Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp779-780

PS-4-04

The effect of TiW thickness on non-polar to bipolar switching transformation in ZrO2-based CBRAM

Sridhar Chandrasekaran [1], Firman Mangasa Simanjuntak[2] and Tseung-Yuen Tseng[3]
[1] Department of Electrical Engineering and Computer Science
[3] Department of Electrical Engineering and Institute of Electronics
National Chiao Tung University
Hsinchu 30010, Taiwan
Phone: +886-978654099 E-mail: sridharc9020@gmail.com
[2]Department of Electrical Engineering
National Dong Hwa University
Hualien 97401, Taiwan

Abstract

In this work, we studied the effect of varying the thickness of TiW barrier layer on ZrO_2 based-conducting bridge random access memory (CBRAM). The thickness of TiW barrier layer may alter the switching characteristic of Cu/TiW/ZrO2/TiN CBRAM. We found that the non-polar or bipolar switching can be modulated by introducing an appropriate TiW thickness. The presence of metallic Cu cation confirmed by using XPS-3D map. This allows CBRAM to exhibit non-polar switching behavior for the device without a barrier layer.

1. Introduction

Resistive switching random access memory is considered as the stronghold for Next Generation Non-Volatile Memory because of their simple and cost efficient structure. The RRAM can be classified based on their mechanism, CBRAM and OxRAM (oxygen vacancy based conduction)[1]–[5]. CBRAM operation is based on oxidation reaction at the top electrode (Cu or Ag) leading to conduction bridge formation [6],[7]. The conduction bridge allows the electrons to flow easily in the resistive layer; resulting in resistance state change from higher resistance state (HRS) to lower resistance state (LRS). During reset, the applied reversed polarity leading to the rupture of the conductive bridge which allows the resistance state change from HRS to LRS. Conversely, the set process switches the resistance state from LRS. Even though, the influence of top electrode thickness on switching characteristics has been reported [8]–[11]. However, those reports mainly discussed the phenomenon in OxRAM.

In this study, we varied the thickness of the TiW barrier layer to analyze its effect on switching mechanism. XPS Depth profiling has employed for the analysis of Cu diffusion across the resistive switching layer. We are proposing the 3D-Map which allows us to analyze the XPS-depth profile 3-dimensionaly. A detailed discussion on switching operation and is provided in the subsequent section.

2. Experimental

A 15 nm TiN deposited on Pt/SiO_2/P-type Si substrate at 300 ºC by Atomic Layer deposition and a 15 nm ZrO_2 deposited over it at 200 ºC by using RF- Sputter with an $Ar:O_2$ ratio of 12:8. The Cu top electrode and TiW layer patterned with metal shadow mask of 150µm diameter. It is deposited by using DC-sputter at room temperature of thickness 200 nm (Cu) and 5, 10 & 15 nm (TiW). The electrical measurement is carried out with the help of Agilent B1500 with Cu top electrode is forward biased and TiN bottom electrode grounded.

3. Results and Discussion

The electrical measurement is carried out by operating the devices by employing current compliance of 5mA. The 0 nm and 5 nm TiW device is exhibiting non-polar switching behavior Figs. 1 (a) & (b). We observe the absence of non-polar switching after increasing the TiW thickness beyond 10 nm, as depicted in the Figs. 1 (c) & (d), The switching characteristics of 10 and 15 nm TiW is positive (P)-Bipolar and negative (N)-Unipolar, the absence of P-Reset. To further investigate the effect of TiW thickness variation, we employed XPS Depth profiling to examined the diffused Cu atom across the resistive switching layer.

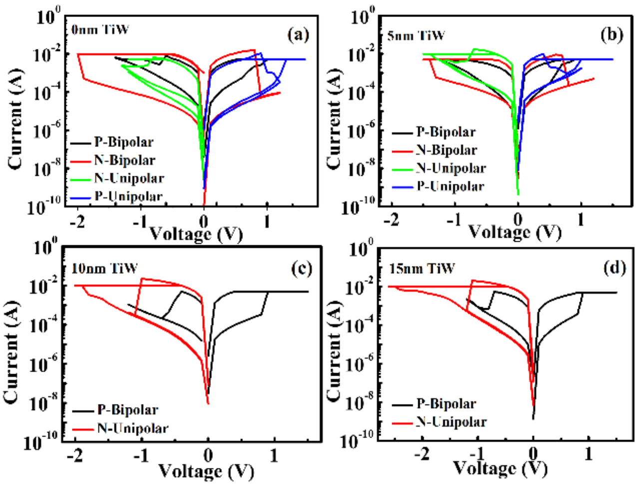

Fig. 1 Typical I-V curves of ZrO_2 based CBRAM of various TiW thickness (a) 0, (b) 5, (c) 10 and (d) 15 nm.

