Simple Fabrication of an Inexpensive Impedance Based Sensor for Contamination Detection

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***Abstract*— Escherichia Coli (E-coli) is a bacterium commonly found in the environment, foods and intestines of people and animal. The presence of E-coli in water can severely threaten human health condition. The quality of drinking water is vital and avoid using contaminated water is a must. In fact, the water that contaminated by E-coli is cannot easily be detected by physical observation. Dedicated ways used to detect the presence of E-coli are required. The current techniques available are quite bulky in size, also require high expenses and professional training operation. With these limitation, new technique is proposed which are considerably low-cost and user friendly device in detecting presence of E-coli. The fabrication of impedance based sensor using interdigitated electrode (IDE) and Polydimethylsiloxane (PDMS) as sensor package have been done in this study. The impedance response of the proposed sensor have been observed using impedance analyser. Based on the observation, the sensor device able to differentiate the sample's condition tested in frequency of 1000 Hz until 3000 Hz, but no significant changes observed at the higher frequency range. With the initial results obtained, the proposed device was demonstrated being able to distinguish different E-coli concentration.**

Keywords—E-coli, PDMS, Interdigitated Electrode (IDE), Impedance Analyzer

I. INTRODUCTION

Water is one of basic needs in our life and its safety are most essential [1]. The risks of water quality either drinking or tap water that we used in daily life must carefully be identified. This is because we did not know the water consumed is safe or not because the presence of pathogens or contaminants are hardly be detected by the physical observation. Moreover, there is no significant color or odor itself. Species like Escherichia Coli (E-coli) [2][3] and Salmonella [4][5] bacteria are some examples of contaminant commonly found in in water. The contaminated water can severely threaten our health conditions [6].

Some of the challenges in current techniques or practices to detect the presence of E-coli includes the usage of heavy equipment which commonly big in size, and need to be done at the specialized laboratory for preparation needs. Although, there are alternative hand-held tools that is portable device to detect the presence of E-coli, but it might took higher cost. For example, the spectrophotometer analysis which is proven as convincing method still requires to be done in specialized laboratory, and it also requires longer the procedural time. Likewise, some of techniques only allowed for the certified personnel to carry out. Therefore, due to this limitation, a simple low-cost and more convenient sensor to detect the presence of E-coli have been proposed in this project. Using impedance approach, the presence of E-coli in water sample at various concentration could be detected by the device. By lowering the fabrication cost, the device is aimed to be affordable for the end user's budget.

In this study, the interdigitated electrode (IDE) acted as the sensing element to detect the presence of E-coli in water. In fact, the IDE can generate high electric field strength and desire electric field gradient due to its high number of electrode, besides would produce more contact area that lead to more sensitivity. This study will analyze and characterize the performance response of the fabricated impedance sensor using impedance analyzer towards various concentration level of E-coli in water sample.

II. DESIGN STRUCTURE AND WORKING PRINCIPLE

A. Working Principle

In this study, Fig. 1 shows the cross-sectional of the sensor design. This design consists of sensor device which is IDE that made of printed circuit board (PCB) and a pair of sensor package which made by Polydimethylsiloxane (PDMS) layer. The sensing area of this E-coli sensor was designed with IDE pattern because it has several advantages over conventional electrodes for analytical measurements including high signal-to-noise ratio, low resistance, small solution volumes requirement and rapid attainment of steady state.

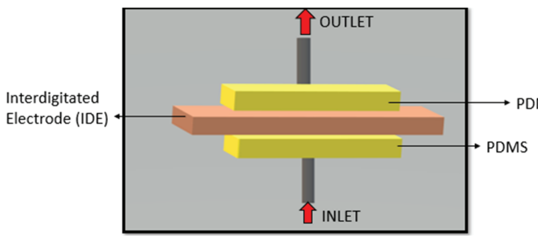

Fig. 1. The cross-sectional of the sensor design.

The inlet and outlet were created at the top and bottom of the device to control the direction flow of the testing samples. The constant volume of 1.5 ml at fixed position of the samples was injected using syringe during the experiment. However, the flow rate and pressure of the liquid sample is not specifically measured using any tools. Basically, there

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were two sets of sample, which namely sample A and sample B with different parameters of the samples as shown in Fig. 2. The structure 's dimension are N=8, W=1.2 mm, and H=0.8 mm for sample A, while N=16, W=1.0 mm, and H=0.8 mm for sample B where number of finger electrodes N, width of the finger electrode W and holes diameter in between the finger electrode, as shown in Fog. 3.

