Memristive Behavior of Lateral Metal-Insulator-Metal Structured ZnO Thin Film

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Abstract- **A sol gel spin coated Zinc Oxide (ZnO) based memristive device was fabricated and investigated for its memristive behavior. In this paper, the effect of spin speed and different structure of the memristor were studied. Two type of memristor structures were fabricated; vertical and lateral structures. In vertical structure, the ZnO layer was sandwiched between two Pt metal layers on the top and bottom, while in lateral structure, the ZnO layer was sandwiched by Pt metal layers on both sides, to form the metal-insulator-metal (MIM) configuration of a typical memristor. Each structure was fabricated by sol-gel spin coating method while varying the spin speed from 2500 rpm to 3500 rpm. We found the suitable method to fabricate the lateral-MIM structure by which the resistive switching behavior of ZnO thin film was observed.**

I. INTRODUCTION

Memristor is also known as memory resistor. It is the fourth fundamental passive circuit element besides inductor, resistor and capacitor discovered by Prof Leon Chu Hua in 1974 [1]. Memristor is a two terminal circuit that creates a relationship between charge and magnetic flux [2]. A device is called a memristor when the I-V characteristics exhibit the hysteresis loop shown in Fig. 1 [3]. Since Strukov *et al.* succeeded in fabricating a memristor based on TiO_2 (titanium dioxide) film [4], many researchers have been interested in this field. There are many applications of memristor. One of the applications is a non-volatile memory which can replace SRAM and DRAM [5]. Besides that, a memristor can be an artificial brain because of its capabality to store different resistance based on voltage pulses [6].

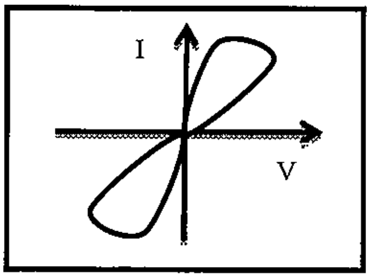


Figure 1: Hysteresis loop of a memristor

Recently, many studies have been carried out to study the memristive behavior of TiO_2 thin film [7].A memristor based on TiO_2 film can be fabricated by RF magnetron sputtering method [7], atomic layer deposition (ALD) [8] and sol-gel method [9].Sol-gel is one of the most attractive method compared to other method because it does not required expensive and complicated equipment and easy to be coated on the desired shape and area [9]. Spin coating technique is used to deposite uniform thin films [9]. Generally the process involved dispersing an amount of solution onto the substrate that is rotated at high speed in order to spread the solution by centrifugal force [9].

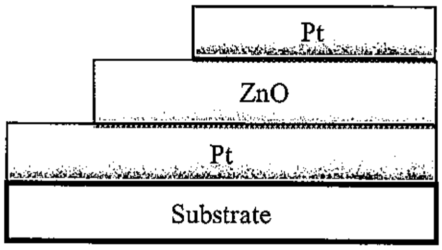


Figure 2: Schematic diagram of vertical memristor

Besides TiO_2, memristors can also be fabricated based on ZnO (zinc oxide) thin film [10], CuONW (copper oxide nanowire) [11], SiOx-based [12] and NiOx-based [13]. Of the various available materials for memristor, ZnO receives the considerable attention. Zinc oxide (ZnO) is n-type semiconductor. It has a direct band gap of 3.37eV at room temperature. ZnO has free-exciton binding energy of 60meV [9]. It is a non-toxic material and stable against thermal as well as chemical reaction [14]. ZnO is well known for its transparency when made into thin film [9]. The applications of ZnO including blue and ultraviolet (UV) light emitter, solar cell windows, photovoltaic device, gas sensor [14], flexible memory application (RRAM) [15] and surface acoustic wave device [16].

In this work, we want to explore the usage of a memristor in sensor application. Lateral memristor might produce a better performance in sensor application compared to vertical memristor. Vertical structure of a memristor has metal on top. Hence, ZnO could not act as a sensing layer. Therefore, a lateral metal-insulator-metal structure was proposed to improve the sensitivity. ZnO was chosen as an oxide layer because of its properties that can be used as a sensor [17]. We investigated the process to fabricate lateral memristor as well as the memristive behavior characterization.