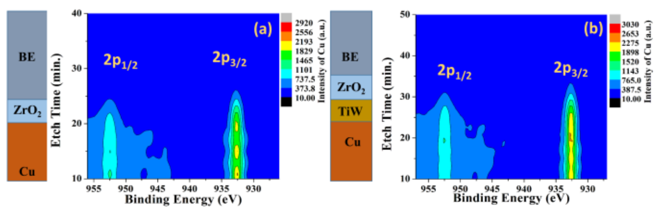

Fig. 2 XPS depth profile (3D-Map) of Cu 2p spectra for, (a) device without TiW ($Cu/ZrO_2/TiN$ stack) and (b) device with TiW ($Cu/TiW/ZrO_2/TiN$ stack)

The XPS depth profile is deployed on 0nm and 15nm TiW pristine devices for the investigation of copper diffusion on ZrO_2. The intensity of the individual elements can be understood well by observing the changes in the color of the contour plot. On observing the Cu $2p_{3/2}$ spectra as in Fig.2 (a) & (b), there is a substantial amount of Cu diffusion observed on the ZrO_2 layer for Cu/ZrO_2/TiN stack, almost half of the ZrO_2 layer suspected with Cu diffusion. It further confirms the contribution of diffused Cu atom for non-polar switching The device with TiW shows a significant resistance towards Cu diffusion which suggests that higher dependence of diffused Cu atom for non-polar switching [12]. For the device without TiW, The conductive filament rupture can happen on both polarities, due to the electrochemical reaction assisted by the joule's heating across the nano-filament.

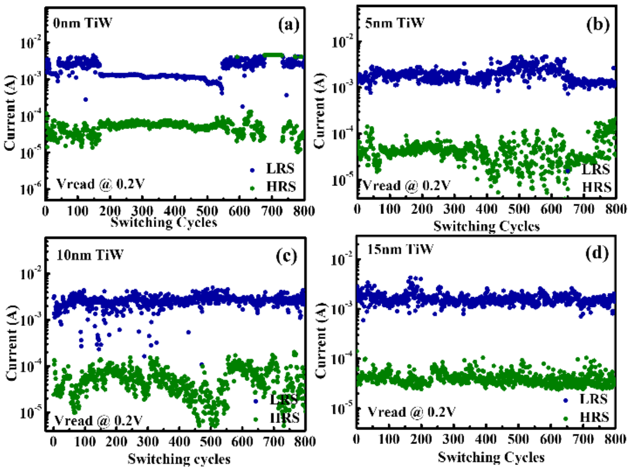

Fig. 3 (a)-(d) DC Endurance for ZrO_2 based CBRAM, (a) 0 nm, (b) 5 nm (c) 10 nm and (d) 15 nm TiW.

Figure 3 (a)-(d) illustrates the DC-endurance for a device with various thickness TiW. The DC endurance is measured by considering the V_{read} at 0.2V during the set operation. On increasing the thickness of TiW thickness, more stable the endurance characteristics. Moreover, the device with a thickness of less than 15 nm TiW thickness shows highly unstable or fluctuating switching is observed. A highly stable resistive switching is observed in a device with 15 nm TiW thickness.

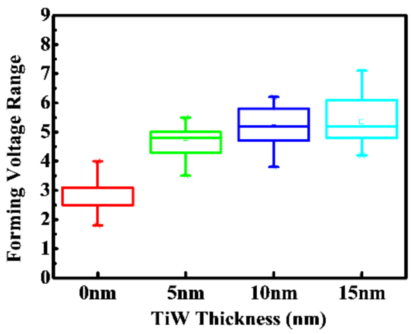

Fig. 4 Variations of forming voltage range on varying thickness of TiW layer.

Figure 4 depicts the direct dependence of forming voltage range on increasing the TiW thickness. The forming voltage is found to be larger for a device with thicker TiW, the step by step rise in forming voltage range is observed. A smaller voltage is sufficient enough to carry forming on a device with 0 nm TiW thickness. Moreover, the effective resistance is increased by increasing the thickness of TiW layer which requires much larger voltage for the complete CB formation.

4. Conclusions

In summary, the effect of varying the thickness of TiW layer on the resistive switching characteristics of ZrO2-based devices has been investigated. It is found that the non-polar to bipolar switching transformation occurs on increasing the TiW layer thickness beyond 10 nm which is also further evidenced by observing the diffused Cu atom on the resistive switching layer by XPS 3D-Map. Thus by introducing the TiW layer, we observe highly stable DC-endurance and prominent change in resistive switching mechanism from non-polar to P-bipolar and N-unipolar switchings.

Acknowledgements

This work was supported by the Ministry of Science and Technology, Taiwan, under project MOST 105-2221-E-009-134-MY3

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