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Understanding of the abnormal unipolar resistance switching behavior in CBRAM

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Abstract

In this paper, we report an abnormal unipolar resistive switching (RS) behavior in Conductive Bridge RAM (CBRAM) for the first time. Different to the normal unipolar RS generally observed in CBRAM, the abnormal RS shows three unique features, i) RESET voltage is larger than SET voltage, ii) I-V curve is "N" shape and iii) current of the SET process is self-limited. The abnormal unipolar RS is very stable and has multilevel storage potential. The results of I-V fitting, variable temperature test and impedance spectra analysis demonstrated that abnormal RS is dominated by charge trapping and detrapping in the discontinuous conductive filaments.

Introduction

CBRAM is considered as a promising candidate for the next generation nonvolatile storage [1-2]. Generally, the CBRAM shows bipolar and unipolar RS characteristics based on the formation and rupture of metallic conductive filament (CF) [1-3]. Recently works found that the CF microstructure can be modulated by compliance current of forming process [4, 5]. Systematical investigation of the impaction of CF microstructure on the RS characteristics is very important for deeply understanding of the charge and mass transfer mechanism in RS. In this work, we first successfully achieved an abnormal unipolar RS beside from the generally bipolar and unipolar RS in our CBRAM device by designing program scheme. Experimental results clearly demonstrated that the abnormal unipolar RS is dominated by electronic effect, which is different from the generally bipolar and unipolar RS dominated by nanoionics redox effect.

Experiment

A typical CBRAM device of $Ag/SiO_2/Pt$ was chosen for this study. Firstly, 50 nm SiO_2 film was deposited on $Pt/Ti/SiO_2/Si$ substrate by sputtering. Then, 80 nm Ag deposited by e-beam evaporation as the top electrodes after photolithography. The schematic of device structure is shown in inset of Fig. 1. During all the electrical tests, the Pt electrode was grounded and the voltage bias was applied on the Ag electrode.

Results and discussions

The as-deposited devices are in high resistance state (HRS). After forming process with positive voltage and high I_{CC} (100μA in Fig. 1), the device show both bipolar (Fig. 1) and unipolar (Fig. 2) RS behavior. When reducing the I_{CC} of forming to 5 nA, the threshold switching (TS) behavior was observed (Fig. 3). Recent works have demonstrated that the CF is composed of isolated Ag nanocrystals after low I_{CC} forming process [4, 5]. Interestingly, then the device shows an abnormal unipolar RS behavior under negative voltage sweep (0V→-5V) without I_{CC} and the I-V curve shows "N" shape, as shown in the inset of Fig. 4. SET and RESET processes are achieved under 0V→-1V and 0V→-4V voltage sweep, respectively (Fig. 4). It is noted that the OFF-state resistance can be modulated by controlling the stop voltage in RESET process. The dependence of temperature on ON- and OFF-state resistance indicates that both states are of semiconductor property (Fig. 5). Fig 6 shows I-V fitting result of SET process, the negative slop in $Ln(I/V^2)$-1/V scale confirms that the conductance mechanism is tunneling emission. To further study the physics mechanism in different RS, the impedance spectra test was utilized both in ON- and OFF-states of unipolar and the abnormal unipolar RS. The impedance spectra in ON-state of unipolar RS show a resistance characteristic, indicating a complete Ag filament connecting between top and bottom electrodes (Fig. 7) [6]. The impedance spectra of unipolar RS in the OFF-state show capacitor characteristic (Fig. 8). The capacitor is origin to the gap generated after CF rupture [7]. Different to the unipolar RS, the impedance spectra in ON- and OFF-state of abnormal unipolar RS exhibit capacitor characteristic, as shown in Fig. 9 and Fig. 10. The results prove that CF during negative voltage sweep keeps discontinuous. The resistance in ON-state of abnormal RS exponentially increases with time, obeying Kohlrausch relaxation law (Fig. 11). Based on the above experimental results, a schematic diagram for the abnormal RS mechanism is presented in Fig. 12. Different to the unipolar RS controlled by metallic CF formation and rupture, the abnormal unipolar RS is dominated by the electronics effect. After low I_{CC} forming, the formed CF is composed of isolated Ag nanocrystals chain [4]. During negative SET process, the electrons tunnel through Ag nanocrystals and some of them are trapped, resulting in the device switching to ON-state. Under high RESET voltage, the trapped electrons will be dragged out of Ag nanocrystals by high electrical field, leading to the device switching back to OFF-state.

