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One-Diode-One-Resistor Titanium-Oxide RRAM Fabricated at Room Temperature

Chih-Wei Kuo* , Jiun-Jia Huang , Wei-Cheng Chang, Tuo-Hung Hou

Department of Electronics Engineering and Institute of Electronics, National Chiao Tung University, Hsinchu, Taiwan

Tel: +886-3-5712121 ext 54219; *E-mail: jinjain.ee92@nctu.edu.tw

Abstract

A nonpolar Pt/TiO_2/Pt RRAM and a high forward-current Ti/TiO_2/Pt oxide diode are realized using identical TiO_2 by room-temperature evaporation. Excellent characteristics are reported for the individual diode, RRAM, and diode / RRAM in series. Owing to the simplicity of fabrication and low thermal budget, the proposed RRAM is attractive for the memory application in future flexible electronics.

Introduction

Resistive-switching random access memory (RRAM) has emerged as a serious contender for the next-generation nonvolatile memory. However, read disturbance due to the cross-talk among neighboring memory cells is a significant issue for memory array implementation. Traditionally, an additional transistor may be utilized as the selection element, but significantly increases the total cell size and requires high thermal-budget in fabrication. For high bit-density applications, the one-diode-one-resistor (1D-1R) memory cell holds particular promise because of its minimal $4F^2$ cell size [1]. Moreover, oxide-based diodes allow monolithic integration of 1D-1R in a low-temperature, stackable process. In a TiO_2 oxide diode reported in the literature [2], rectification is achieved by controlling oxygen composition in oxides to form Schottky and ohmic-like contacts at two metal/oxide interfaces, but the turn-on voltage and the forward-current density were less than ideal. In this study, we demonstrate a promising 1D-1R RRAM cell utilizing TiO_2 in both the oxide diode and the resistive-switching (RS) element. All the fabrication was done at room temperature. Owing to the simplicity of fabrication and low thermal budget, the proposed RRAM is attractive for the memory application in future flexible electronics.

Experiments

All metal and TiO_2 deposition in this work were done by electron-beam evaporation at room temperature. First, the tri-layer bottom electrode (BE) of Pt/Ti/n+Si was deposited. To fabricate the oxide diode, 10 nm TiO_2 was deposited, followed by deposition and lift-off of the Ti top electrode (TE). For the RS element, 40 nm TiO_2 was deposited, followed by deposition and lift-off of the Pt TE. XRD analysis in Fig. 2 (a) detects no rutile or anatase phase of TiO_2 except peaks from the Pt BE. XPS analysis in Fig. 2 (b) indicates the peak of binding energy in $2p^{3/2}$ is located at 458.8 eV, associated with O^{2-} bound to Ti^{4+}.

Results and Discussion

The TiO_2 oxide diode with high forward current and good rectifying characteristics is obtained by utilizing two metal electrodes with different work function to realize Schottky (TiO_2/Pt) and ohmic (Ti/TiO_2) contacts. As shown in Fig. 3, excellent rectifying characteristics including a rectifying ratio at least 10^4 at ± 3 V, a forward current density of 2×10^3 A/cm^2, an ideality factor of 1.2, and a turn-on voltage of -0.5V are achieved. The rectification is stable up to at least a thousand cycles under ±3V sweep.

To construct 1D-1R memory array, unipolar instead of bipolar RS is required owing to the nature of unipolar conduction of diodes. While TiO_2 with Ti TE does not exhibit desirable unipolar RS, TiO_2 with Pt TE in Fig. 4 shows symmetrical nonpolar RS, *i.e.* both bipolar and unipolar RS are possible. Stable DC unipolar switching properties at 25°C and 125 °C with at least 1000 times difference in resistance are shown in Fig. 5. Very tight distribution of V_{SET}, V_{RESET} , resistance (R_{ON}) at low resistance state (LRS), and resistance (R_{OFF}) at high resistance state (HRS) measured at 25°C and 125 °C are depicted in Fig. 6 and Fig. 7, demonstrating the superior RS properties. The RS mechanism can be explained by oxygen-deficient conduction filaments and joule heating effect. During the forming process, high electrical field applied to the TiO_2 layer induces oxygen ion migration toward the anode (TE) and form localized oxygen-deficient filaments with high conductivity [3]. The nonpolar RS is accomplished by the rupture and connection of conducting filaments by joule heating and oxygen migration. It is interesting to note that the RESET voltage and its variation at 125 °C operation is less than those at room temperature. The filament rupture at RESET is a temperature-activated process by thermal dissolution [4]. At high temperature, the required RESET power by joule heating is lower owing to the additional thermal energy. Therefore, RESET voltage and the fluctuation associated with are reduced for RS at high temperature.

