Fabrication of fluidic based capacitive pressure sensor using printed circuit board and soft lithography process

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Abstract. This paper describes the process of developing a device with planar electrode sensor using capacitance measurement. The project investigate the feasibility and characterization of planar pressure sensor integrated on a polydimethylsiloxane (PDMS) channel. A 2-planar electrodes, with each dimension of the electrode, 50 mm x 4 mm (length x width) and the gap between 2 electrodes was 0.4 mm was fabricated using a printed circuit board (PCB) technology due to its low cost advantage. The PDMS channel was bonded on the PCB with cured to create a rectangular shape sensing for loading the pressure. The mold of PDMS channel was developed by designed using Autodesk Inventor 2017 and was fabricated using a 3D printer. Capacitance measurement of the planar electrodes was carried out using water and ethanol as the sample that inside the channel. Experimental result shows that the measured electrodes are ethanol and water, linear proportional to the capacitance value. The value of ethanol is higher that the water which was the range was 11 pF to 13pF for ethanol and for the water was 9 pF to 10pF. The result shows that the planar sensors are able to provide capacitance measurement within the device platform where, the ethanol value provide larger output as compared to the water value.

1 Introduction
Recently, the uses of the sensor in our daily has increasing drastically in a wide range of applications such as medical [1], aerospace [2], industrial [3], commercial application [4], automotive [5] and others. The types of sensor are used in sensing such as flow [6], pressure [7-8], optics [9] and the resonant behavior of structures [10]. The choose of type sensor to measure the pressure value on the devise is generally depend on the uses of application that’s, the cost, the ease of integration of the system [11] and the complex fabrication technique with enhancement of sensor design due the mechanical properties of the sensor is affect the changes to any geometry layer. The types of pressure sensor are capacitive, piezoresistive and piezoelectric. The capacitive pressure sensor is move advantage due to low power consumption, high sensitivity, and a robust structure than micromachine piezoresistive pressure sensor [7-8], [11].

Basically, 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 [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. There are many examples of fluid application such as an inclinometer sensor to measure angle with the electrical double layer principle capacitance (EDLC) [12], acoustic applications [13] and the detecting of droplet in a microfluidic system [14] using a coplanar electrode which have two electrodes in one microchannel to generate capacitance.

Generally, capacitive pressure sensors are fabricated on silicone by bulk micromachining or surface micromachining [15 - 16]. Printed circuit board (PCB) technology is an alternative technique for fabricate capacitive pressure sensor. This method fabrication usually used the available material which is Flame Retardant 4 (FR4) as a substrate and a copper layer for connecting electronic components [11]. This technique provides easy method due the low-cost fabrication. The PCB technology have been used in [17] for fabricate capacitive pressure sensor. In this technique, consists steps of patterning process, deposition, etching layer that is need precise control [7] is required in process fabrication of the gap of two electrodes.

In this paper, the process fabrication using printed circuit board and soft lithograph process is proposed for manufacturing a capacitive pressure sensor. Using printed circuit board, the achievement of a gap with reasonable value [11] is easy to fabricated. In addition, soft lithograph process is one method to able simplify the process with the formation of membrane and body structure [7]. Besides that, Polydimethylsiloxane (PDMS) is used in order to overcome fabrication complexity for capacitive pressure sensor. Capacitance measurement of the planar electrodes was carried out in this paper.

2 Sensor Design
Sensor design consists two fabrication process: sensor fabrication and device fabrication. The sensor and channel were designed and later combined together to form a device.

2.1 Fabrication of Planer Electrode
The fabrication process was beginning by using a sensor design that was designed using AutoCAD Eagle 2017. Copper electrode was fabricated by using a printed circuit board (PCB). The planner electrode sensor design is shown in Figure 1.

Figure 1. Sensor design with planar electrode pattern.
From the Figure 1, the size of device is 50mm and 50mm which is label a and b. The diameter of the sensing area is label as c and d in the diagram is 10mm x 10mm. total diameter of the electrodes configuration label as e is 60mm and the width of the electrode is labeled as f is 0.4mm. The gap between the electrodes is 0.4mm.

Besides that, the capacitance of pair of electrodes is measured using LCR meter (4100) Wayne, Germany. The frequency is set to 10 kHz in this experiment. The reading was obtained by using the LCR meter to measure the electrode in capacitance value. Figure 2 is shows the sensor device with planar electrodes.

![Sensor device with planar electrodes.](image)

The electrode pattern was fabricated on a printed circuit board (PCB) is shown in Figure 2. The process of PCB fabrication follows the commercial PCB fabrication technique. There are Exposing, Developing and Etching. For exposed, the pattern design will expose the surface of board in Exposure Box (Mega Electronic, LV202E). Next, using developer to remove the layer that is not expose in process exposing to show the copper foil with using the powder (PCB developer). After that, the unwanted copper layer was eliminated in the etching process using ferric chloride. The time taking for the PCB process was 1 hours and 15 minutes. The electrodes end is drilled and the soldered on the respective electrodes. From these processes, the produce of copper electrode sensor was successfully.

