Chemical Sensor Development Using Planar Interdigitated Electrode

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Abstract: This study consists of designing Interdigitated Electrodes (IDE) using AutoCAD for chemical solution detection. Three types of IDE sensors were designed based on different types of parameters such as length, width, space between electrodes and sensing area and the effect of electrode spacing and electrode length were then analysed for chemical solution characterization. The IDEs were fabricated on FR4 using photolithography techniques. The sensing approach was based on distinguishing a shift in impedance value of the sensor when material under test is introduced at the sensing area. The IDEs were then experimentally presented as sensing element for characterization of chemical solvents such as tap water, distilled water, ethanol and methanol. The impedance measurements were collected and analysed using Microsoft Excel. From the experiment conducted, an observable shift of impedance values was identified upon introduction of material under test. It is identified all the parameters affects the impedance value of the chemical solvents. Therefore, the impedance measurement given by the proposed sensors is very potential to provide information for chemical detection.

Keywords: Interdigitated Electrode, Chemical Sensor, Impedance measurement

1.   Introduction

In recent years, there has been an increasing interest in the development of chemical and biomolecule sensors which plays an important role in many industries such as biomedical, food analysis, agriculture and many more (S.Mackay et. al., 2015).The electrochemical sensor is working based on the interaction between the electronic system and chemical systems that provide changes in electrical properties (A. Bourjilat et. al., 2017). The sensor's electrode is used to interact with the material under test and work as an interface to provide an electrical signal. The measured electrical signals such as impedance or capacitance are varied based on application. The sensitivity of the detection system is depending on the ability of the sensor to convert the biochemical interaction into a readable electrical signal with the smallest amount of material under test to detect (Hammond, et. al., 2016).

Currently, a lot of researchers have employed Interdigitated Electrode (IDE) for chemical and biomolecule detection. Interdigitated electrode sensor has lots of advantages especially to its simple structure design (Khamil et. al., 2017). In addition, one of the potential benefits of this type of IDE is the ability to integrate with other electronics instruments due to their flexibility in design (S.Partel, et. al., 2017). They have been widely used for the detection of capacitance, dielectric constant and bulk conductivity in biological mediums (Mazlan N. et. al., 2017). The detection mechanism for these IDEs were based on

measuring the changes in capacitance or impedance when biomolecular binding occurs. Further, the IDE based sensor is currently being used in gas sensor application (G. P. Alcantara & C. G. M. Andrade, 2015) and electrochemical sensor (Farehanim et. al., 2017). IDE sensor is also used for signal acquisition as a part of sensor application (Kostal E. et.al., 2018).

Generally, IDE is a type of sensor that works based on capacitive sensing method. By applying the concept of capacitive sensing, the Interdigitated Electrode (IDE) is composed of two parallel plates with two positive and negative connections tracks (Md, Nurul et. al., 2016). These two plates can generate a capacitive sensing field and able to measure the changes of dielectric material.

Since each material has its own relative permittivity, ε_r, this method basically based on a general equation of capacitance plate by the difference value of permittivity of material under test.

$$C = \frac{\varepsilon_r \varepsilon_o A}{d} \tag{1}$$

where ε_o permittivity of vacuum, A is the area of the plate and d is the distance between the plates (A. R. Mohd Syaifudin, et. al., 2009)

A few methods have been identified to convert the measured capacitance value to another readable electrical parameters for the purpose of recording and monitoring (Stevan, S.L. et. al., 2015). The methods are:

(a) Measuring capacitive impedance by applying specific frequency signal and monitoring the amplitude and phase of the output signal. Generally, the impedance of the capacitor is reduced when the capacitance of the sensor is increased.

(b) Measuring inductance and capacitance using AC bridges. This output signal is not being affected by any change of frequency.

(c) Measuring sensor's capacitance value by converting into a square wave signal using oscillator circuit with proportional frequency.