The working principle of the proposed device is illustrated in Fig. 2 (a) and (b). The impedance response of them material under test could be determined by connecting the interdigitated electrode, then the changes in electric properties will result in change of impedance and enabling the measurement of a direct electrical signal [7]. The electric field lines would transfer from one electrode to another of opposite polarity.

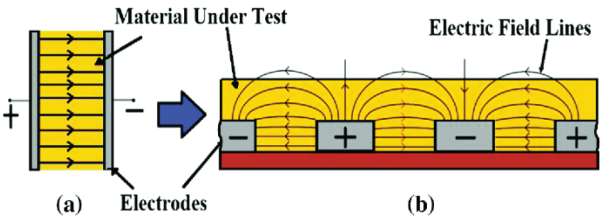


Fig. 2. The working principle of the interdigitated electrode.

The impedance response was observed for all tested level of E-coli concentration in water samples. By default, the data collected was in $Z\angle\theta$ form, where θ is phase and Z is impedance. Then, the data could be converted into real and imaginary parts for the analysis, $Z = R + jX$, where R is real part which represents resistance and X is imaginary part which represents inductive resistance.

X can also be represented as capacitance (C) and frequency (f) as follows:

$$X = \frac{1}{2\pi f C} \tag{1}$$

Meanwhile, C also can be represented as

$$C = \frac{\varepsilon_o \varepsilon_r A}{d} \tag{2}$$

where A is effective sensing are of electrode, d is the effective spacing between positive and negative electrodes, ε_o and ε_r are the dielectric constant of free space and the relative dielectric constant of the material.

B. Fabrication of IDE and PDMS

The IDE was firstly designed in Proteus software. Next, the fabrication process was started by sanding and cleaning the PCB to ensure the surface is smooth and excessive oxide would be removed. After that, it was continued with the lamination process to make the printed design properly attached to the board which take about 20 minutes. Finally, the etching process was done using chemical reagent of ferric chloride solution. Once the PCB results were confirmed, the holes were created by drilling the board at diameter of 0.8 mm. The water with E.coli samples will be injected to flow throughout the hole from the inlet towards outlet. The fabricated IDE using PCB is shown in Fig. 3.

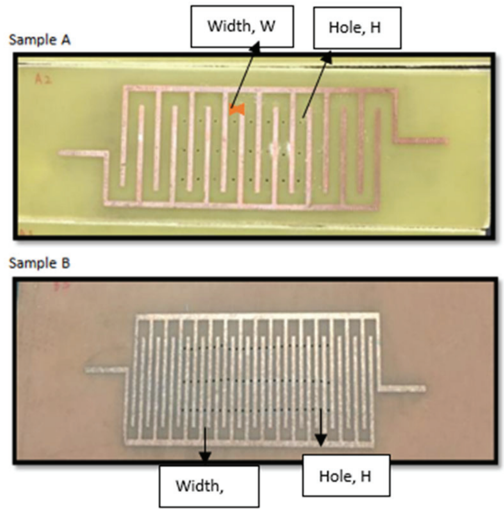


Fig. 3. The sensor design of IDE

PDMS [8] is a flexible elastomeric polymer that is an excellent material for microfluidic device fabrication. PDMS can protect the electrode from mechanical damage and can absorb external impact. PDMS layer is used to concentrate the external force, this force will then change the shape of PDMS which cause the change of electrical of conductor attached to it, and this depends on the device design structure. The electrical characteristics that involved here is resistance, capacitance and voltage. The mechanical force is being translated into electrical signal which is ready for measure and convert into digital form easily.

The PDMS fabrication process starts by mixing the elastomer with the curing agent (Dow Corning ® Sylgard 184 part A and part B) at a ratio of 10:1 and stirred for 5 minutes. Next, the mixture was put into vacuum chamber for degassing process. Additionally, the mixture also was put in chiller for 30 minutes to further ensure the mixture does not have any bubbles which will affect the elasticity of the PDMS. Lastly, PDMS was poured in the prepared mold that was made using glass slides. PDMS mixture was keep at room temperature and set for one day. The resulted PDMS layer as shown in Fig. 4.

