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Improved Resistive Switching Uniformity of a Bilayer TiO_2 Films

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1. Introduction

We investigated the resistive switching properties of bilayer TiO_2 thin films using 250nm via-hole structure. Sol–gel method has various advantages such as low cost, simplified manufacturing and large area applications. However, compared with conventional deposition process, films deposited by sol–gel method show inferior electrical characteristics and uniformity for nano-scale device applications.

In this study, to solve the problems of conventional sol-gel device, we have investigated the effects of additional atomic layer deposition (ALD) TiO_2 (~8 nm) layer on resistive switching behavior.

2. Experimentals

Pt/TiO_{2-x}/TiO_2/W device were fabricated using 250 nm via-hole substrate as shown in Fig. 1(a). After depositing 8nm-thick TiO_2 layer by ALD (defined here as TiO_2), 50nm-thick sol-gel layer (defined here as TiO_{2-x}) was prepared by spin coating. TiO_2 solution made of Titanium (IV) isopropoxide according to the previous work reported elsewhere [1]. The resulting films were thermally annealed at 400℃ for 2h under a nitrogen atmosphere. Using the cross-sectional transmission electron microscopy (TEM) images as shown in Fig (b), we have confirmed a Pt/TiO_{2-x}/TiO_2/W structure. Crystalline TiO_2 layer can also be confirmed from the TEM figure. After conventional lithography process, a 100nm-thick Pt top electrode was deposited by sputtering.

3. Result& Discussion

To confirm the concentration of oxygen in each layer, X-ray photoelectron spectroscopy (XPS) analysis were performed as shown in Fig. 2. The Ti $2p_{1/2}$ and $2p_{3/2}$ XPS peaks were resolved into two spin-orbits, which were assigned to Ti^{3+} and Ti^{4+} peak [2]. Because the Ti 2p area ratio of the Ti^{3+} to the Ti^{4+} peak can show the defect concentration of Ti^{3+}, we calculated defect ratio for TiO_2 and TiO_{2-x} layer results 0.17 and 0.23 respectively [3]. This indicates that the TiO_{2-x} layer has a significant number of oxygen vacancy compared to TiO_2 layer. Fig. 3 (a) shows bipolar switching characteristics of TiO_{2-x}/TiO_2 film. After forming process, the devices switch from HRS to LRS by applying positive bias. We can change the resistance state back to HRS by applying negative bias. Inset of Fig. 3(b) shows switching characteristics of Pt/TiO_{2-x}/W structure. The switching characteristic of Pt/TiO_{2-x} /W device shows more fluctuation than Pt/TiO_{2-x}/TiO_2/W device. Statistical distribution of switching parameters (I_{ON} and I_{OFF}) for the TiO_{2-x}/TiO_2 and TiO_{2-x} layer were depicted in Fig. 4 (a). The distribution of 50 cell to cell uniformity in TiO_{2-x}/TiO_2 layer shows in Fig.4 (b), and the average value and standard deviation of I_{ON} and I_{OFF} are summarized in Table.1. Significant improvement of switching uniformity was observed by adopting TiO_2 layer. Endurance characteristics of the TiO_{2-x}/TiO_2 devices were investigated as shown in Fig. 5. We have confirmed that TiO_{2-x}/TiO_2 devices exhibit high ON/OFF ratio ($>10^2$-10^3) up to 10^4 cycles. The retention property at room temperature is shown in Fig.6, and there are no significant changes in the resistance magnitudes up to 10^4sec.

We propose the conduction model for the TiO_{2-x}/TiO_2 structure shown in Figure 7. Sol-gel layer is highly conducting film with lots of oxygen vacancies (V_o^{2+}) and ALD layer is highly resistive. To confirm the switching mechanism, we measured I-V curve with varying bias windows (2V, 5V, and 7V). As shown in Figure. 7(a), the negatively charged oxygen ions (O^{2-}) are attracted and move into TiO_{2-x} layer. Such ionic movement towards top electrode reduces the thickness of the insulating TiO_2 region which in turn causes LRS state. In contrast, by applying negative bias as shown in (Fig. 7 (b)), oxygen ions (O^{2-}) move back to their original place which in turn causes HRS state [4-5].

