Electrical Characterizations of Electrodes Microfluidics System for Microbio Object Analysis

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Abstract— We have designed and fabricated electrodes microfluidics system for microbio object analysis. Two parallel plate electrodes were fabricated using soft lithography technique integrated with PDMS microfluidics channel. Gold (Au) material was decomposed to fabricate the electrodes. Voltage response through charging and discharging of the electrodes were observed using oscilloscope. For a constant dc voltage of 5 V we have obtained the time constant of the electrodes as 3.6 ms. On the other hand, it requires 850 ms to discharge completely without an external load. We have measured the capacitance of the electrodes as 0.37 pF in air (room environment) medium, on the other hand in distilled water medium electrodes capacitance is 0.77 pF. This is because of the high dielectric constant of distilled water (80.1). We have also measured electrodes capacitance by changing the medium to microbio objects such as; yeast cells (5 pF) and live bacteria cells (30 pF). Results showed that, bacteria have a higher electrical capacitance rather than yeast.

Index Terms—Parallel plate electrodes, microfluidics system, capacitance of water medium, dielectric properties microbio object.

I. INTRODUCTION

Electrical properties like conductivity, dielectricity, permittivity of microbio objects such as cells, tissues, C. elegances have a great interest to the researchers. They are the fundamental properties of living elements [1]. These properties elucidate the complex electrical behavior of microbio objects [2]. For instance, single cell viability was determined from cell’s electric conductive property using dual nano probe [3]. Moreover, electrical properties of microbio object has been studied for century as it is related to the thickness of membrane, also the ionic nature of the cytoplasm and gene [4].

Previously, our colleagues have reported a capacitance based micro chip for characterizing the volume of C. Elegances [5]. But that work was limited to C. elegances volume estimations only. Moreover, scale of the electrodes was in millimeter range. While we are proposing a micro meter range parallel plate electrodes integrated with microfluidics channel to analyze the microbio object’s dielectric properties. Figure 1 illustrates the working mechanism of the proposed device. Figure 1(a) shows the electrodes and microfluidics channel without any objects through the channel. The capacitance of the device was measured from the fundamental equation of capacitor (C) as in (1)

$$C = \frac{\varepsilon A}{d}$$

where, $\varepsilon$ is the permittivity of the medium, $A$ is the surface area of the parallel plate electrode and $d$ is the distance between two parallel plate electrodes. Figure 1(b) illustrates the electrode microfluidics system when any microbio object is presented between the electrodes. Objects are allowed to pass through the electrodes through the microfluidics channel. In presence of bio objects such as cells, tissues, fluidic organs, dielectric constant of the medium will be changed which will cause the capacitance to be changed as well. As a result dielectric properties of the object can be extracted accurately. This analysis will elucidate the electrical properties of the single cell as well the fluidic organisms of bio objects.
II. FABRICATION PROCEDURES

A. Fabrication of parallel plate electrodes

Fabrication of the entire chip has been divided into two different parts; fabrication of the parallel plate electrodes and the microfluidics channel. Fabrication was performed at Micro Nano System Engineering Laboratory, Nagoya University, Japan. Figure 2 shows the finite element model of the parallel plate electrodes. Length of each inner electrode is 180 µm with a gap of 10 µm and length of the outer electrode is 8 mm. Finite element model was developed with ABAQUS CAE/6.12. Lift off soft photolithography technique was used to fabricate parallel plate electrodes [6]. Ions of gold (Au) were decomposed on the glass surface with appropriate dimensions to obtain the desired structure of the parallel electrodes. Figure 3 (a)-(f) illustrates the fabrication procedures of the parallel plate electrodes. Initially photoresist AZ 5214 (AZ E. Materials, Japan) was coated on the glass surface as shown in Fig. 3(a). Pattern of the electrodes was obtained by exposing the photoresist under UV light [see Fig. 3 (b)]. AZ 300 MIF (AZ E. Materials, Japan) was used to develop the pattern on the glass surface [see Fig. 3(c)]. Later on, gold (Au) was sputtered on the patterned glass surface for 4 minutes [see Fig. 3(d)]. Finally, using ultrasonic cleaner AZ 5214 was removed [see Fig. 3(e)], and remains Au electrodes on the glass surface [see Fig. 3(f)]. Two wires were connected with the Au electrodes by silver (Ag) pasting on the electrodes edge. Outer electrode was 8 mm in length, 2 mm of width and a height of 176 nm. On the inner electrodes, the length is 180 µm, width 10 µm, the gap between two inner electrodes is 10 µm.
Microfluidics channel was fabricated in polydimethylsiloxane (PDMS, SILPOT 184, Dow Corning Corp.) material. PDMS is inexpensive, nontoxic, transparent and biocompatible [6]. Figure 4 (a)-(d) illustrates the steps of the microfluidics channel fabrications. Soft lithography technique was used to develop the master mold on silicon surface. Figure 4(a). The width and height of the channel is 20 µm and 10 µm respectively. Figure 4 (b), PDMS material was then poured on the mold surface and treated at room temperature for 24 h. PDMS replica is then peeled off from the surface and drilling operation was performed to obtain inlet and outlet, Figure 4 (c). Finally the PDMS microfluidics channel is ready, Fig. 4 (d). Fabricated PDMS channel was then aligned properly on the gold electrodes surface. Alignment was performed carefully, so that the microfluidics channel is placed exactly between the inner electrodes. Figure 5 shows the fabricated lab-on-chip, inset show the microfluidics channel which is exactly between the electrodes.

