# UNIPOLAR RESISTIVE SWITCHING BEHAVIOUR IN Al/ZnO/Al HETEROJUNCTION STRUCTURE

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***Abstract:*** The fabrication of resistive switching memory device (random access memory) is based upon ZnO. Thin films based on ZnO have the characteristics of resistive switching. ReRAM (Resistive Random Access Memory) fabrication based on heterostructure Al/ZnO/Al/$SiO_2$ is shown in this work. This fabrication which is based on ZnO thin film, shows the better unipolar switching behaviour. Magnetron sputtering was done to fabricate the complete device. XRD analysis was done to know the presence of ZnO thin film on $SiO_2$ surface. SEM of ZnO film was done to know the surface smoothness. Finally the electrical characterization was done to analyse the switching behaviour. A decreased ratio between high resistance state and low resistance state was found after investigating the I-V graph of device. This research may highlight the ZnO based ReRAM fabrication with low power consumption, high density and low cost.

***Index Terms* – ReRAM, Switching Mechanism, magnetron sputtering, XRD, SEM.**

## I. INTRODUCTION

ReRAM based on Zinc oxide (ZnO) thin films have been found as the best substitute to the flash memories. Recently resistive switching based memories are drawing the attention of many researchers for the fabrication of new generation non-volatile memory. Traditional DRAM may include million or billions of transistors in itself. These transistors can be charged/ discharged [0 or 1]. Disadvantages of DRAM is that it requires refresh and power supply gradually. In ReRAM charge particles stores the data in the place of electron as in DRAM. ReRAM is a part of memristive technology. Lower power consumption, high endurance, low leakage are few advantages of ReRAM. ZnO based resistive switching memories show a high on-off ratio, good endurance and low operating voltage with the help of magnetron sputtering.

A fourth fundamental circuit device element, memristor (memory + resistor) behaves as a two terminal passive device element. This element functions as non-linear device like as- resistor, capacitor, and inductor. ReRAM memory device works on the principal of memristor. Results revealed that, schottky emission mechanism was occurred because of oxygen deficiency in ZnO layer. Moreover, a decrement in power consumption was found because of compliance current of memory devices. This occurs because of deficiency in oxygen vacancies.

During last decades the impact of oxygen composition of ZnO metal-oxide on unipolar resistive switching characteristics of Al/ZnO/Al resistive RAM_has been observed [1]. ZnO has been investigated as a promising candidate to provide resistive switching with the help of thin film deposition using sputtering [2]. A resistive switching characteristics in ZnO based non-volatile memory devices was observed by Fu-Chien Chiu [3]. A work was done on ITO coated glass to show the permanent storage in ZnO thin films by filamentary resistive switching [4]. ZnO film thickness also affects the resistive switching characteristics of ZnO thin film was improved by changing the substrate temperature from room temperature to 400ºC [6]. Homogenous and filamentary types of memristive behaviour were also investigated to find the effect of $O_2$ deficiency [7]. In the same way, a work presented by Lin et al [8]. They have also found the effect of different oxygen composition (10%, 25% and 33%) on unipolar switching. Chiu et al. reported a bipolar resistive switching behaviour in M-I-M (Pt/ZnO/Pt) structure [9]. Firstly Wu et al. had given a difference between unipolar and bipolar behaviour.

This study investigates the characterisation of ZnO thin film in an M-I-M (Al/ZnO/Al) structure. This work is helpful for NVM (Non-Volatile memory) applications. Experimental work shows a better switching behaviour at lower set/reset voltage, after investigating the I-V graph of the device.

## II. EXPERIMENTAL ANALYSIS

The process of fabrication ReRAM was started from RCA1 and RCA2 cleaning of p-Si sample. Wet oxidation was done to grow 200nm thick $SiO_2$ layer on p-Si substrate. ReRAM fabrication starts with Zn target (99.99% pure) and $SiO_2$ wafer as substrate. $SiO_2$ wafer was prepared by 200nm thick film on p-type silicon having 001 orientation and nominal resistivity 1-10 ohm-cm by wet oxidation process. To form M-I-M structure, 150 nm thick Aluminium film was grown on $SiO_2$ substrate at 0.493 mtorr deposition pressure and 15 sccm Argon gas flow with the help of RF magnetron sputtering. 50 nm thick ZnO thin film was sputtered using RF magnetron sputtering machine over the aluminium film. This sputtering was done by using Zn target to provide oxygen vacancies in the ZnO thin film. This sputtering took place in the presence of argon and oxygen gas mixture 30% = [$O_2$ / ($O_2$+Ar)] = [10sccm /

(20scccm+10sccm)] at 7.16 mtorr deposition pressure and 8.42×10$^{-3}$ mbar base pressure. Deposition rate was 0.5-0.9 A°/s and transmitted RF power was 70 watt with 30 mint deposition time. The top electrode was also taken of aluminium. Al material is light weight material. This Al was deposited on ($ZnO/Al/SiO_2$) with the help of masking. Masking was taken of 1 mm diameter with the help of circular shadow mask. Fig. 2.1 shows the device structure of ReRAM.

