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Miniaturized Planar Sensor Development

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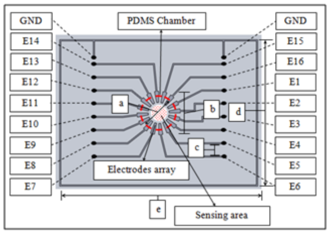
Graphical abstract



Abstract

This paper describes the process of developing a miniature device with planar sensors utilizing electrical capacitance measurement. The project investigates the feasibility and characterization of a miniaturized planar sensor integrated on a polydimethylsiloxane (PDMS) chamber. A 16-planar-electrodes array, with each dimension of the electrode, 4 mm × 2 mm (length × width) was fabricated using a printed circuit board (PCB) technology due to its low cost advantage. The measurement chamber for the sensing area was fabricated using PDMS. The PDMS chamber was bonded on the PCB with a semi cured PDMS to create a round sensing area for sample loading. The mould to develop the PDMS chamber was designed using AutoCAD 2010 and was fabricated using a 3D printer. Capacitance measurement of the planar electrodes was carried out using water as the sample and was validated using a theoretical calculation. Experimental result shows that the distance of the measured electrodes is inversely proportional to the capacitance value. The range of the measured capacitances of the measurement varies from 10 pF to 20 pF. The result shows that the planar sensors are able to provide capacitance measurement within the miniaturized platform where the measured capacitance showed good agreement with the theoretical calculation.

Keywords: Planar sensors; polydimethylsiloxane (PDMS); printed circuit board (PCB); capacitance measurement

■1.0 INTRODUCTION

The usage of sensors is essential to our daily lives, not only in domestic applications but in industry [1-3], biomedical [4-6] and environmental [7-9]. Specifically in biomedical engineering field, the utilizations of sensors are crucial for cells detection [10-11] and medical sample analysis purposes [12-14]. For environmental measurement and analysis, sensors need to be in portable form as some samples are far from the laboratories, therefore mobility [4,15] is crucial for all environmental instruments, specifically the sensors. The need of the portable sensors arises due to sample degradation problem during the transferring period. Furthermore, some research obtained only limited sample number, and have difficulty to move the sample out from site, making portable feature more favorable for environmental result analysis. For environmental analysis application, portable sensors with miniaturized features have begun to grab researchers' attention. Miniaturized approach can be achieved through the lab on chip (LOC) concept. LOC is defined as the integrations of the laboratories activities in a device [15,17] . The concept of LOC was coined by Manz [16] in 1990s through his research. One of the most important elements within a miniaturized device is the sensing element. The sensors consists of an optical sensor [18-20], a wave sensor [21-23] and electrodes [4,24-25]. Electrodes are commonly used as it is cheap and can be easily integrated to the micro devices. Electrodes can be integrated on plastic or glass substrate using screen printing methods [26-27], deposition [28-29] and hot emboss techniques [30-31]. These methods are applied for planar electrode devices [25, 32-33]. The reason for implementing planar electrodes is due to the limited space and the difficulties of installation since the platform and the chamber are fabricated in small size [34]. Shrinking the size of the platform means the size of the sensor need to be reduced as well as to ensure that the sensor can fit within the size of the platform.

Planar electrode based sensor in micro devices normally provides only 1D data for most microanalysis process [4,26]. For example, in cell detection system only one data is obtained at a time showing the condition of the cell. However, the single data obtained at a time only reflects a local point of measurement is used to represent the overall condition of cell. Thus, assumption could cause many uncertainties of the whole detection of the cell. By using more electrodes and integrating the tomography concept into the micro devices, the detection will able to cover the whole detection area by providing high throughput and eventually 2D data acquisition of the condition of the cell.

Tomography system consists of transmitter and receiver. The transmitter will transmit a signal through a medium within the sensor array detection area and the transmitted signal will be captured by the corresponding receiver. Normally the measured signal is based on density, permittivity and concentration. Hence, tomography concept provides several techniques to retrieve the signal by the introduction of tomography projection techniques.