III. ELECTRICAL CHARACTERISTICS OF THE PARALLEL PLATE ELECTRODES

Electrical characterizations of the microfluidics chip have been performed to understand the electrical behavior of the parallel plate electrodes [7]. As the fabricated electrodes are parallel to each other, we expect that it will behave like a parallel plate capacitor.

A. Charging of the parallel plate electrodes

Charging behavior of the electrodes was analyzed to extract the time constant of the parallel plate capacitor. We have applied a constant electrical potential of 5 VDC and observed the response of changing electrical potential through the electrodes. Tektronix TDS 2014B oscilloscope was used to observe the voltage response of the electrodes. Figure 6 shows the voltage response while charging the electrodes. According to the principle of capacitor, time constant of this device is at 68 % of the input voltage which 3.4 V and the time constant is 3.6 ms. Time constant of the parallel plate electrode can be adjusted using (2)

\[ \tau = RC \]

where, \( R \) is the external resistor and \( C \) is the capacitance of the parallel plate electrodes. Adjusting the time constant is important to get an accurate observation of the bio objects whose flow through the microfluidics channel.

B. Discharging of the parallel plate electrodes

Discharging of electrodes was observed by switching off the power supply. We observed that, discharging time of the electrodes is 8.6 ms without any external load. Discharging time can be adjusted by adding external resistor to the wire. The discharging time will control the sensitivity of the electrodes in terms of detecting objects. Figure 7 shows the exponential decrease of the voltage while discharging.

IV. RESULTS AND DISCUSSIONS

A. Capacitance of the parallel plate electrodes in air medium

Capacitance of the parallel plate electrodes was measured in room environment with Agilent LCR Precision Meter 4263B. Initially, LCR meter was calibrated in room environment. Later on, we measured the capacitance of the microfluidics chip. In this stage, medium of the parallel plate electrodes is air and due to air dielectric constant (1.05) capacitance increase exponentially through the frequency. Maximum capacitance was measured as 0.39 pF. This result ensures the capacitive property of the fabricated parallel plate electrodes.

B. Capacitance in distill water medium

We also observed the capacitance of the electrodes in distilled water medium. We were able to flow water through the microfluidics channel. Legato 200, Syringe micropump (KdScientific) was used to control the water flow precisely. Water flow of 5 µl/min was used to flow through the microfluidics channels. Figure 8(a) shows that, water is pretending to cross the electrodes and capacitance is 0.39 pF. On the other hand, capacitance of the electrodes is 0.77 pF when water is on the electrodes [see Fig. 8(b)]. Due to the
The potential applications using the electrode liquids as well as micro bio object such as cells and liquid proposed device is able to analyze the dielectric properties of through charging and discharging of electric potential. Our microfluidics chip is working like a parallel plate capacitor presented in this article. Results showed that, the fabricated microfluidics system eases this work by measuring the capacitance of electrode in presence microbio object and medium. We have chosen yeast and bacteria as sample to extract dielectric constant of yeast and bacteria, without the dielectrophoresis technique [11].

V. CONCLUSION

Electrodes microfluidics system has been successfully presented in this article. Results showed that, the fabricated microfluidics chip is working like a parallel plate capacitor through charging and discharging of electric potential. Our proposed device is able to analyze the dielectric properties of liquids as well as micro bio object such as cells and liquid organs. The potential applications using the electrode microfluidics system will help researchers to understand the electrical properties of living elements, which may lead us to differentiate healthy and unhealthy conditions of the living organs through their electric properties.

ACKNOWLEDGMENT

We would like to express our hearties gratitude towards Ministry of Higher Education Malaysia (MOHE) grant no. 78677 (FRGS), (MOHE) grant no. 4L038 (ERGS) and Universiti Teknologi Malaysia, grant nos. 77973 (NAS), 03H80 (GUP) and 02H34 (GUP).

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