Read disturbance at 25°C and 125 °C for LRS and HRS is shown in Fig. 8. Both LRS and HRS are stable at 25°C under a constant voltage stress at -0.3V up to 1000 s. Moreover, while LRS maintains excellent immunity to disturbance at 125 °C, HRS starts to show notable degradation, but does not merge completely with LRS. Retention characteristics show similar behavior of less stable HRS at elevated temperature in Fig. 9. The carrier transport of HRS is dominated by space-charge-limited-current according to the fitting of $I \sim V^2$ (not shown). Thermal energy provided by electrical or thermal stress may rearrange defects in TiO_2 and lead to the degradation of HRS stability and formation of a new intermediate state.

Fig. 10 shows the *I-V* characteristics of 1D, 1R and 1D-1R. If the diode is reverse biased, the lack of RS and high resistance of 1D-1R prevent program and read disturbance in the memory array. However, V_{SET} and V_{RESET} are increased in the 1D-1R structure because of the insufficient driving current provided by 1D. The additional serial resistance of 1D at LRS also results in reduced resistance ratio between LRS and HRS. Therefore, further improvement on the forward-current density of 1D is important and currently under investigation.

Conclusion

A nonpolar Pt/TiO_2/Pt RRAM and a high forward-current Ti/TiO_2/Pt oxide diode are realized using identical TiO_2 by room-temperature evaporation. Well-behaved RS is also demonstrated in a serial 1D-1R cell, promising for future flexible electronics requiring low thermal budget.

References

[1] M.-J. Lee *et al.*, *IEDM Tech. Dig.* **07**, 771, 2007.
[2] H. Shima *et al.*, *Appl. Phys. Lett.* **92**, 043510, 2008.
[3] D. S. Jeong *et al.*, J. Appl. Phys. **104**, 123716, 2008.
[4] U. Russo, *et al.*, *IEDM Tech. Dig.* **07**, 775, 2007.

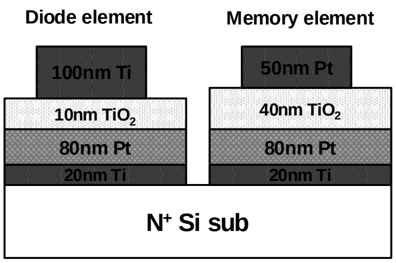

Fig. 1 The schematic of an oxide diode of Ti/10nmTiO_2/Pt, and a resisitve-switching element of Pt/40nmTiO_2/Pt.

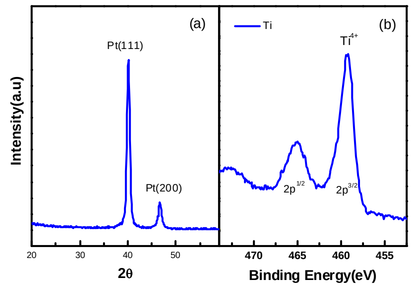

Fig. 2 X-ray diffraction pattern and XPS analysis of TiO_2/ Pt stack. TiO_2 films appear amorphous and the binding energy of Ti ion is associated with Ti^{4+}.

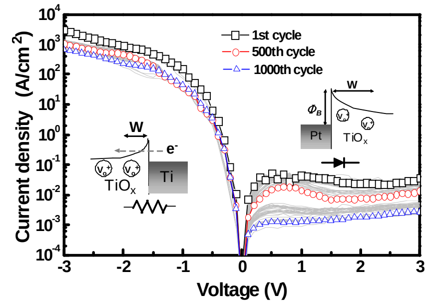

Fig. 3 Rectifying characteristics of TiO_2 diode under 10^3 successive cycles. Insert shows the band diagrams at metal/oxide interface under forward and reverse bias.

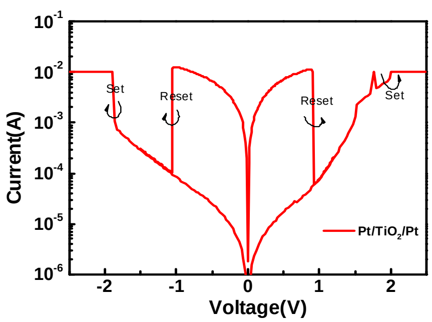

Fig. 4 Typical nonpolar resistive switching I-V curves of TiO_2 with Pt TE. Switching is possible by any combination of SET and RESET operations.

