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The Effect of Current Compliance on the Resistive Switching Behaviors in TiN/ZrO_2/Pt Memory Device

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1. Introduction

Resistive random access memory (RRAM) based on simple binary transition metal oxides has attracted extensive attentions due to the excellent characteristics such as low power, high speed, high scalability and high density integration [1-4]. The resistive switching characteristics of various transition metal oxides such as NiO [1-2], TiO_2 [5], Nb_2O_5 [6] and ZrO_2 [7-9] have been extensively addressed. It is reported that resistance states of RRAM devices are dependent on the current compliance [10]，However, the detailed characteristics and mechanism related to the effect of the current compliance on the resistive behaviors of RRAM devices need to be further investigated.

In this study, TiN/ZrO_2/Pt resistive switching memory devices were fabricated. The resistive switching behaviors with different current compliance were studied, bipolar resistive switching behaviors with read current increased with current compliance were observed, and the devices exhibited unipolar resistive switching behaviors when the current compliances were large enough. A physical model based on oxygen vacancies conducting filamentary paths is proposed to explain the resistive switching behaviors in TiN/ZrO_2/Pt memory devices under different current compliance and it can be identified by the retention characteristic in LRS under different polarity voltage stress.

2. Experimental

ZrO_2-based RRAM devices with TiN top electrodes were fabricated on Pt/Ti/SiO_2/Si substrates, as Fig. 1 shows. ZrO_2 films were prepared on Pt/Ti/SiO_2/Si substrates by sol-gel process and annealed by a furnace at 600°C in O_2/N_2 mixed gas ambient for 15min. TiN electrode was deposited at room temperature by reactive sputtering. 100×100μm^2 square-shaped TiN top electrode was patterned by dry etching. Electrical measurements were performed at room temperature by using HP4156C.

3. Results and Discussion

The typical bipolar resistive switching behavior of the memory devices in DC sweep mode is shown in Fig. 2, the devices could switch from low resistive state (LRS) state to high resistive state (LRS) with 100uA current compliance while the absolute value of reset current was < 200uA. The resistance ratios were 2.5 and 6.0 at -0.5V read voltage and 0.5V read voltage, respectively, exhibiting its potential for NVM application. A current compliance was needed when DC voltage sweep was performed in the set process.

As Fig. 3 shows, different current compliances were using during the set process. The resistance ratio increased rapidly with the current compliance. For RRAM application, certain resistance ratio is needed, and this can be achieved by set proper current compliance. As it can be seen in fig.3, the average current values in LRS increased linearly with set current compliance increased from 1mA to 5mA, while the set current compliance has negligibly influence on the read current in HRS. When the current compliance increased from 5mA to 9mA, the average read current in LRS increased less than extrapolate value of the linear fitting data and the HRS current decreased slightly. However, when the set current was larger than 10mA, the bipolar resistive switching TiN/ZrO_2/Pt memory device changed to show unipolar resistive switching behaviors as Fig.4 shows.

It should be noted that metal/ZrO_2/Pt devices always exhibit bipolar resistive switching behaviors when the top electrode are Ti [7] and TiN, both of them are reported as effective oxygen reservoir[7][11]. Based on the above observations, a physical model is proposed to explain the resistive switching behaviors with different current compliances. As Fig. 5(a) shows, there are no oxygen filaments connecting the top and bottom electrodes in HRS, applying a positive set voltage, soft-breakdown occurs, Zr-O bonds rupture, oxygen ions are absorbed by TiN top electrode, oxygen vacancy filamentary paths form as Fig. 5(b) shows, carriers can transport though the vacancies by hopping and the devices switch to LRS. When a negative bias is applied on the device, oxygen ions are extracted from TiN top electrode, and the oxygen vacancies recover with oxygen ions and Zr-O bonds form again, the conducting oxygen vacancy filaments rupture at the interface between TiN and ZrO_2, the devices switch to HRS as Fig. 5(a) shows.

The number of the oxygen vacancy filamentary paths is dependent on the current compliance and bias applied on the devices. During the set process, when low current compliance is applied, filaments generated are insulated from each other; all the filaments have almost same conductance, the number of filaments is proportional to the current compliance resulted in the linear region as Fig. 3 shows. Increasing the current compliance, the number of filaments increases and soft breakdown simultaneously occurred between filaments that close to each other as Fig. 6(a) shows, and it is hard for electrons hoping between filaments at read voltage, the read current in LRS increases less than extrapolate value of the linear fitting data as shown in Fig. 3.

However, when the current compliance is large enough, filaments closed to each other are incorporated into one stronger filament with large size as Fig. 6(b) shows, the soft-breakdown process between the filaments generate large amount of movable oxygen ion that absorbed into TiN top electrode, during the reset process, oxygen vacancies at the interface between TiN and ZrO_2 recovered with oxygen ion completely as Fig. 7(a) shows，resulted in the deceased average read current in HRS as shown in Fig. 3. As a result, it is large positive voltage that needed to set the device to LRS that always make the device hard-breakdown. In this condition, oxygen vacancy filaments can generate by using proper negative voltage and the devices exhibited unipolar resistive switching behaviors as Fig. 7(b) shows, it could just switch few times. When oxygen ions in TiN were exhausted, the device could never switch from LRS to HRS.