The permittivity and conductivity of the material under test can be calculated by relating the impedance equation from the equivalent circuit with equations (1) and (2) which are defined as (X. Wang, et.al. 2015):

$$R_E = \frac{d}{\sigma A} \tag{2}$$

where R_E is the resistance of the material under test, d is the thickness of the sample between electrodes, A is the area of the plate in which current is carried, and σ is the conductivity of the material under test. The complex terms of impedance obtained can be represented using Bode or Nyquist plots (A.I Zia, et.al., 2013) in terms of real and imaginary values as shown in Fig. 1.
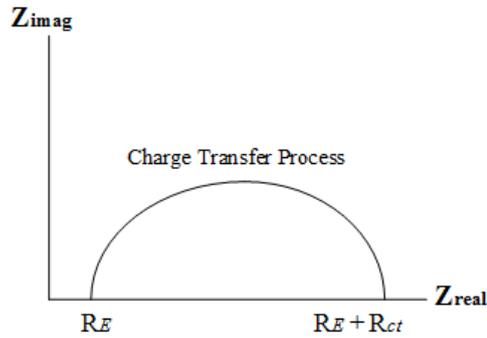
Fig. 1.Nyquist Plot

Therefore, in this paper, planar IDE was chosen in this project due to low cost and simple fabrication process that suits the capability of fabrication equipment in our laboratory. The proposed IDEs were designe to analyze the impedance value of chemical substances. The impedance measurement gives better sensitivity due to size of the sensing area.

2.   Methodology

The detection mechanism for the proposed sensors are based on the operating principles of two parallel plate capacitor. The impedance or the capacitance of the sensor will be changed when the electric field generated by the electrode penetrate to the material under test. In this experiment, few factors affecting the dielectric sensing sensitivity such as electrode width,W, electrode length, L and spacing between electrode, S will be identified.

2.1   Sensor Design

Three types of novel interdigital sensors have been designed and fabricated. Fig. 2 illustrate one of the structural designs of IDE-2 for this study. Each sensor has the same width, with different values of electrode length and space between electrode. The numbers of electrode were same for all sensors. Table 1 shows the specification of the proposed sensors.
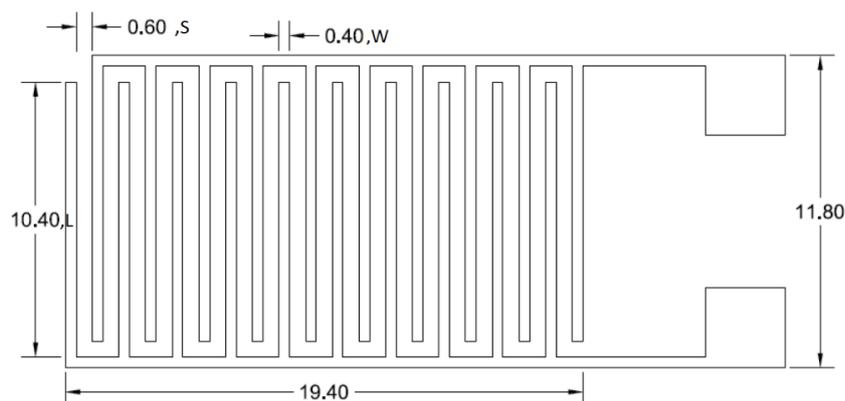

Fig. 2. Structure and dimension of proposed IDE -2

Table 1. Specification of Sensors

| No.	Width of electrodes (W), mm	Length of electrodes (L), mm	Space between electrodes (S), mm	Sensing Area, mm^2
1	0.4	8.4	0.4	156.0
2	0.4	10.4	0.6	228.9
3	0.4	12.4	0.8	324.8