II. METHODOLOGY

ZnO solution was prepared by sol-gel method. In this work, Zinc acetate dehydrate, 2-methoxyethanol and ethanolamine were used as the precursor, solvent and stabilizer respectively. The solution was prepared by dissolving 4.4g zinc acetate dehydrate into 23 ml of 2-methoxyethanol. Then, 1.2 ml of ethanolamine was added to stabilizethe solution. Another 23 ml 2-methoxyethanol was then added in order to obtain the 0.4 molar ZnO solution. The solution was then sonicated for 30 minutes at 50°C. After that, the solution was subjected to stir-heated process for 3 hours at 80°C. The stirring was continued for another 24 hour in a room temperature environment.

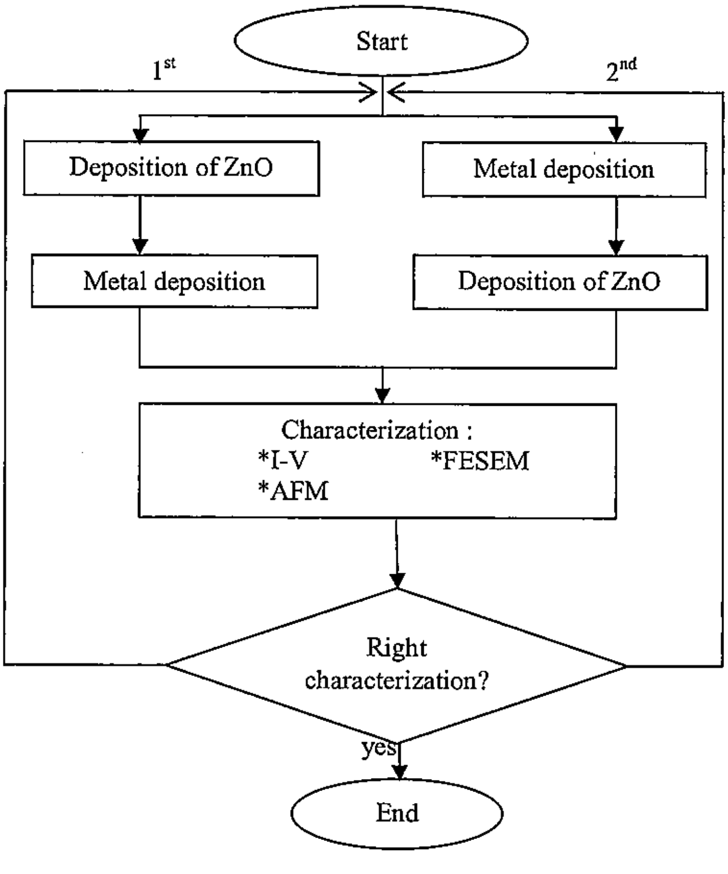


Figure 3: The flowchart of lateral ZnO thin film fabrication

Fig. 3 shows the flowchart of lateral ZnO thin film deposition. In this study the lateral thin film was fabricated using spin coating technique. Two fabrication methods were applied and the structure of both lateral memristor was shown in Fig. 4. In the lateral structure, instead of having Pt on the top and bottom, Pt layers were sputtered on both sides to form MIM configuration.

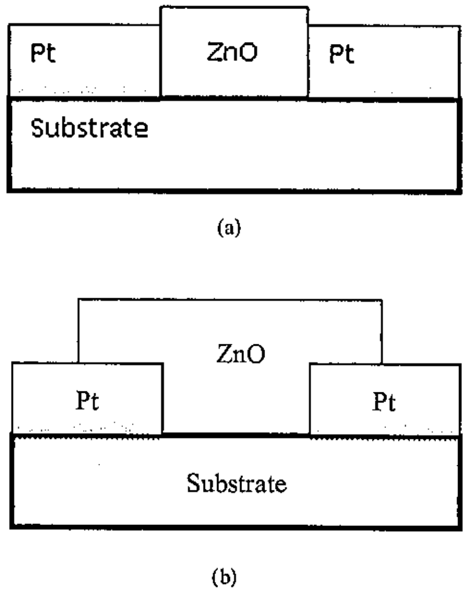


Figure 4: Structure of lateral memristor for (a) first fabrication method (b) second fabrication method

