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Research paper

Measurement Methods Effects on the Swithing Behaviour of Sputtered Titania Thin Films

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Abstract

The paper presents the issues regarding on the effect of measurement methods to the memristive behaviour to get a reliable and repeatable data. The measurement methods include the measurement cycles and different direction of bias voltage applied to the sample. A one layer of titania thin films was deposited sandwiched between Pt and ITO substrate to form metal-insulator-metal (MIM) structure which is the fundamental structure of memristive device. The oxygen flow rate was varied to 10, 20 and 30% during deposition process of sputtering method. The measurement cycles was repeated for three times. It was found that the device with thinner film required lesser time to get a repeatable I-V curve compared to the device with thicker film. The memristive behaviour is depended on ions movement either positively charged oxygen vacancies or negatively charged excess of oxygen ions. Thus, starting the voltage sweeps either positive or negative voltage applied to the sample is studied in this work. The oxygen vacancies movement in the active layer is proposed.

Keywords: *Memristive behaviour; titania thin films; measurement methods; sputtering method*

1. Introduction

Three fundamental passive circuit elements are known to be resistor, capacitor and inductor, until 1971, Leon Chua argued that there should be the fourth element to complete the symmetry of the basic fundamental passive circuit elements. Memristor is a fourth fundamental passive circuit element theorized by Leon Chua, but was physically realized only in 2008 by HP Labs [1]. Memristor is a short form for 'memory resistor' because of its function to remember its previous state. Memristor is two terminal devices that relate magnetic flux and charge. The device shows I-V characteristics of bow-tie like structure or known as pinched hysteresis loop which crosses at zero point. The simpler structure compared to transistors which is based on metal-insulator-metal (MIM) configuration and its ability to remember the history of the last resistance even when the current was turned off has attracted much attention to be used as non-volatile memory [2-3]. Moreover, they have potential to be used in biological inspired computing and smart interconnects. Different kinds of materials and deposition methods have been reported to fabricate the memristive devices [4-8].

There are two main issues in fabricating memristors; (i) the oxide layer thickness and (ii) oxygen content during deposition process. The memristive behaviour is said can only be seen if the active layer is in nanometer scale thickness [9-10]. Easy formation of defects (oxygen vacancies) to the TiO_2 films at low temperature has attracted great attention from researchers to use TiO_2 as the active layer. Thus, in this work, TiO_2 also known as titania is chosen as an active layer for the device. They also stated that the main carrier in the switching behavior is the positively charged oxygen vacancies. These mobile ions moving through the active layer as the bias voltage is applied to the device. To date, the most common methods in fabricating memristor are nano-imprint lithography (NIL) and atomic layer deposition method (ALD) that have better control on the film thickness and oxygen concentration control [11-15].

However, there are only few studies reported on the issues of how to characterize the memristive behaviour to obtain a reliable and repeatable data. Most have reported that the electroforming process is stated to enhance the switching behaviour and improve the repeatability in I-V curve but better control need to be done since the high voltage applied to the sample can affect the device performance [16-17]. J. Yang et al. have suggested that the switching cycling can eliminate the needs of electroforming process [18]. Due to that, the issues regarding on the measurement cycles is presented in this work in order to eliminate the needs of electroforming process. Besides, different bias direction applied to the sample is also studied.

2. Experimental Details

Prior to deposition process, the substrates must be thoroughly cleaned. The cleaning process was done to remove the contaminant on the substrate surface which will cause low adhesion of deposited thin film due to the formation of cracks or uneven thickness. Indium-doped tin oxide (ITO) coated glass with a sheet resistance of 15.7 Ω/cm and dimension of 2 × 2 cm was used as a substrate and bottom electrode for the device. The substrate was ultrasonically cleaned in ultrasonic water bath using acetone for 10 minutes. The process was repeated using methanol and deionized water (DI). Lastly, the samples were dried using nitrogen gases.

The titania thin films was deposited on ITO substrate by RF magnetron sputtering method using Ti target (99.99% purity). The deposition process was performed at 300W RF power with applied heat, heating time, bias power and working pressure at 200 °C, 120 s, 20 W and 5 mTorr, respectively. The 5 mins deposition process was carried out with 50 sccm Ar gas was introduced into the chamber while varying the oxygen flow rate (O_2/(O_2+Ar) x100 = 10, 20 and 30%). Pt as a top electrode for the device was sputtered through a metal shadow mask with 60 nm thickness. The I-V characteristics of memristive behaviour was measured using two point probe of Keithley 2400 semiconductor characterization system connected to the probe station at room temperature. The bias voltage is swept from the 0V to 5V, 5V to -5V and back to 0V with a constant step of 0.05V. The resistance ratio (R_{OFF}/R_{ON}) measurement of the sample was calculated by taking the maximum and minimum current at a particular voltage giving the biggest switching loop. The larger ratio is better to differentiate the state of the memory. As reported by R. Waser et al., a minimum resistance ratio of 10 is required for circuit design [19].

3. Result and Discussion

3.1. Measurement Cycles

The I-V characteristics of the samples deposited at different oxygen flow rate is shown in Figure 1.