Sputtering technique taken in the whole process was RF magnetron sputtering. Oxygen vacancies and the structural analysis of ZnO thin film deposition was done using XRD data analysis (X-Ray Diffraction) with the help of PANalytical X'pert Pro apparatus. Scanning Electron Microscope (SEM) was done to find the surface smoothness of ZnO film using the apparatus NOVA NANOSEM 450. Finally the electrical characterization was done on semiconductor parameter analyser.

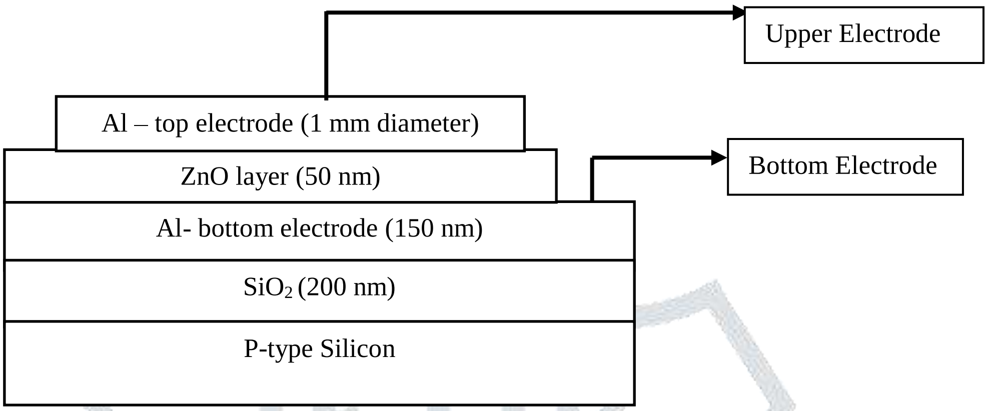

**Figure 2.1-** ReRAM fabrication process

## III. RESULTS AND DISCUSSION

### 3.1 Structural Analysis

The structural analysis of ZnO was done by using XRD (X-Ray Diffraction). Fig.3.1 shows the XRD graphs for the range of 2θ = 30°-80°. Two highest peaks of ZnO were observed at 2θ = 34°, 65°. Similarly, the Al peaks were found at 2θ = 36°, 44°, 78°. The XRD data was compared with JCPDS data – (010750576). ZnO peak (002) with high intensity is comparably useful for resistive switching, which is also given by Cheng-Li Lin [1]. Wurtzite structure of ZnO was observed in XRD analysis with a high intensity peak (002).

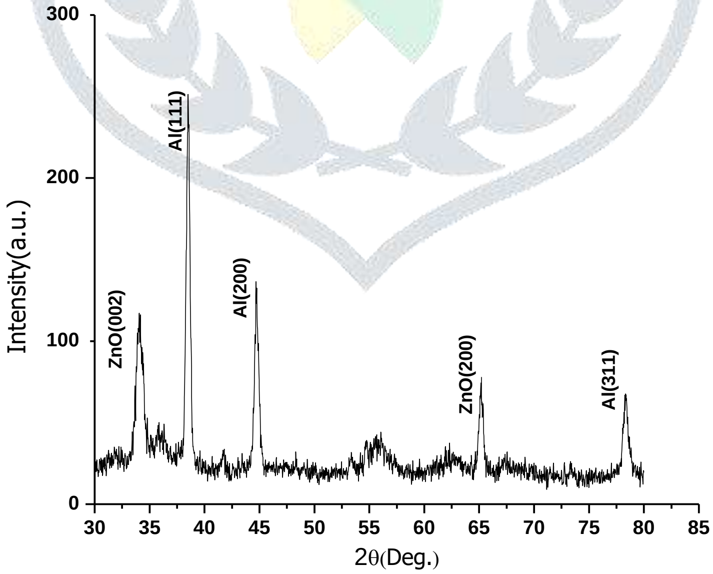

**Figure 3.1-** XRD graph of $ZnO/Al/SiO_2$

Corresponding values of crystallite size and FWHM are shown in table 3.1. From the XRD analysis it is cleared that a ZnO layer has been grown on $SiO_2$ surface. Average crystallite size was found (~20nm). Crystallite size was calculated using Scherrer's relation which is given below-

$$t = \frac{0.9\lambda}{\beta \cos\theta_B} \tag{3.1}$$

Where, t = Crystallite size, λ = (Cu-kα) range, β = FWHM broadening, $\theta_B$ = Bragg's Angle.