There are four projection techniques in tomography such as parallel beam projection [35-36], fan beam projection [37-38], ultrasonic echo projection [39-41] and electrostatic field projection. The selection of the projection method is based on the suitability of the sensor used in research or in industry, and the application requirements. For example, by comparing a parallel beam projection and a fan beam projection data acquisition, a fan beam projection provides more data as compared to the parallel beam projection, thus the resolution of this projection is higher than the parallel beam projection. Therefore for miniaturized devices, high resolution is important in order to harvest information from micro scale samples.

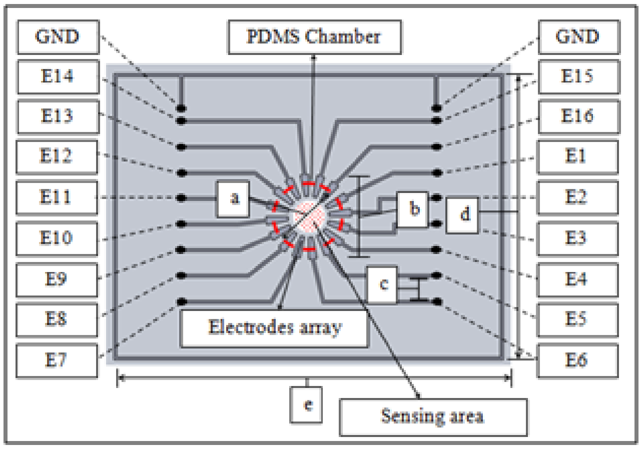
This paper illustrates the process in developing a miniaturized planar tomography device and the characteristic of the planar sensors for tomography measurement. The miniaturized planar tomography device consists of two main fabrication components which are miniaturized planar sensor and PDMS chamber. Miniaturized planar device is used to measure the capacitance value based on the cells properties while PDMS chamber works as a barrier to hold the sample that consist of cells. The obtained result from the device is compared to the theoretical calculation for verification.

■2.0 MINIATURED PLANNAR SENSOR DEVELOPMENT

Miniaturized planar sensor development consists of two fabrication processes; the micro sensor fabrication and micro device fabrication. The sensor and chamber were designed and later integrated together to form a micro device

2.1 Fabrication of Planar Electrode Array

The fabrication process was initiated by using a sensor design that was designed using AutoCAD 2010. Copper electrodes were fabricated using a printed circuit board (PCB). Figure 1.1 shows the planar electrode sensor design including the dimensions of the electrodes.



From Figure 1.1, the total size of the device is 111 mm x 151 mm which is labeled as 'd' and 'e' in Figure 1.1. The diameter of the sensing area marked as 'a' in the diagram is 24 mm. Total diameter of the electrodes configuration marked as 'b' is 33 mm and the width of the electrode pin output marked as 'c' is 10 mm.

For tomography data acquisition, the electrodes are labeled in a sequence of number which started clockwise from position 2 o'clock (E1) in order to indicate the electrode excitation configuration (refer Figure 1.1).

In the first experiment, the capacitance of each combination pair of electrodes was measured using LCR meter (U1733C), Agilent, USA. In this experiment, the frequency is set to 100 kHz, and the readings are obtained by using the LCR meter to measure the pairing electrodes manually. There are 16 complete cycle of data for each excited electrodes and each series of these data consists of 15 data. For instance, as E1 is excited, the capacitance readings are measured between E1 to all the remaining 15 electrodes. Figure 1.2 illustrates the assembled device with 16 planar electrodes.