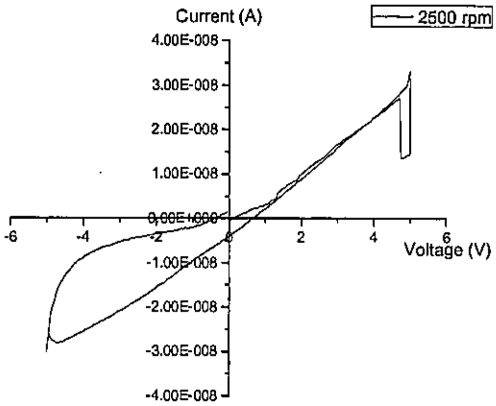
In the first fabrication method, ZnO solution was intially spin coated onto the glass substrate. During the ZnO deposition, the left and right sides of the substrate were covered with capton tape to later form the electrodes for lateral structure. Unlike the first method, in the second method, Pt was sputtered onto the substrate. A glass of 1 cm × 2.5 cm was used to cover the middle area of the glass substrate. After that, the ZnO solution was spin coated onto the metal coated glass substrate. Prior to the spinning process, the metal coated areas were covered with capton tape.

The spinning process was carried out at variable spinning speed of 2500 rpm to 3500 rpm with the interval of 500 rpm for 1 minute. Followed by the drying process for 10 minutes at 150°C. Lastly, the samples were annealed for 60 minutes at 450°C. As comparison, a vertical structure of ZnO thin film was also fabricated. The vertical structure was fabricated using similar spin coating method as described above.

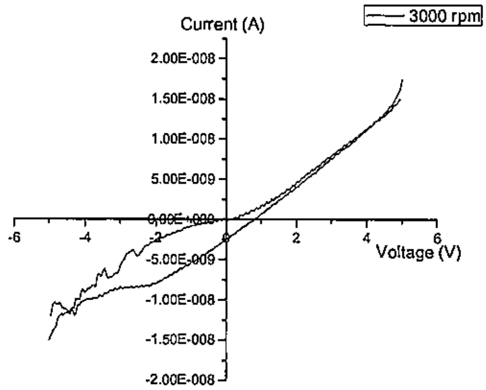
The fabricated thin films were then subjected to electrical characterization. The electrical characterization was carried out using 2-probe I-V measurement to study the memristive behavior of the ZnO thin film. The I-V measurement was performed by sweeping the bias voltage from 0V to 5V, then 5V to -5V and back to 0V. The current was measured simultaneously during the voltage biasing.

III. RESULTS AND DISCUSSION

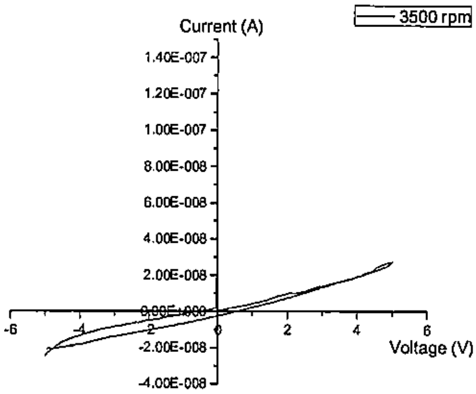
Fig. 5 (a-c) show the I-V characterization of lateral memristor fabricated using the first fabrication method. The results show that asymmetrical hysteresis loop was observed. As can be seen, the hysteresis loop is only available at the negative sides for all ZnO thin films deposited at 2500, 3000 and 3500 rpm. Low value of current in a range of nano-ampere was measured. This is presumably due to the existence of gap between the ZnO and metal electrode that will result in the obstruction of electron flows which in turn cause the low current measurement.