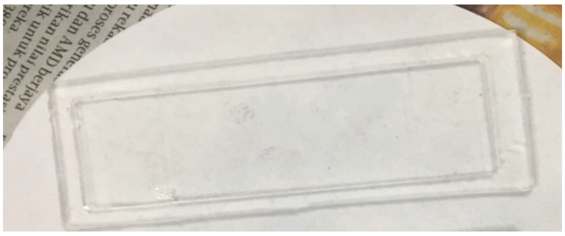


Fig. 4. The PDMS structure as the sensor package

C. Assembly Process

The assembly process was done by attaching the fabricated PDMS with same size at the top and bottom of the fabricated IDE board. The PDMS used to avoid leaking of the E-coli solution.

In making the attachment of both sensor device on PCB and PDMS package, the uncured PDMS adhesive [9] has been used to bond the PDMS and PCB. The solution was prepared with the same ratio 10:1 in small amount. Then, the sensor was left for one day to make them bond perfectly. Fig. 5 shows the resulted device after assembly completed. Basically, the material and resources used for this whole fabrication and assembly process are low in cost.

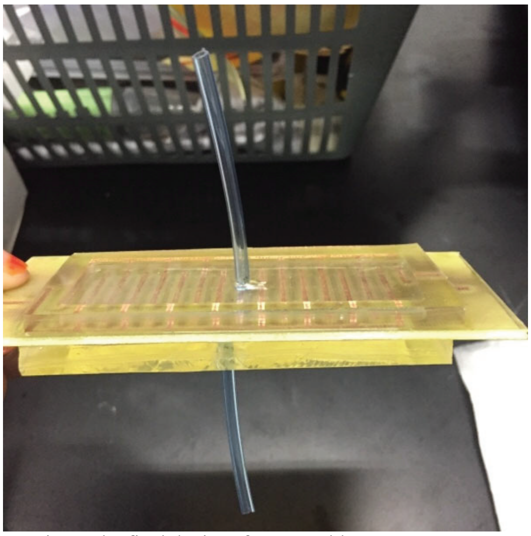


Fig. 5 The final device after assembly process.

D. Measurement Setup for Impedance Response

For characterization, the impedance response of samples were observed using impedance analyzer IM3570. The E-coli concentration in water samples used in this experiment were 10^1, 10^2, 10^3, 10^4 and 10^5 cfu/ml which prepared using dilution method. Based on the impedimetric characterization, the impedance response would have different results when the microbial took place. The impedance sensor derived from the ration between the excitation voltage and induced current, consisting of the impedance modulus (Z) and phase shift (θ) between voltage and current [10]

III. Results & Discussions

A. Sensor Characterization

In this study, sample A and sample B have been test in two extreme condition which is dry and wet condition. The dry condition is open air without anything in contact with the sensor devices, while wet condition is a fixed volume of 1.5 ml distilled water inserted to the device's sensing area. Based on the response as shown in Fig. 6, the impedance readings using device named Sample B is higher than Sample A in dry condition. On the other hand, the impedance response of Sample A is higher than Sample B in wet condition. According to the equation (2), since d is inversely proportional to the capacitance, Sample B should obtain higher capacitance due to the width of the each finger electrode is smaller than sample A.