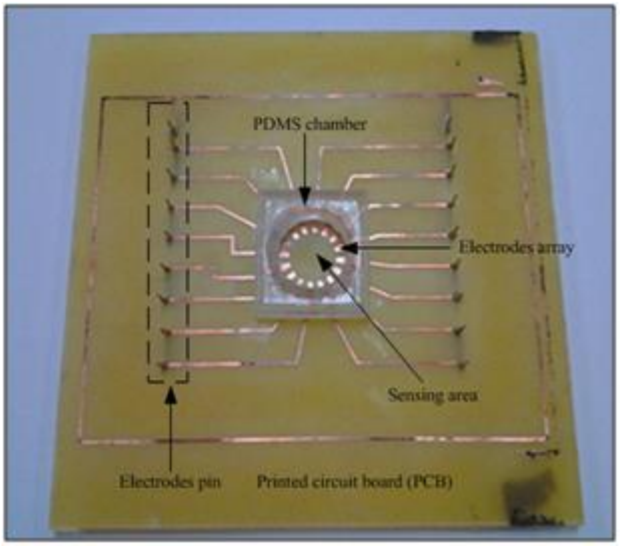


Figure 1.2 Assembled device with 16 planar electrodes

From Figure 1.2, the electrode array was fabricated on a printed circuit board (PCB). The process of the PCB fabrication follows the commercial PCB fabrication technique. The unwanted copper layer was eliminated in the etching process using ferric chloride. The time consumed for the PCB process was 30 minutes. The electrode pins was then drilled and the connector were placed and soldered on the respective electrodes. From these processes, the copper electrode sensor was successfully produced.

2.2 PDMS Chamber Development

The PDMS chamber for the sensing area was fabricated by designing the 3D master template for the PDMS casting process. The master template was printed using 3D printer. The materials of master template made from copolymer comprised polymerized styrene and acrylonitrile.

2.2.1 3D Master Templete Development

The 3D master template was designed using AutoCAD. Figure 1.3 shows the CAD of the 3D model for the PDMS casting.

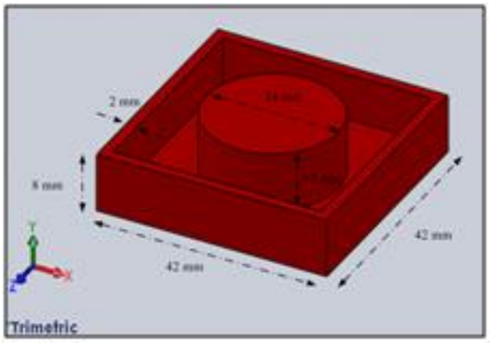


Figure 1.3 3D model for the PDMS casting

From Figure 1.3, the dimension of the design is given by; the total size of the master template (PDMS Casting) is 42 mm × 42 mm. The diameter of the sensing area which is the circle shape on the middle of the design in Figure 1.3 is 24 mm. The height of the sensing area is 8 mm and the thick of the wall is 2 mm. Figure 1.4 shows the complete 3D model on the printer platform.

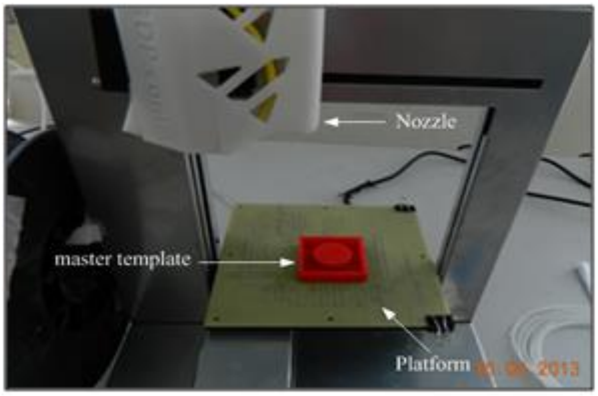


Figure 1.4 3D master template after printed process

The 3D master template was fabricated using a 3D printer according to the design. The nozzle of 3D printer melted the plastic feed and dispensed it to the platform. The process executed in a total of 15 minutes where the printer prints layer by layer, from bottom to top controlled by the software in the computer.

2.2.2 PDMS Platform Chamber Development

After completing the 3D master template, the next process is to fabricate the PDMS chamber. The fabrication of the PDMS chamber is illustrated in Figure 1.5.