2.2   Fabrication and Experimental Set-up

The proposed structure of 2D Interdigitated Electrodes (IDEs) were constructed using AutoCAD software. The designed were then transferred to FR-4 printed circuit board as a substrate for fabrication processed. Fig. 3 depicts the photographs of the fabricated sensor.
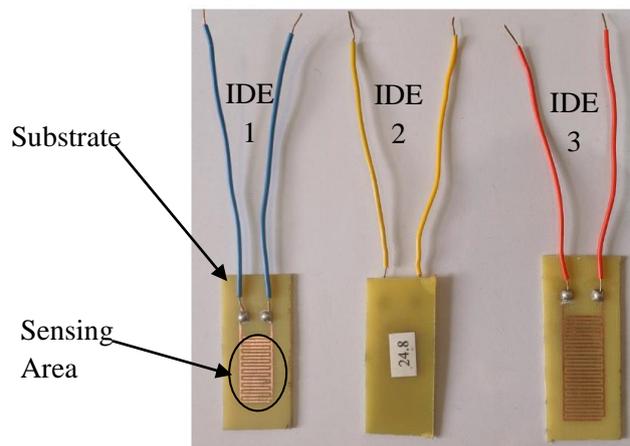
**Fig. 3.** Photograph of the fabricated sensor

Fig. 4 shows the outline of the experimental setup. During the experiment, those sensors were immersed in a beaker full of liquid substances as material under test. Distilled water is used as calibration material as this sample has common and constant value of permittivity,ε_r compared to another chemical substances that will be used in this experiment (N.I.M. Johan et. al., 2016). The measurements of material under tests were carried out in room temperature after calibration process was conducted in room temperature. The response of the sensor is then observed and documented upon introducing with the variation of liquid materials. Here, by introducing several liquid materials at the sensing area, the capacitance value between the electrodes is compromised.
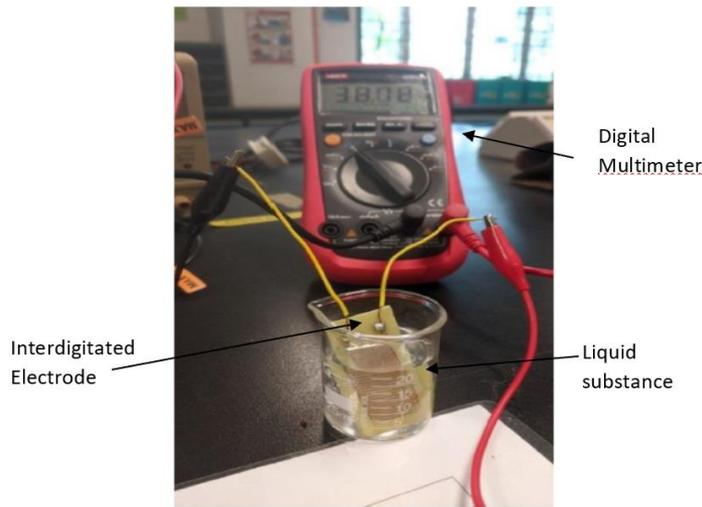
Fig. 4. Experiment Set-Up