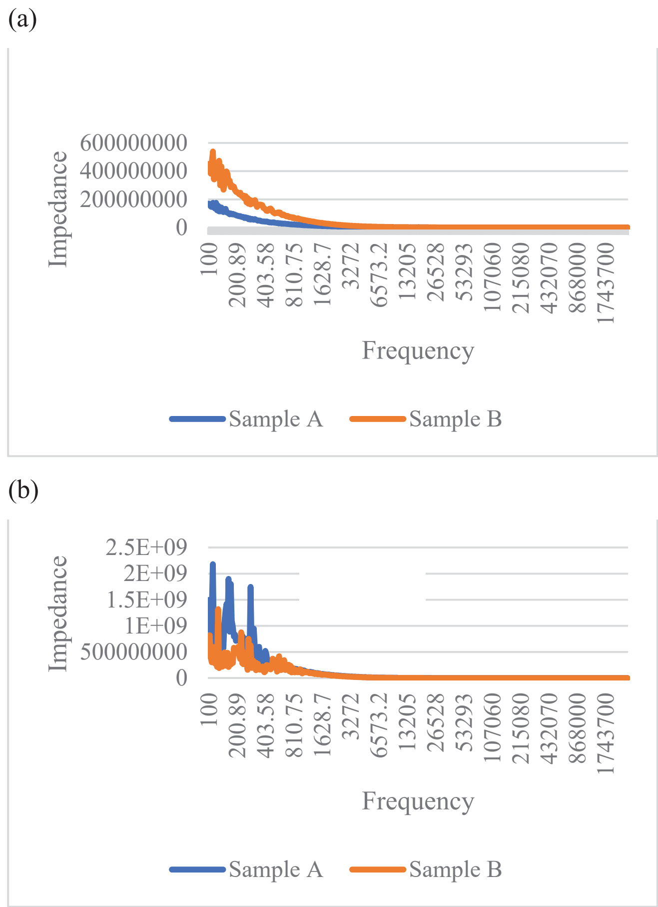
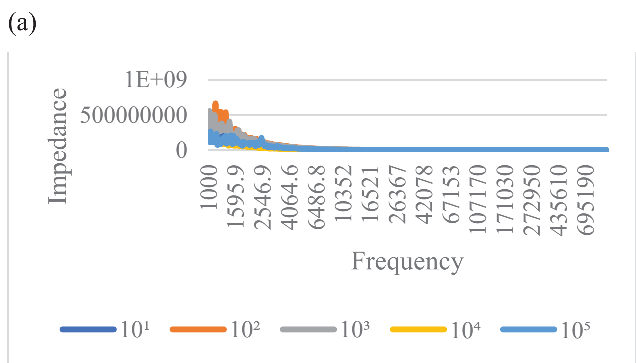


Fig. 6 Graph of impedance against frequency of sample A and sample B in (a) dry and (b) wet condition.

B. Concentration Response

The impedance response for E. coli in water samples at different concentration is shown in Fig. 7. Based on the observation, the sensor device able to differentiate the sample's condition tested in frequency of 1000 Hz until 3000 Hz, but no significant changes observed at the higher frequency range. This could be due to the device structure which having holes that might affect the distribution of samples being equally throughout the contact area besides leakage issue that may affect the sample flow and pressure. Thus, make it the device sensor not fully stabilize during measurement. In general, the 10^5 cfu/ml E-coli concentration gave the highest impedance response compare while the lowest impedance response was given by 10^1 cfu/ml E-coli concentration.



(b)

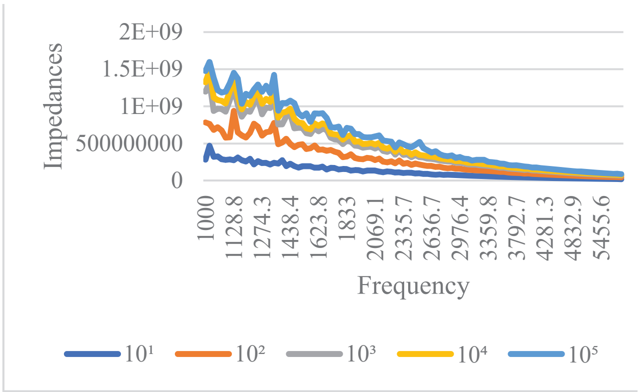


Fig. 7. The impedance response of the E-coli concentration (a) up to 60000 Hz (b) up to 6000 Hz

Further optimization on impedimetric measurement and device packaging are still in progress to better understand the physics of device operation. Moreover, some issues like effective contact area and minimizing sample's leakage should be improved.

IV. Conclusions

In conclusion, a simple low-cost and convenient impedance sensor to detect the presence of E-coli is feasibly studied as an alternative sensor. This can simply be performed by using conventional PCB handling process and curing of PDMS processes. Based on initial results, it is evidenced that this device able to differentiate E-coli concentration at working frequency range from 1000 Hz to 3000 Hz only. Hence, this new device sensor can be used as alternative approach in dealing with water contamination issue..

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