2.2 PDMS Channel Development

The PDMS channel was for the sensing area and the base were fabricated by design the 3D master template (STL File) for the PDMS casting process. The molding template was printed using 3D printer. The materials of molding template made form Acrylonitrile Butadiene Styrene (ABS).

2.2.1 3D Master Molding Development

The 3D molding template was designed with using AutoCad Inventor 2017. The pattern of the 3D model for the PDMS casting in Shown in Figure 3.
Figure 3. 3D model for the PDMS casting.

The dimension of the design of the molding template is given the total size of the molding template (PDMS molding) is 33mm x 33mm is shown in Figure 3. The diameter of the sensing area which the rectangular shape in middle of the design is shown in Figure 3 is 10mm x 10 mm for length and width. The sensing area height is 0.8 mm and the thick of the wall of 3D model is 2mm. The complete 3D model on the printer platform is show in Figure 4.

Figure 4. 3D molding template after printed process.

The design of 3D molding template was fabricated with using 3D printer. The nozzle of 3D printer will melted the filament ABS and it will dispensed to the platform. The process is carried out in a total of 20 minutes which is the printer is printed layer by layer controlled by the software of the computer (UP!) from bottom to top.

2.2.2 PDMS Platform Channel Development
After finished the 3D molding template, to fabricate the PDMS channel is the next process. The fabrication of the PDMS channel is shown in Figure 5.
Figure 5. PDMS channel development process

From the Figure 5, the PDMS polymer was fixed by mixing the PDMS resin to harden at ratio 10:1. The polymer was mixed comprehensively in a plastic cup for 3 minutes. After that, the PDMS solid was poured into the 3D molding template and bubbled trapped was remove by placing inside a vacuum for 30 minutes. Then, the polymer PDMS was heated in an oven at temperature 60°C for the 30 minutes. After the heating process, the harder PDMS is removed from the mold with carefully to ensure the harder PDMS would not easy torn. An epoxy was applied before pouring the PDMS solvent for to easily remove the hardened PDMS.

2.3 Integration of planar Electrode and PDMS Channel

The integration of PDMS channel and planar electrode is done in this research. The fabricated PDMS channel and electrodes parallel were bonded by using PDMS pre-polymer. The planar electrode and PDMS channel intergration process is shown in Figure 6.

The same PDMS mixing was prepared is shown in Figure 6. A thin layer of PDMS mixture was spread on the surface of the board to coat the electrode with the PDMS channel by using spin coating. The uncured PDMS was placed upward on the PCB in a preheated oven at 100°C for 15 minutes to create semi cured PDMS surface to be bonded to the PDMS channel. Then, whole device was cured in an oven at heat at 100°C for another 15 minutes to ensure the whole device is proper cured.
3 Experiment
The fabricated device was tested on the bonding/adhesive quality between the electrode substrate (PCB) and the PDMS channel. Besides that, the electrode was characterized by measuring capacitance depends on the pressure.

3.1 Bonding Test
Bonding test was conducted to examine the bonding strength between the PDMS channel and PCB after finishing the integration process between planar electrode and PDMS channel. The experiment was done by applying liquid dye within the channel to determine the bonding gap by checking in case there is any dye diffused in the bonding area. The bonding test conducted to the device is shown in Figure 7. From the observation, there was no leakage marks found around the channel bonding area which is that show no trace of red dye was diffused between the PDMS channel and the PCB.
3.2 Capacitance Measurement

The characteristic of the electrode was done by measuring the capacitance with electrodes. Water and ethanol were used as a medium for the experiment. The experimental results have been done. For measurement and calibration, an LCR meter is used. The measurement data is collected by using the LCR meter with the electrodes compared with the different liquids. Figure 8 shows the results of the capacitive measurement between the different liquids.

From Figure 8, the plot shows that capacitance value increases with two different liquids. The capacitance of value ethanol is higher than capacitance of value water. The experimental shows that the liquid with different viscosity hardly influenced the liquid displacement inside a channel. Besides that, the difference between the value capacitance of ethanol and water are due to environment issues such as, noise, vibration and temperature. However, in terms of stability, the ethanol is more stable compared to the water. The ethanol has low surface tension compared to water.
4. Conclusion

In conclusion, the capacitance pressure sensor has been successfully assembled by using low cost materials. The process to fabricate the electrodes using a PCB was demonstrated and the whole process of the fabrication by using soft lithography process is less than 5 hours. All process and procedures were showed good reproducibility and the result was also showed good value between the ethanol and water. The ethanol data is higher than the water was caused by various conditions. From the results obtained, fabricated electrodes is function well. The range of the ethanol capacitance 11 pF to 13 pF and the water capacitance range from 9 pF to 10 pF. Therefore, the ethanol value is provided larger capacitance as compared to the water value.

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