3.   Results and Discussion

To characterized and validated the sensor, two chemical solvents which Ethanol and Methanol and tap water were used as material under test. The chemical solvents measured in this experiment such as ethanol and methanol were commercially bought from Sigma Aldrich. Distilled water was used as calibrated material for this experiment. The graph for each IDEs that have been tested with liquid substances was described and analysed. The analysis is based on the design of IDEs and the impedance values obtain when the sensors were being tested with liquid material. In this experiment, three designs of IDE with different length and space between electrodes and were tested using tap water, distilled water, methanol and ethanol. The sensing mechanism can be considered as label-free and non-destructive, since the liquid is directly probed by the electric field produce by the electrode. To ensure the reliability of the data, five sets of measurements were taken for each material under test. The measured impedance value was recorded and plotted as in Fig. 5, Fig. 6 and Fig. 7 for all fabricated IDEs.
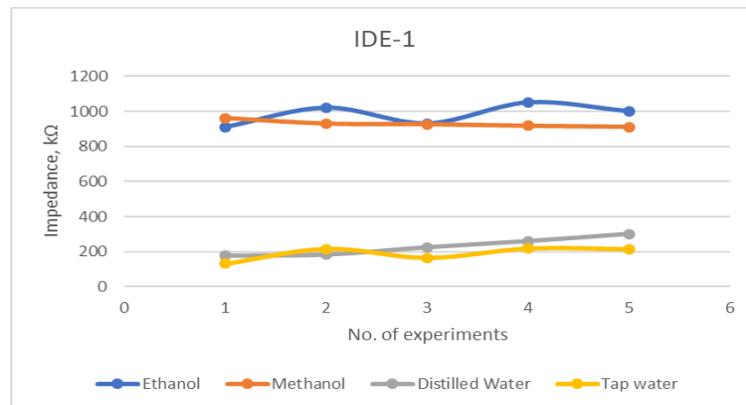
Fig. 5. Impedance measurement for IDE1
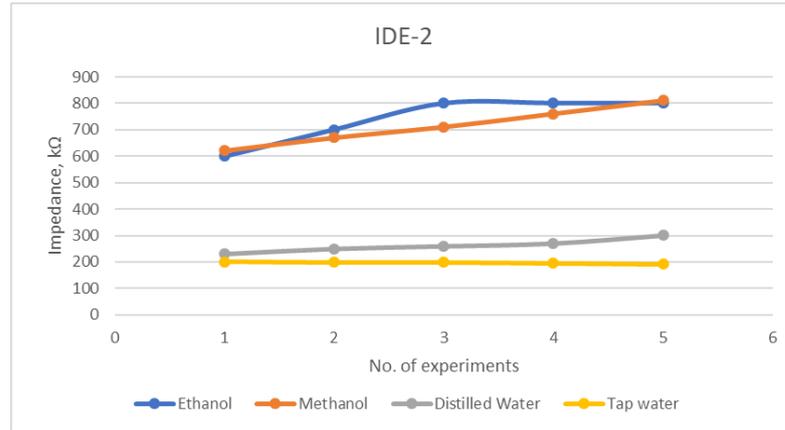
Fig. 6. Impedance measurement for IDE 2
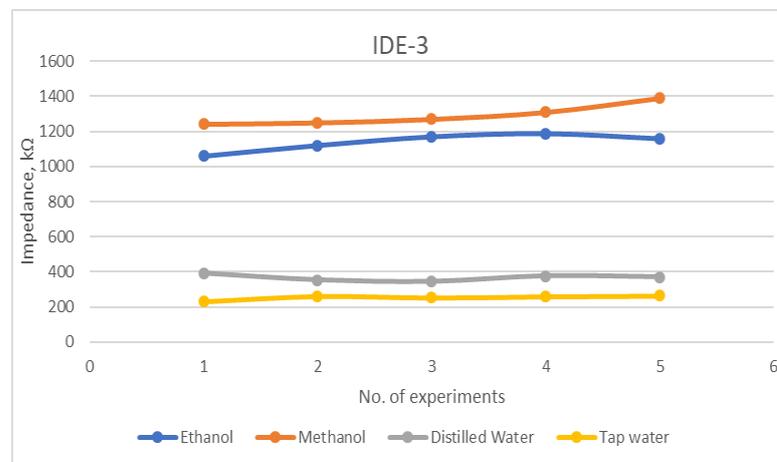
Fig. 7. Impedance measurement for IDE 3

The results from the figure above show that, the proposed sensors were able to detect the presence of the material under test. The sensors are able to distinguish each type of liquid under test by providing a different amount of impedance value for every measurement taken.

Fig. 7 that represent IDE-3 illustrate the most consistent impedance value for all material under test. This is because the sensor is more sensitive due to the larger sensing area. Moreover, the results for all sensors show that, samples with the highest conductivity,σ value (Distilled and tap water) has the lowest impedance value (Azman et. al., 2016). In addition, the difference in impedance value shows the different permittivity value, ε_r of the liquid itself. Therefore, the result shows some agreement of correlation between conductivity and permittivity of material under test for Eq. (1) and Eq. (2). The experiments were then carried out with the different design of IDEs and yet it still shows significant different of impedance value when the IDEs is tested.

4.   Conclusion

By exploiting the special relationship of capacitance and impedance value, an Interdigitated Electrode is able to act as a sensor to detect the presence of liquid material

under test. The proposed sensor showed an observable value of impedance when the highest permittivity value of the liquid material was being tested. In addition, each of the parameters involved in designing the sensors gives a significant impact on the sensitivity of the proposed sensor.

5. Acknowledgements

6. References

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