To identify the proposed physical model, the retention characteristics of $TiN/ZrO_2/Pt$ devices under voltage stress in sampling mode were studied as Fig. 8 shows. Considering the effect of electric field on oxygen ions, it is fitted very well by using diffusion equations to determine the resistance of the devices under stress in LRS.

4. Conclusion

Resistive switching behaviors of $TiN/ZrO_2/Pt$ memory devices are studied. The results show that bipolar resistive switching with read current increased with the current compliance and unipolar resistive switching behavior when the current compliance was large enough. A physical model based on filament paths mechanism was proposed to explain the observed phenomenon and it was identified by studying the retention characteristic of the device under different polarity voltage stress in LRS.

Acknowledgment

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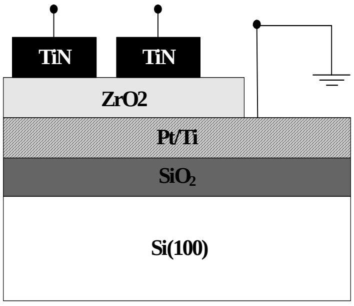

Fig.1 The schematic structure of memory devices. Pt was 100nm, ZrO2 was 20nm, TiN was 100nm thick.

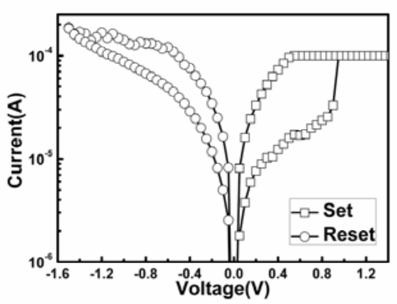

Fig.2 The typical current-voltage curve of the memory device. Set under positive bias while reset under negative bias.

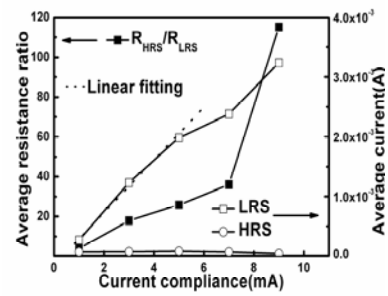

Fig.3 The resistance ratio and average read current VS current compliance curves. All the data were measured at -0.5V

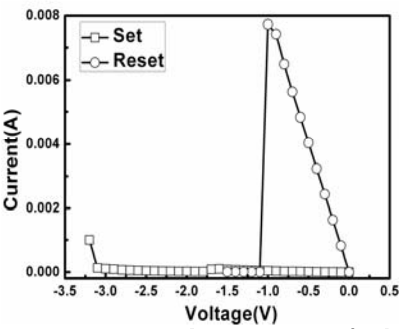

Fig.4 Current-voltage curve of the Unipoar resistive behavior of the memory device under negative bias

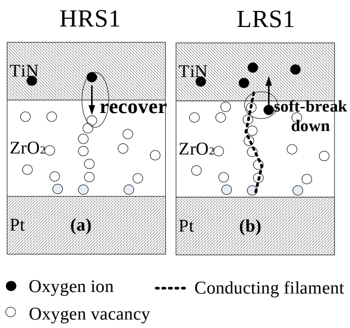

Fig.5 Distribution of oxygen vacancies in the device under low current compliance (a)HRS (b)LRS

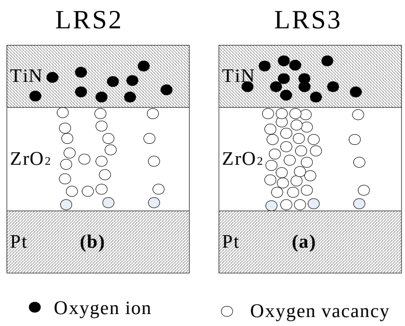

Fig.6 Filaments distribution with large current compliance(a) filaments interact with each other (b)filaments incorporated into one

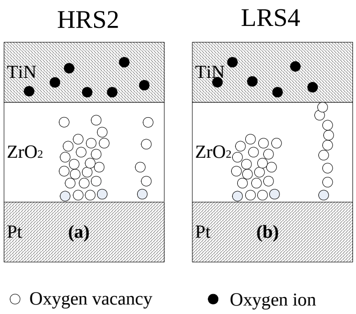

Fig.7 Unipolar resistive switching in $TiN/ZrO_2/Pt$ by negative bias, the unipoalr switching could switch only few times.

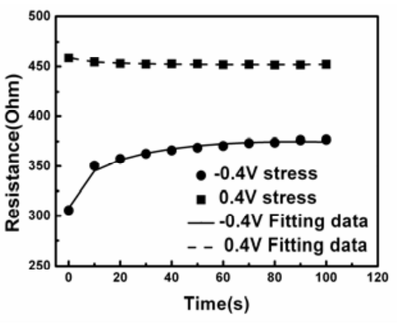

Fig.8 Retention characteristics of the device under stress in sampling mode, the resistance increased more quickly at -0.4V than that at 0.4V sampling voltage.

References

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