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Fabrication and characterisation of fluidic based memristor sensor for liquid with hydroxyl group

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ABSTRACT

Two types of memristor sensor were fabricated using two different TiO_2 deposition methods of sputtering and sol-gel spin coating. The surface morphology of the sensors and the behaviour of the sensors were analysed by using scanning electron microscopy with energy dispersive x-ray system and I-V characterisation system respectively. The sensors were applied with liquid with hydroxyl group to check the capability of this sensor in sensing different concentration of hydroxyl ion inside the liquid. For that purpose, D-glucose liquid with four concentrations of 10 mM, 20 mM, 30 mM and 40 mM were chosen. The liquids dispensed onto the TiO_2 surface to act as sensing material. The TiO_2 surface was initially covered with polydimethylsiloxane to control the liquid. The sensing capability of the sensors was determined via the current-voltage measurement and off-on resistance ratio. The sensitivity of the sensors was analysed from the off-on resistance ratio analysis. Type II memristor sensor which was fabricated using sol-gel spin coating technique recorded high sensitivity of 120.65 $(mM)^{-1}$, while Type I sensor fabricated using the sputtering technique recorded low sensitivity of 0.035 $(mM)^{-1}$. However, SEM-EDX image illustrated that the sputtering technique produced more uniform TiO_2 thin film than sol-gel spin coating technique with larger atomic number of oxygen through the sol-gel spin coating technique. This indicates Type II sensor that has large number of oxygen atom produced more reaction with hydroxyl ion inside the liquid. While, Type I sensor produced less reaction compared with Type II and thus produced smaller off-on resistance ratio.

1. Introduction

Theoretical concept of memristor was introduced by Leon O. Chua in 1971 [1]. Chua characterised the device by a relationship between charge and flux-linkage. Chua also has developed operational laboratory models for the memristor with the help of active circuits [1].

The first physical device of memristor was revealed by Hewlett Packard (HP) in 2008 [2,3]. The research team of HP was led by Dmitri Strukov. Since then, researchers have started to design their own device to suit their application targets such as the applications of memory [4–8], computing [9], neural network and bio-sensing [10–12]. Memory application seems to have the largest potential compared with the others due to the device ability in remembering the past [4]. It is proven by just calculating the large amount of research that has been produced in this field [4–8]. Other than this, the bio-sensing application also offers a great future due to its stable sensing mechanism in the memory application. In 2010, a memristor was designed as a temperature sensor through spintronic implementation to be applied in a dry condition by Wang et al. [12]. While in 2012, Carrara et al. and Puppo et al. developed silicon nano-wire memristor sensor for the dry condition biomolecules detection [10,11]. The sensing process takes of more than 1 h to do its process including incubating, washing and drying processes [10,11].

In this paper, memristor sensor is developed to sense liquid with hydroxyl group (OH) in wet condition through fluidic based platform. The liquid with hydroxyl group chosen because a lot organic compounds contain hydroxyl group. Therefore, this study could be useful for another researcher to implement the sensor concept to any compound liquid that suits their application.

Besides, this sensor developed to be used in wet condition which offers fast output measurements whereby the output measurements can be obtained instantly once the liquid placed on the surface of the

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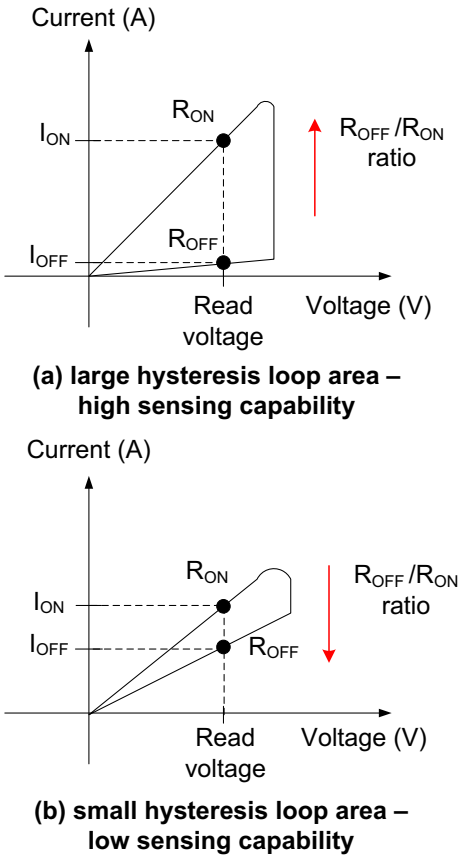

Fig. 1. R_{ON} and R_{OFF} measurements on I-V curve (a) large loop area produce large ratio (present high sensing capability) (b) small loop area produce small ratio (present low sensing capability).

sensing area.