4. Summary

Improved resistive memory based on solution process was intensively investigated. A resistive memory device with additional TiO_2 layer shows improved switching uniformity that can be explained by exchanging oxygen ion between undoped (TiO_2) and doped layer (TiO_{2-x}). Our approach shows promise for future low-cost, large area flexible memory applications.

Acknowledgements

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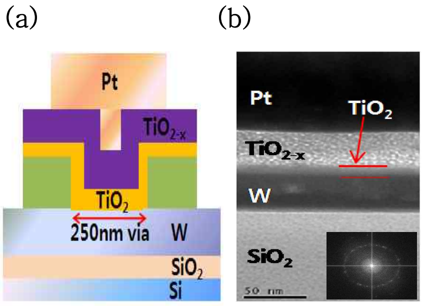


Fig.1 (a) Schematic view of Pt/TiO_{2-x}/TiO_2/W 250nm via-hole structure. (b) Cross-sectional TEM images and diffraction pattern of TiO_2 layer.

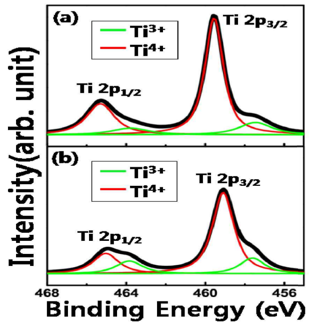


Fig.2 The binding energy of Ti $2p_{1/2}$ and $2p_{3/2}$ were measured by XPS (a) ALD deposited TiO_2 (b) Spin-coated TiO_{2-x}

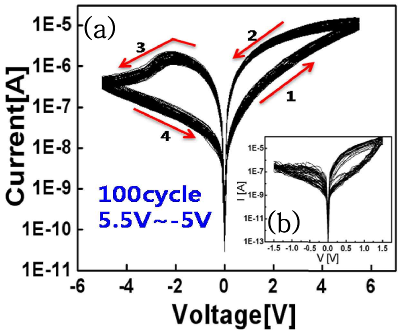


Fig.3 I-V hysteresis of different structure (a) Pt/TiO_{2-x}/TiO_2/W (b) Pt/TiO_{2-x}/W

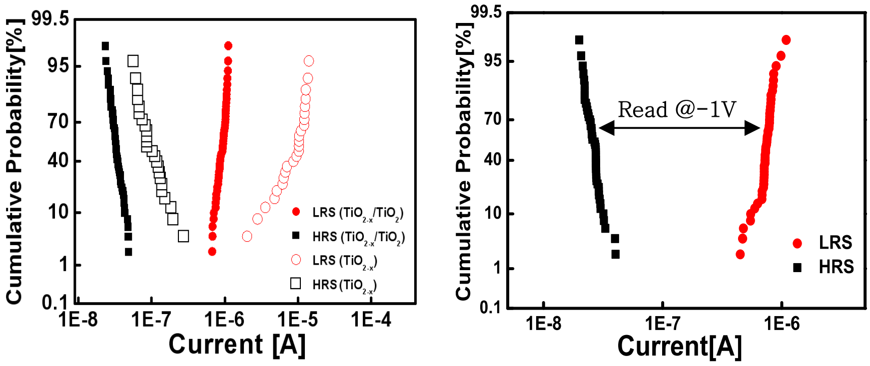


Fig.4 Cumulative probability of current distributions for HRS and LRS (a) One cell uniformity of TiO_{2-x}/TiO_2 and TiO_{2-x} structure (b) 50 cell to cell uniformity of TiO_{2-x}/TiO_2 structure.