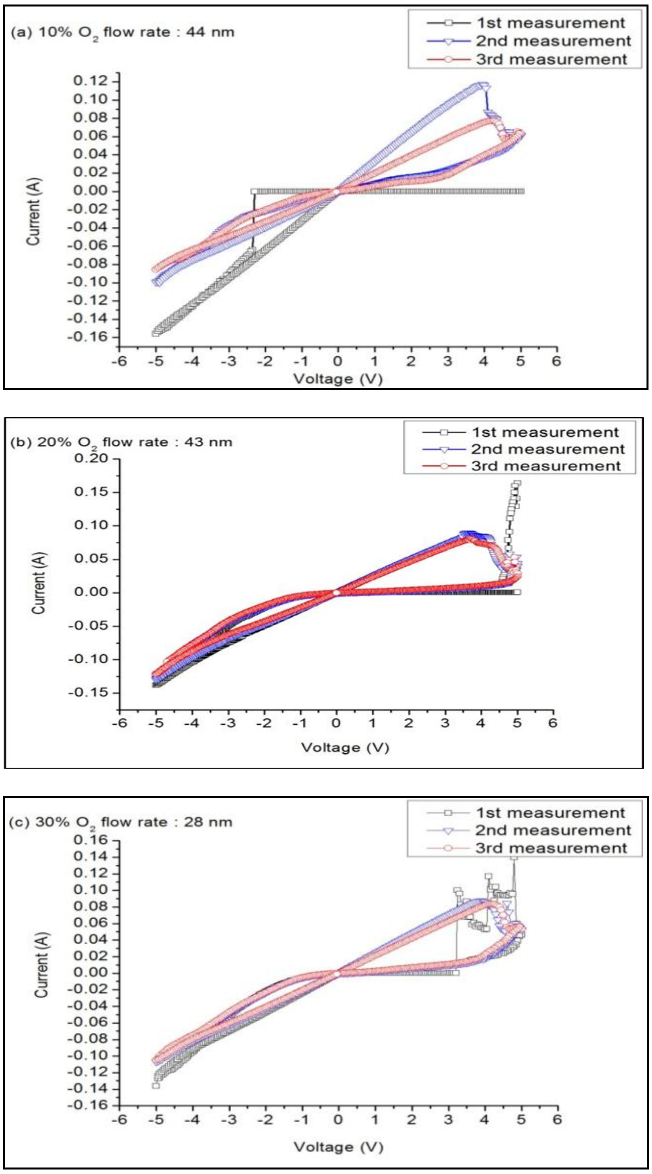

Fig. 1: I-V characteristics of the samples deposited at (a) 10% (b) 20% and (c) 30% oxygen flow rate.

The film thicknesses of the samples deposited at 10, 20 and 30% oxygen flow rate were 44, 43 and 28 nm. It can be seen that the sample deposited at 20 and 30% oxygen flow rate showed repeatability of the I-V curve after 2nd and 3rd measurement of memristive behaviour. So, this suggests that a device with thinner film thickness takes a shorter time interval to get a stable switching loop compared to the device with thicker film thickness. Note that the need of electroforming process is eliminated in this work, due to fact that the high voltage from the electroforming process can damaged the cells and degrade the device endurance. Since no electroforming process was performed to the virgin sample, thus, it can be said that the 1st measurement triggered the switching behaviour of the device. It has been reported that the conducting channel can be formed by the switching cycling [18]. In this work, the 1st measurement can be considered as the electroforming during which, the conducting paths are established. The resistance ratio of the samples was calculated by taking the maximum and minimum current at a particular voltage giving the biggest switching loop. The samples deposited at 10, 20 and 30% oxygen flow rate gave resistance ratios of 5, 9 and 7.

3.2. Different direction of bias voltage

Since sample deposited at 20% oxygen flow rate gave better switching behaviour due to larger resistance ratio of 9, the performance of the memristive behaviour is studied using this method. It was found that starting the positive voltage sweep (0V→5V→5V→0V) result in a different switching loop compared to the negative voltage sweep (0V→-5V→5V→0V). Figure 2 shows the stable switching loop of the sample deposited at 20% oxygen flow rate with positive and negative voltage sweep.

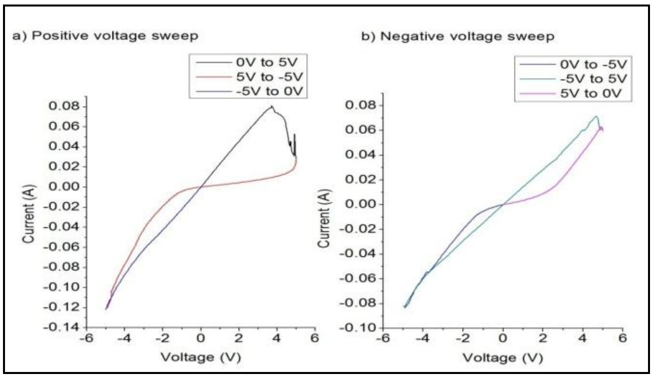

Fig. 2: I-V characteristics of the sample deposited at 20% oxygen flow rate with (a) positive voltage sweep and (b) negative voltage sweep.

It can be seen that the I-V characteristics of the positive voltage sweep showed better switching behaviour compared to the negative voltage sweep. The negative voltage sweep showed smaller hysteresis loop compared to positive voltage sweep. Lower oxygen flow rate during deposition process result in lower oxygen content in the films, which means there are more oxygen vacancies (mobile positive ions) are scattered at the upper surface of titania thin film. When positive voltage is applied to the sample, the positively charged oxygen vacancies will be pushed downwards and cause the vacancies to spread within active layer. So, the sample will be more conductive. In contrast, when negative voltage is applied to the sample, the vacancies will be attracted upwards and caused the conductive region becomes smaller.

4. Conclusion

In this work, it was found that the switching cycling improve the repeatability of the I-V curve. Sample with thinner film thickness required lesser time to get a repeatable I-V curve. Different I-V characteristics can be observed when starting the positive or negative voltage sweep to the sample. Since the memristive behaviour is dealing with the oxygen vacancies movement, further study on this mechanism need to be done.

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