For the sensor characterisation, the liquid used is D-glucose ($C_6H_{12}O_6$) liquid made up of D-glucose powder and distilled water. D-glucose contains multiple hydroxyl groups [13]. In the proposed investigation, four different concentrations of D-glucose liquid were placed on the sensor device to determine the sensor sensitivity. The selected concentrations were 10 mM, 20 mM, 30 mM and 40 mM.

2. Sensing technique

The current-voltage (I-V) characteristic of the sensor devices was observed and the off-on resistance (R_{OFF}/R_{ON}) ratio was analysed based on the I-V result. The I-V characteristic is obtained by sweeping a dc voltage to a device and the current passes through the device was then measured. The R_{OFF}/R_{ON} ratio is obtained by analysing the I-V characteristic data. Fig. 1 shows the method to determine R_{OFF} and R_{ON} from I-V curve.

The R_{OFF}/R_{ON} ratio is selected as the sensing analysis process due to its stable sensing mechanism in the memory application. The high ratio (large loop area) in bio-sensing indicates high sensing capability while the low ratio (small loop area) in the bio-sensing represents low sensing capability. Therefore, a sensor with high ratio (large loop area) is suggested as the most suitable sensor in the bio-sensing applications.

3. Sensor design

The memristor sensor was built with titanium dioxide as its sensing material. The sensing material is expected to produce reaction when it is applied with any liquids that has hydroxyl group. This sensor was designed with nine wells with a diameter of 1 mm for each well. The number of wells is fixed to nine due to the sensor sizes and fabrication facility limitation. However, the variations in wells diameter is under investigation and will be presented in another project. The physical structure of the sensor device with the size of 21.5 mm × 11 mm is shown in Fig. 2.

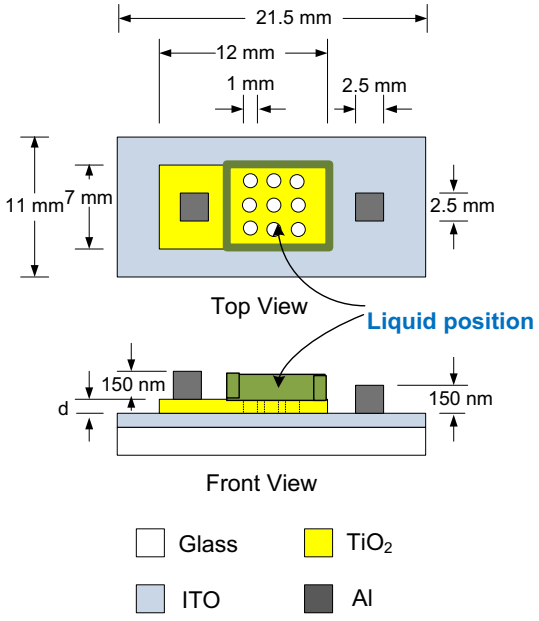

Fig. 2. Top view and front view of the memristor sensor.

The thickness of the well depends on the thickness of the titanium dioxide material labelled as d. The TiO_2 thickness for these two deposition methods is different. The thickness is control by the equipment, setting parameter, chemical, deposition time and speed. It is difficult to produce the same thickness for both depositions method. The thickness for Type I sensor is 40 nm ± 5 nm, while the thickness for Type II sensor is 30 nm ± 5 nm.

The testing liquid is placed on the liquid position area. The liquid position area is covered with Polydimethylsiloxane (PDMS) mold. The diameter of the fabricated wells is 1 mm with the patterned well obtained via the lift-off technique.

4. Sensor fabrication

4.1. Initial preparation

The fabrication process started with 30 min' indium tin oxide (ITO) coated substrate cleaning process by using acetone followed by distilled water and nitrogen gas. The substrate was then baked at temperature 160 °C for 5 min.

4.2. Lift-off mask preparation

Lift-off resist type LOR30B from Tokyo Ohka Kogyo was used in this process. LOR30B was deposited on the top surface of ITO coated substrate using a spin coater. The coating process was set at the speed of 2000 rpm for 25 s. The substrate was then pre-baked at the temperature of 100 °C for 5 min. Then, OAP was coated on the top of the LOR30B layer using spin coating technique at the speed of 2000 rpm for 25 s. It was followed by positive photoresist (ip3100Hs) deposition process via the spin coating method at the same speed of 2000 rpm for 25 s. OAP and ip3100Hs is also supplied by Tokyo Ohka Kogyo. The substrate was later pre-baked again at the temperature of 110 °C for 90 s.

The layers of the resist were patterned through a UV exposure via a film mask. The layers were exposed for only 20 s. The final lift-off mask was obtained by dipping the substrate in NMD-3 developer (a product