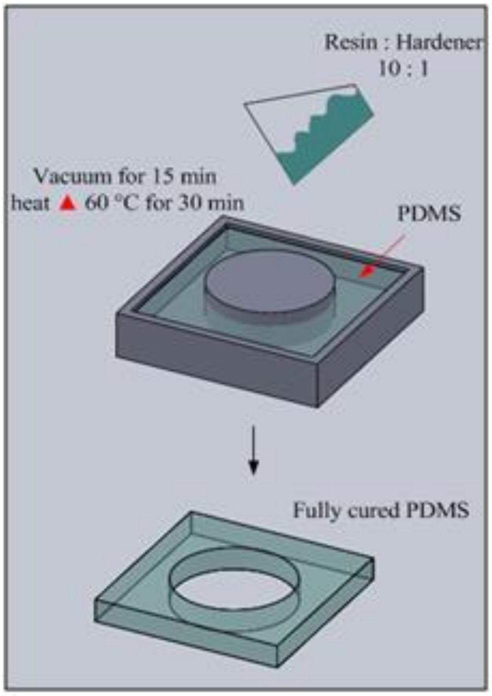


Figure 1.5 PDMS platform chamber development process

According to Figure 1.5, the PDMS pre-polymer was prepared by mixing the PDMS resin to harden at ratio 10: 1. The pre-polymer was mixed thoroughly in a plastic bowl for 5 minutes. Then, the PDMS mixture was slowly poured into the 3D master template and degassed in a vacuum chamber to remove the gas bubbles trapped within the PDMS for 15 minutes. Later, the pre-polymer was cured in a preheated oven at 60 °C for 30 minutes. After the curing process, the cured PDMS is removed from the master mould and rested in room temperature for 5 minutes.

2.3 Intergration Of Planar Ellectrode And PDMS Chamber

The integration of planar electrode and PDMS chamber is crucial in this research. The cured/fabricated PDMS micro chamber and 16 electrodes array were bonded irreversibly by using PDMS pre-polymer. Figure 1.6 shows the planar electrode and PDMS chamber integration process.

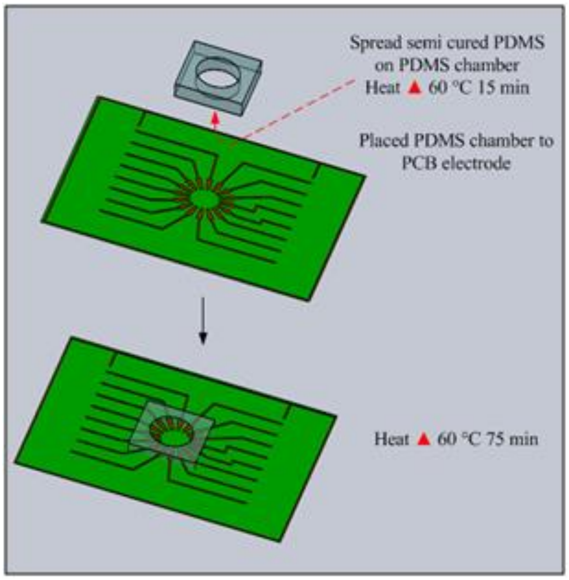


Figure 1.6 Planar electrode and PDMS chamber integration process

From Figure 1.6, the same PDMS mixture was prepared. A thin layer of PDMS mixture was spread evenly on the surface of the PDMS micro chamber. The uncured PDMS was placed upward in a preheated oven at 60°C for 15 minutes to create a semi-cured PDMS surface to be bonded to the PCB. The whole device was then cured in an oven (preheated at 60°C) for another 75 minutes to ensure proper curing of the whole device.

■3.0 EXPERIMENT

The fabricated device was tested on the bonding/adhesive quality between the electrode substrate (PCB) to the PDMS chamber. In addition, the electrodes were characterized by measuring the capacitance between the fabricated electrodes.

3.1 Bonding Test

After finishing the integration process between planar electrode and PDMS chamber, bonding test was conducted to examine the bonding strength between the PDMS/pre-polymer PDMS. The experiment was done by applying liquid dye within the chamber for three days to assess the bonding gap by checking whether there is any dye diffused in the bonding area.. Figure 1.7 shows the bonding test conducted to the device.