Conclusions

In summary, we found and investigated the abnormal unipolar RS in CBRAM. The experimental results demonstrated that the abnormal unipolar RS is related to the electron trapping and detrapping in the Ag nanocrystal chain, which is different to the generally bipolar and unipolar RS in CBRAM by nanoionics redox effect.

Acknowledgement

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References

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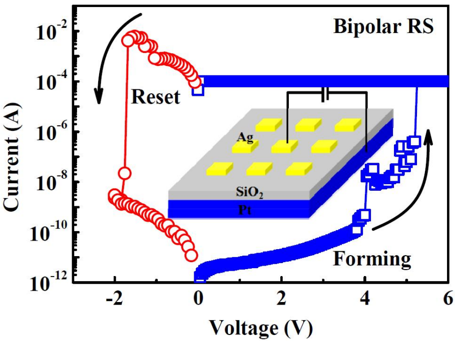

Fig. 1 Current-Voltage curves of Forming and RESET processes in bipolar RS mode, the inset is schematic of device structure.

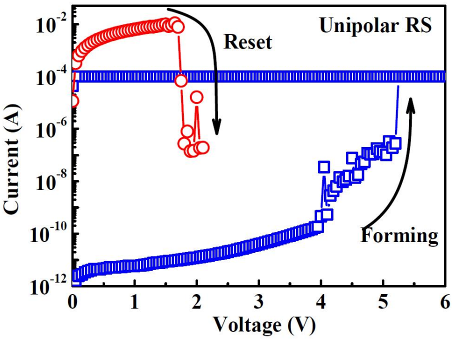

Fig. 2 Current-Voltage curves of Forming and RESET processes in unipolar RS mode.

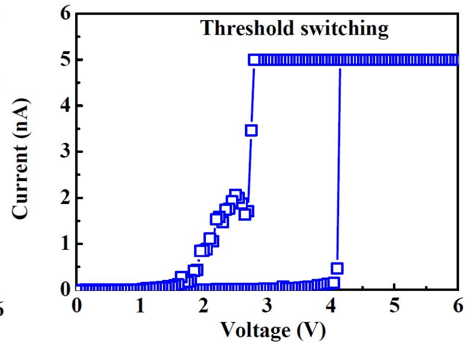

Fig. 3 Using 5 nA I_{CC} to proceed the Forming process, the device shows threshold switching behavior.

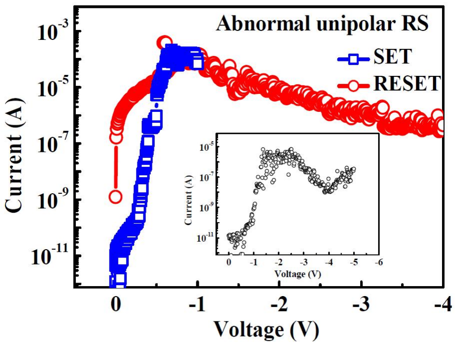

Fig. 4 SET and RESET curves of abnormal unipolar RS, the inset is whole I-V curve showing "N" shape.

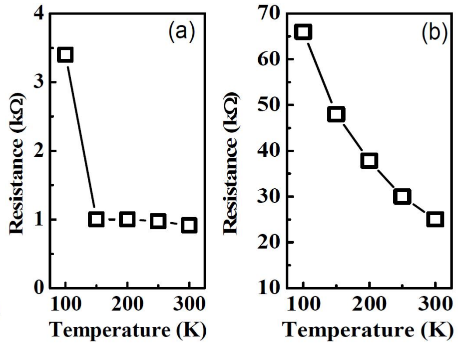

Fig. 5 Temperature dependence of resistance both in ON-(a) and OFF-states (b) of abnormal unipolar RS.

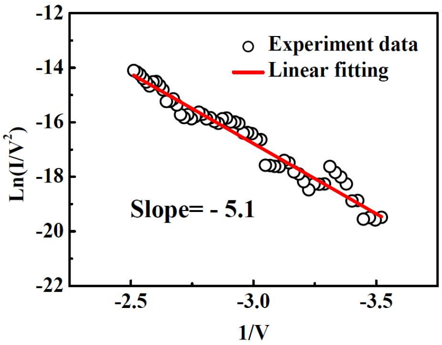

Fig. 6 Data from -0.25V to -0.4V in blue curve of Fig. 4 were replotted in $Ln(I/V^2)$ vs 1/V, implying tunneling emission.