(a) One cell uniformity

	AVG of $\log_{10}(I_{set})$	AVG of $\log_{10}(I_{reset})$	①STD of $\log_{10}(I_{set})$, ②$\Delta I/\sigma$	①STD of $\log_{10}(I_{reset})$, ②$\Delta I/\sigma$
With ALD (Read@-1V)	-6.04	-7.48	①0.07 ②20.57	①0.08 ②18
W/O ALD (Read@0.7V)	7.00	5.08	①0.18 ②10.7	①0.23 ②8.35

(b) 50 cell to cell uniformity

	AVG of $\log_{10}(I_{set})$	AVG of $\log_{10}(I_{reset})$	①STD of $\log_{10}(I_{set})$, ②$\Delta I/\sigma$	①STD of $\log_{10}(I_{reset})$, ②$\Delta I/\sigma$
With ALD (Read@-1V)	-6.13	-7.59	①0.1 ②14.6	①0.09 ②16.22

Table. 1

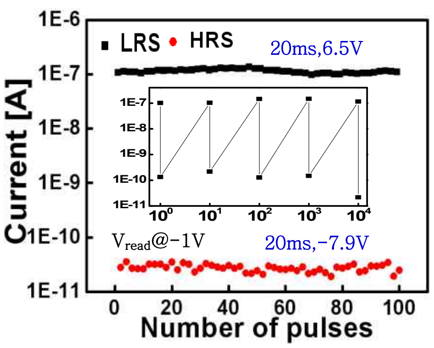
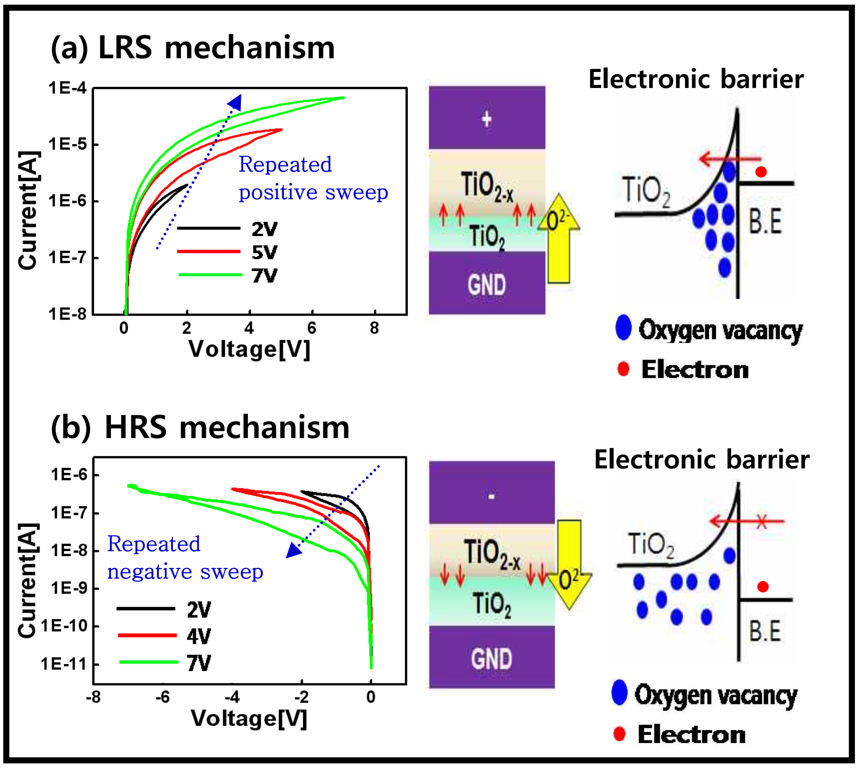


Fig.5 Pulse switching properties of the Pt/ TiO_{2-x}/TiO_2/W device for 10^4cycles.



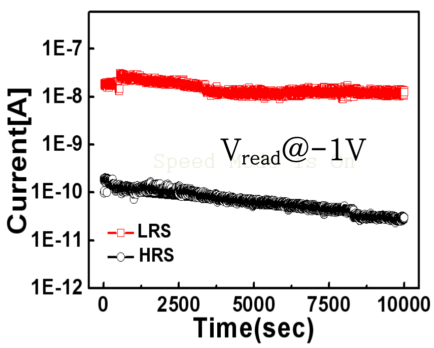


Fig.6 The retention property of the Pt/TiO_{2-x}/TiO_2/W device at room temperature.

Fig.7 Scheme of the proposed conduction model for the TiO_{2-x}/TiO_2 structure. (a),(b) As applied voltage, change insulating layer thickness and schottky barrier between TiO_2 layer and bottom electrode.