(a)



(b)



(c)

Figure 5: I-V characteristics of lateral memristor using first method for spin speed at (a) 2500rpm, (b) 3000rpm(c) 3500rpm

In order to fix the problem, the lateral MIM structure was fabricated using the second fabrication method. Fig. 6 shows the FESEM images of ZnO and Pt edges for the (a) ×1000 and (b) ×10000 magnifications. As can be seen the ZnO thin film and Pt layer overlap to each other. Hypothetically using this structure will result in the improvement of the memristive behavior of ZnO thin film.

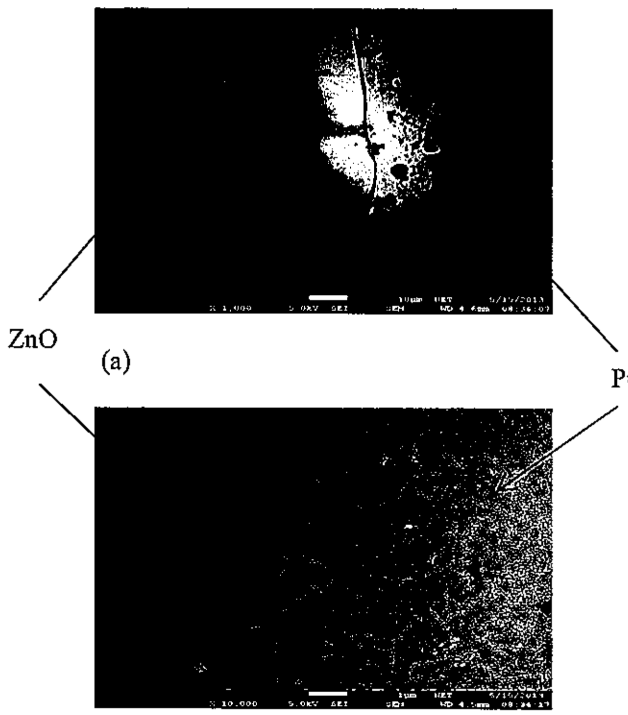
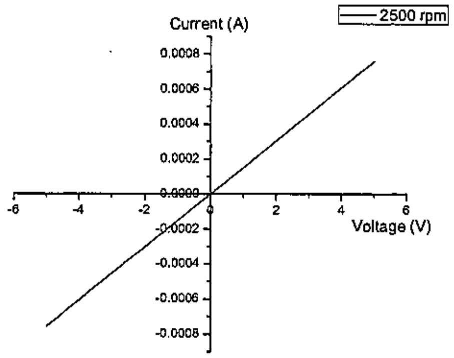
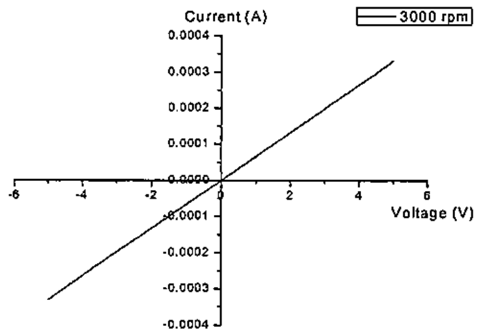


Figure 6: FESEM images of lateral memristorfabricated using second fabrication method for spin speed at 3000 rpm at (a) ×1000 and (b) ×10000 magnifications

Fig.7 shows the I-V characterization of ZnO thin film deposited at varying spin speed of 2500-3500 rpm. It is observed that the ZnO MIM lateral structure deposited at different spinning speeds exhibit ohmic behavior. No hysteresis loops were however obtained for both positive and negative voltage sides. This is maybe due to the width of ZnO thin film fabricated in this work. Since memristive behavior can only be detected at nanometer range, it is therefore suggested that narrow width of ZnO thin film would result in better performance. In this work the width of the ZnO thin film was in centimeter range. It is also observed that the maximum current of 0.8 mA at 3 V was measured for the ZnO thin film deposited using 2500 rpm spinning speed. The current however decreases as the spinning speed increases.



