematic viscosity and surface tension as list in Table I. The important factors to select the liquid is the movement of liquid which easy to move. The movement of liquid depends on the surface tension and kinematic viscosity. However, a liquid with high dielectric constant must be used to ionize the solution to realize the high performance of capacitive type sensor.

Table 1: Properties of different types of liquid

Properties	Types of liquid	
	Water	Ethanol
Dielectric constant	80.10	24.3
Surface tension (nN/m)	72.86	22.39
Kinematic Viscosity (mm^2/s)	1.79	1.30

4.2 Validation for Liquid Mechanism

In this section, the movement of different types of liquid was measured at mili scale for various applied pressures. In addition, the analytical result is validated with the experiment result. The graphs in Figure 6 shows that liquid displacement for different types of liquid are linearly increased as the pressure increased where a liquid displaced approximately 1 mm for each 1 kPa. One of the important factors to select the liquid is easy liquid movement. Water with high dielectric constant, was not considered in this study due to high surface tension resulted in difficult movement. The liquid movement depends on the surface tension, kinematic viscosity and dielectric constant. Liquid with high surface tension and high kinematic viscosity such as water will restrict the movement of liquid inside the microchannel. Considering the requirement for electrical and surface tension of liquid, ethanol was selected as electrolyte.

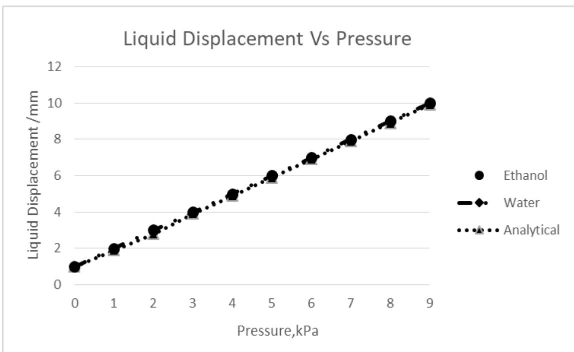


Figure 6: The measurement liquid displacement with Ethanol, Water and Analytical

4.3 Pressure Measurement

For pressure measurement, the applied pressure was varied from 1 kPa to 10 kPa. The measurements were triplicated to ensure accuracy of data. Figure 7 shows the output sensor response in capacitance where the capacitance increased as the applied pressure increased. The experimental data were closely aligned with the linear curved fit. From the graph, the sensitivity of the sensor was obtained as 0.072 pF/kPa.

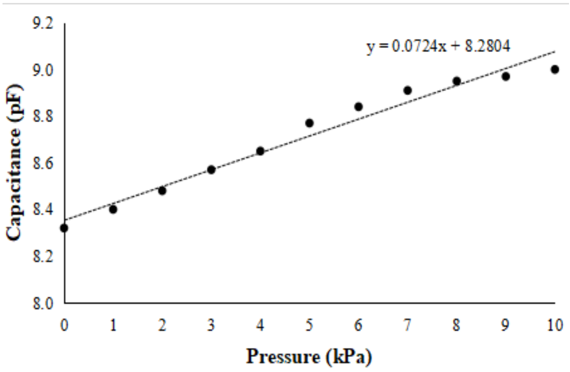


Figure 7: Sensor response in capacitance with variation of input pressure

5. Conclusion

An ionic liquid based capacitive pressure sensor using polydimethylsilaxone fluidic systems has been successfully fabricated and characterized. The proposed sensor consisted of membrane, microchannel and electrodes. Simple fabrication processes of PDMS container using soft lithography process, printed circuit board process for electrode were demonstrated. Ethanol liquid was selected as an electrolyte because it has low viscosity which enhances the sensor response. The ionic liquid based capacitive pressure sensor was characterized for pressure measurement, sensitivity, linearity and hysteresis. The sensitivity of the sensor was equivalent to 0.072 pF/kPa. The results also demonstrated the stability and linearity of the sensor between input and output. As further work, other type of liquid can also be explored this may perform better than ethanol in order to improve sensor response.

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