**Table 3.1**- Crystallite size analysis of ZnO

| Peaks | Orient-ation | 2Θ ($^0$) | Θ ($^0$) | Radian | FWHM (Radian) | Crystal Size (meter) | Avg. Crystal size (meter) |
|---|---|---|---|---|---|---|---|
| Peak 1 | 2 | 34.004 | 17.002 | 0.29659 | 0.00823 | 1.72E-08 | 2.02E-08 |
| Peak 2 | 200 | 65.2097 | 32.6048 | 0.56877 | 0.00686 | 2.33E-08 | 2.02E-08 |

### 3.3 Morphological Analysis

SEM analysis was done for the analysis of surface morphology. High resolution image of ZnO surface was found, which is shown in fig. 3.2. From the figure, spherical structure with a relatively smooth surface was found. This smoothness of the surface is best suitable for switching application.

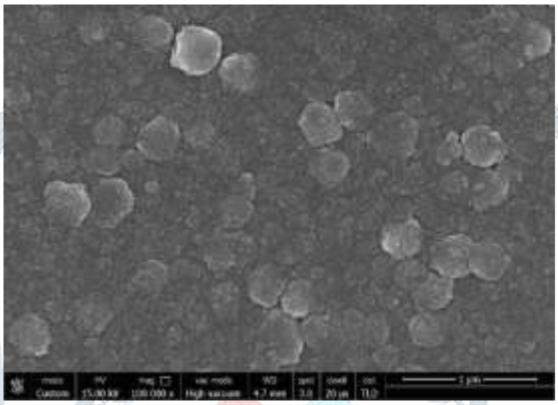

**Figure 3.2**- SEM image of ZnO/Al/$SiO_2$

### 3.3 Electrical Characterization

Initially the process of resistive switching starts from the forming process to provide unipolar resistive switching on filamentary memory cells. I-V characteristics of Al/ZnO/$SiO_2$ is shown in fig. 3.3. The voltage required for forming process is 4 volts. After the completion of forming process, the device was in low resistance state (LRS). After an increase in input voltage with a slower rate, the device transformed to high resistance state (HRS) from LRS. This voltage is called reset voltage. In other words this process is for erase the data in ReRAM. After the completion of reset process, another voltage scan was made to perform the set action. This voltage scan turns the device into LRS state from HRS. This process is performed to complete the write task in ReRAM. Here, the set voltage was calculated as 1.2 volts and reset voltage was calculated as 0.7 volts.

While applying the first voltage scan current increased abruptly up to reset voltage. Another voltage scan transform the device into set condition. The set voltage ($V_{SET}$ ~ 1.2 Volts) is larger than the reset voltage ($V_{RESET}$ ~ 0.7 Volts) as mentioned by Fu-Chien Chiu [3]. The value of set current ( $I_{SET}$ ~ 3 mA) was found lesser in comparison of reset current ($I_{RESET}$ ~ 3.5 mA). Resistive switching of device is completely dependent upon the polarity of applied voltage. Unipolar resistive switching was observed in Al/ZnO/$SiO_2$ heterojunction structure, which was also given by Faith Gul [7].

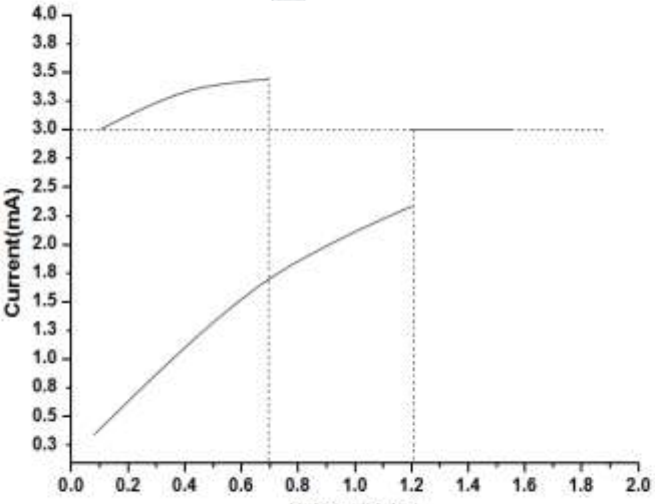

**Figure 3.3**- I-V graph for ReRAM device (Al/ZnO/Al/$SiO_2$)

## IV. CONCLUSION

This study investigates the electrical as well as structural characterization of Al/ZnO/Al/$SiO_2$. Oxygen gas flow ratio of 30% reveals the lowest ration of ($V_{RESET}/V_{SET}$) voltages of (0.7V/1.2V). It was also concluded that, ReRAM device with compliance current of 3mA is showing the decreased power consumption with decreased oxygen deficiency. A better on-off ration with a better set and reset current ratio was found for 50nm thick ZnO layer. Finally, it was found that 50nm thick ZnO layer between to Al electrodes provides the better resistive switching behaviour. This type of ReRAM is cost effective and light weighted as Al is cheaper in comparison of other materials like- Palladium, gold, silver etc.

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