(a)



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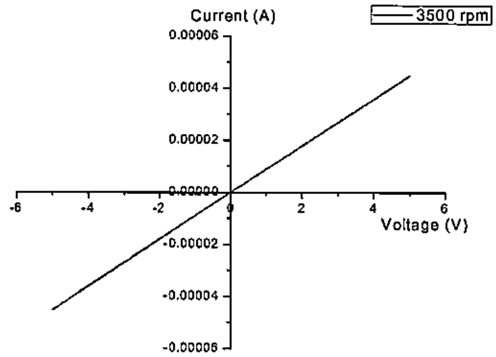
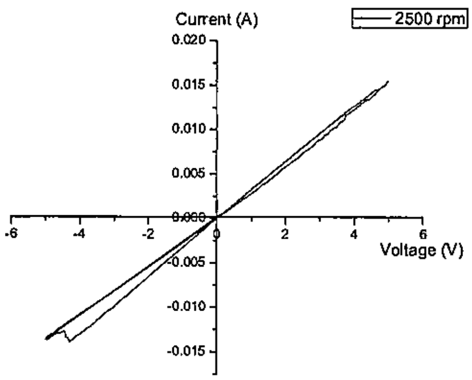


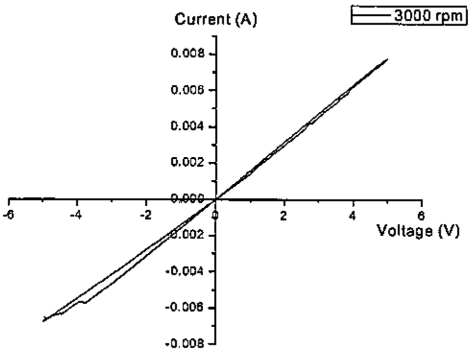
(c)

Figure7: I-V characterization of lateral memristor using second fabrication method for spin speed at (a) 2500 rpm (b)3000 rpm and (c) 3500 rpm

As comparison, vertical MIM structures were also fabricated. Fig.8 shows the I-V characterization of the vertical memristor fabricated at different spin speed. It was found that the memristive behavior can be obtained if the ZnO thin film is fabricated using commonly used MIM vertical configuration. This is due to the nanometer range of the film thickness. In this work the thickness measured by surface profiler was in a range between 85-95 nm. It was found that the widest hysteresis loop was obtained when the ZnO was deposited using 2500 rpm spin speed. The maximum current was found to be ± 0.015 A. As lateral memristor, the current also decreases as the spin speed increases. It thus can be suggested that the suitable spin speed to obtain memristive behavior is 2500 rpm.



(a)



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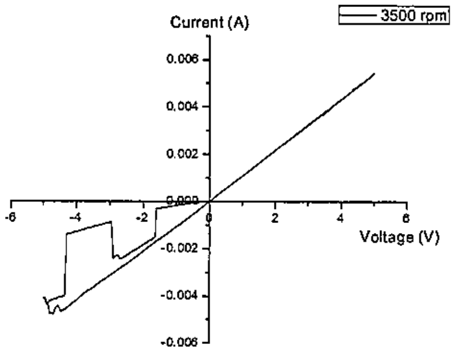

(c)

Figure 8: I-V characteristics of vertical memristor for spin speed at (a)2500rpm(b)3000 rpm and (c) 3500 rpm

IV. CONCLUSION

This work focused on how the fabrication method of lateral memristor. Two fabrication methods have beenused to fabricate the lateral MIM structure. First fabrication method resulted in low current. Using the second method on the other hand produce ohmic I-V characteristic showing that the fabricated sample is conductive. No hysteresis loop was observed. This might be due to the width of ZnO thin film. Unlike lateral configuration, using commonly used vertical structure resulted in the formation of hysteresis loop at both positive and negative voltages. This is due to the nanometer range of ZnO thin film thickness. In this work, using spinning speed of 2500 rpm produces the best memristive behavior.

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