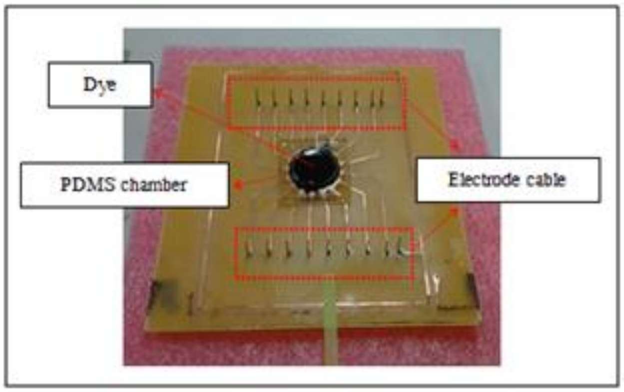


Figure 1.7 Sensor picture after three days

From the observation throughout three days, no leakage marks were found around the chamber bonding area which shows no trace of blue dye diffused between the PDMS and the PCB.

3.2 Capacitance Measurement

The characteristic of the electrodes was done by measuring the capacitance between the electrodes. Water was used as a medium for the experiment. The experimental results were compared with the theoretical formula, which is shown in Equation 1 [42]. For the measurement and calibration, a LCR meter is used.

$$c = \frac{2\varepsilon_r\,\varepsilon_0\,l}{\pi}\,ln\left[1 + \frac{w}{a} + \sqrt{\left(1 + \frac{w}{a}\right)^2 - 1}\right] \qquad (1)$$

Where;
ε_r = dielectric constant
ε_0 = electric constant
l = length of the electrode
w = width of the electrode
a = haft gap between electrode

The measurement data collected using the LCR meter from the electrodes was compared to the theoretical calculation using Equation 1. Figure 1.8 shows the results of the real time measurement and the theoretical data.

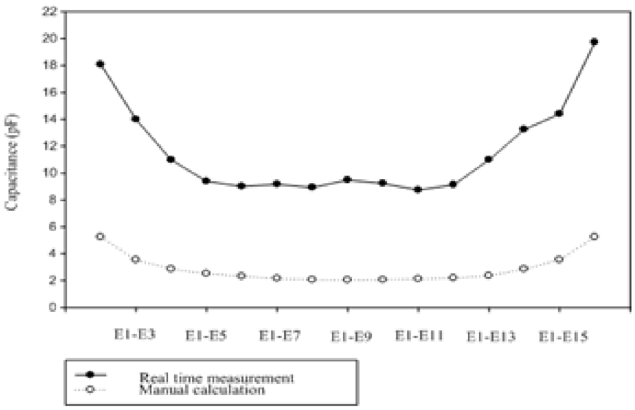


Figure 1.8 Capacitance measurement for 16-planar sensor (E1 serves as excited electrode)

From Figure 1.8, the plot shows that capacitance value increases when the distance between electrodes are shortened. The measurement of the capacitance value from the experiment shows the same tendency to the calculated value. In terms of stability, the calculated capacitance values are more stable compared to the experiment measurement. The measured data is higher than the calculated data. The causes of the difference between the experiment data and the theoretical data are mainly due to environmental issues such as noise, vibration and temperature. However, the trend of the data obtained from the experiment is similar to the theoretical calculation. As the furthest pairs of electrodes are measured, the capacitance reading is the lowest as compared to the paired electrodes which are next to each other. The electrical potential is higher for electrodes that are nearer to the source or the excited electrode which caused significant capacitance reading.

■4.0 CONCLUSION

In conclusion, the miniaturized planar tomography sensor has been successfully fabricated using low cost materials. The process to fabricate the electrodes using a PCB was demonstrated and the whole process of the fabrication is less than 2 hours. All the procedures and processes showed good reproducibility and the results also showed good agreement between the experiment data and the calculated data. The measured data that is higher than the theoretical data are caused by various ambient conditions. From the results obtained, all fabricated electrodes function well and produce similar trend to the theoretical planar capacitance measurement. The range of the measured capacitance is 10 pF to 20 pF and theoretical capacitance range from 2 pF to 6 pF. Therefore the experimental data provide larger output as compared to the estimated value.

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