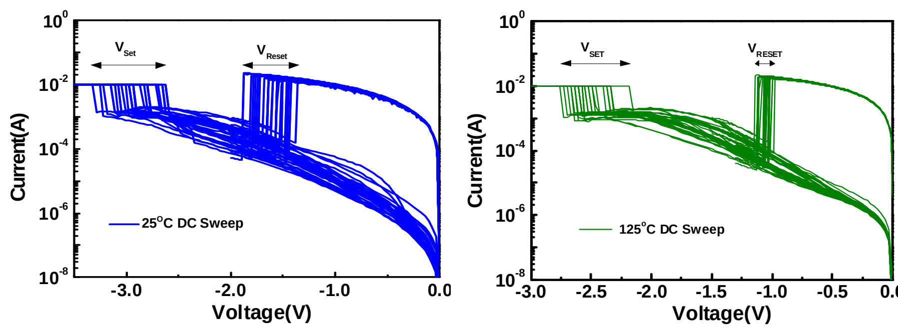

Fig. 5 DC unipolar resistive switching I-V curves of TiO_2 with Pt TE at (a) 25°C and (b) 125 °C. Stable resistive-switching and large memory window are observed.

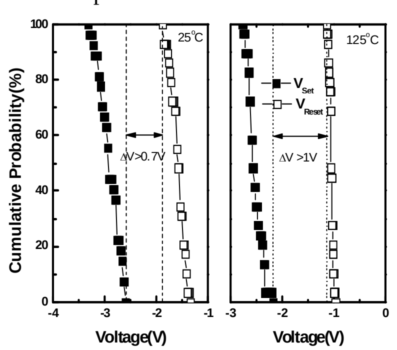

Fig. 6 Cumulative percentage of SET and RESET voltages under DC cycling at 25°C and 125°C.

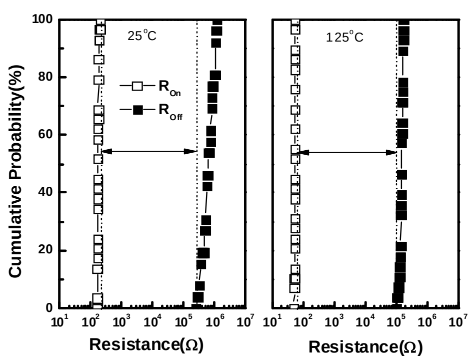

Fig. 7 Cumulative percentage of LRS resistance and HRS resistance under DC cycling at 25°C and 125°C.

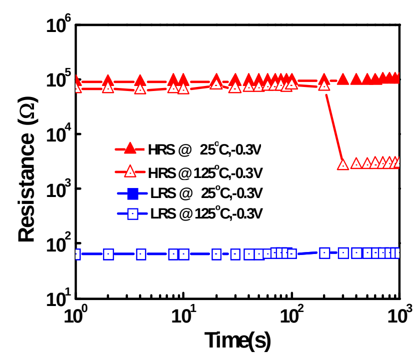

Fig. 8 Read disturbance for HRS and LRS at 25°C and 125°C under constant stress (read) voltage of -0.3V.

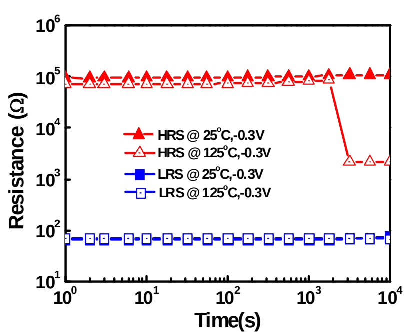

Fig. 9 Retention for HRS and LRS at 25°C and 125°C. The resistance is sampled at a read voltage of -0.3V.

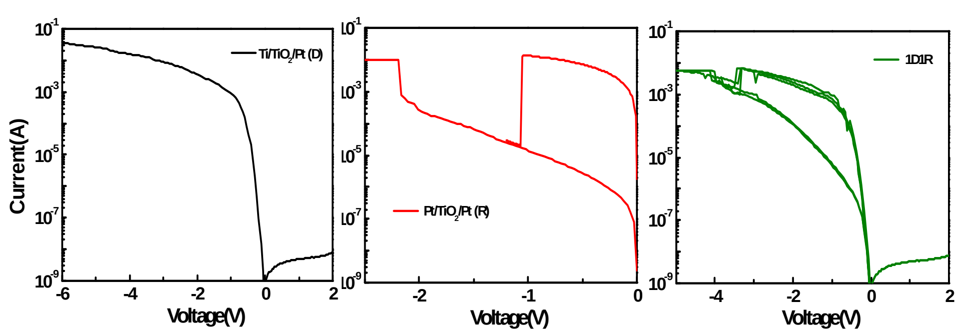

Fig. 10 I-V characteristics of 1D, 1R and 1D-1R of TiO_2.