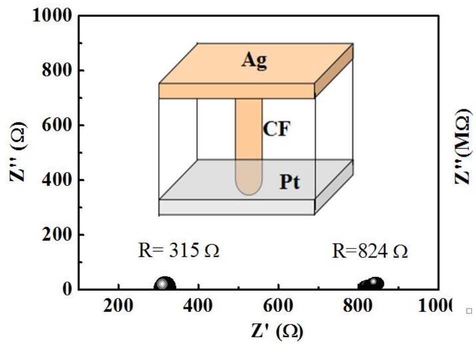

Fig. 7 Impedance spectra of the ON-state resistances obtained by unipolar RS Forming process.

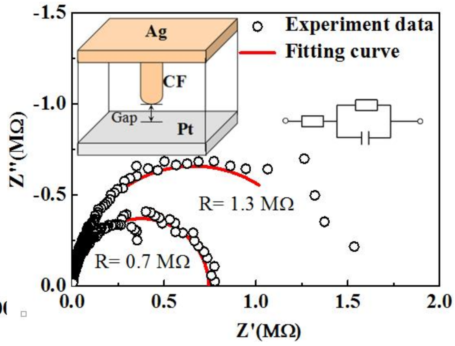

Fig. 8 Impedance spectra of OFF-state resistances obtained by unipolar RS RESET process.

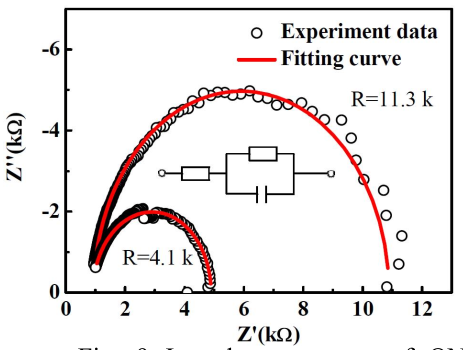

Fig. 9 Impedance spectra of ON-state resistances obtained by abnormal unipolar RS SET process.

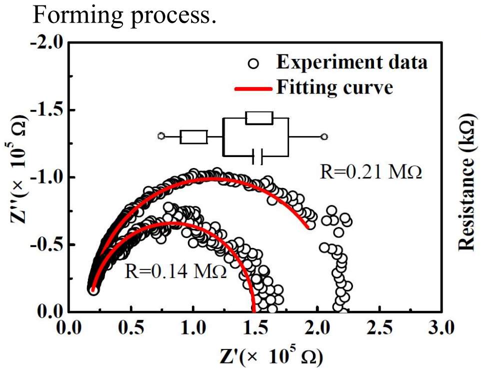

Fig. 10 Impedance spectra of OFF-state resistances obtained by abnormal unipolar RS RESET process.

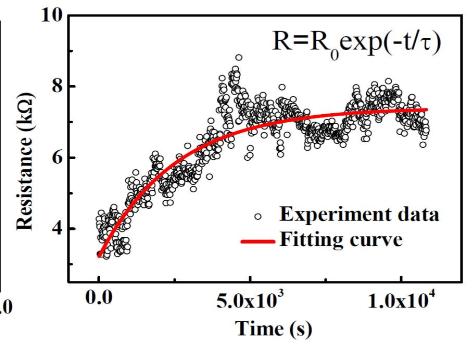

Fig. 11 The ON-state resistance dependence of time in abnormal RS mode.

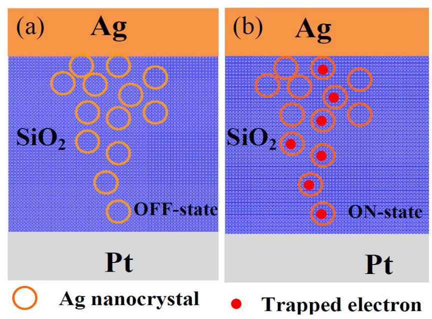

Fig. 12 The schematic of electrons detrapping in OFF-state (a) and trapping in ON-state (b).