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Resistance switching memory in perovskite oxides

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ABSTRACT

The resistance switching behavior has recently attracted great attentions for its application as resistive random access memories (RRAMs) due to a variety of advantages such as simple structure, high-density, high-speed and low-power. As a leading storage media, the transition metal perovskite oxide owns the strong correlation of electrons and the stable crystal structure, which brings out multifunctionality such as ferroelectric, multiferroic, superconductor, and colossal magnetoresistance/electroresistance effect, etc. The existence of rich electronic phases, metal–insulator transition and the nonstoichiometric oxygen in perovskite oxide provides good platforms to insight into the resistive switching mechanisms.

In this review, we first introduce the general characteristics of the resistance switching effects, the operation methods and the storage media. Then, the experimental evidences of conductive filaments, the transport and switching mechanisms, and the memory performances and enhancing methods of perovskite oxide based filamentary RRAM cells have been summarized and discussed. Subsequently, the switching mechanisms and the performances of the uniform RRAM cells associating with the carrier trapping/detrapping and the ferroelectric polarization switching have been discussed. Finally, the advices and outlook for further investigating the resistance switching and enhancing the memory performances are given.

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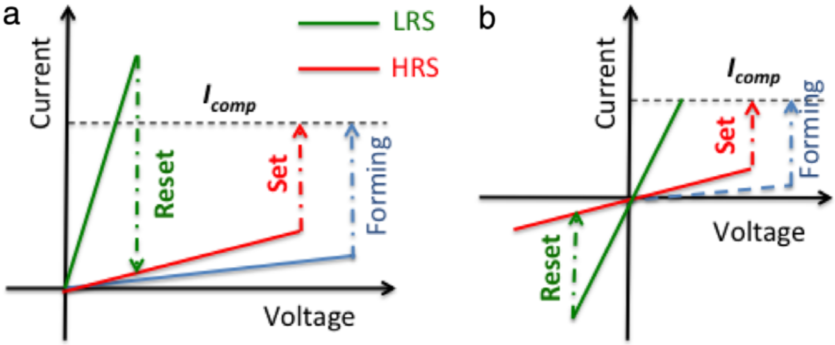

Fig. 1. Schematic I–V curves of (a) unipolar and (b) bipolar switching modes. Symbol I_{comp} denotes the compliance current, which is adopted during the set process to prevent any permanent breakdown.

1. Introduction

1.1. Basic of resistance switching

The resistance switching (RS) behavior has attracted great attention for its application as resistive random access memories (RRAMs) due to a variety of advantages such as simple structure (electrode/active-layer/electrode sandwiched structures), high-density (excellent miniaturization potential down to <10 nm) [1], high-speed (sub-ns operation speed) [2], high-endurance ($>10^{12}$ switching cycles) [1], and low-power (<0.1 pJ energy consumption) [3,4]. There are two ways to activate the RS sequence [5]. One is the unipolar switching mode, in which the voltages with different magnitudes control the memory switching between high resistance state (HRS) and low resistance state (LRS). The other one is the bipolar switching mode, in which the voltages with opposite polarities control the reversible memory switching between the HRS and LRS. The nonvolatile memory effect in RRAM cell is realized through the electrically controlled RS between the HRS and LRS. For many initially fabricated RRAM cells, a “Forming” process, in which a forming voltage (V_{form}) forces the RRAM cell to develop the initially conductive filaments with the limitation of compliance current, is usually done before the memory cell can work. In Fig. 1(a) and (b) the schematic I–V curves of the unipolar and bipolar switching modes are shown respectively. The switching from the HRS to the LRS is named as the “Set” process and the corresponding switching voltage is denoted as V_{set}. During the “Set” and “Forming” processes, a compliance current is usually used to limit the big avalanche current to avoid the damage of memory cell. In contrast, the switching event from the LRS to the HRS is denoted as the “Reset” process and the corresponding switching voltage is V_{reset}. It is noted that the V_{form} is usually higher than the V_{set}.

1.2. Storage media

The RS behavior has been observed in many electrode/active-layer/electrode sandwiched structures. In a basic memory cell, the top and bottom electrodes can use the same or different materials, which can be the elementary substantial metals (Au, Pt, W, Al, Cu, Ag etc.) [4], metallic alloys (Cu–Ti, Pt–Al etc.) [6,7], graphene [8], NiSi [9], nitrides (TiN) [10], and oxides (indium-tin-oxide, Nb:$SrTiO_3$, $SrRuO_3$ etc.) [11–14]. According to the role played in the RS, the electrode materials can be roughly sorted into two types. One is active electrodes (such as Ti, Cu, Ag *etc.*), in which the migration and/or redox of electrode ions occur near the electrode/active-layer interface and contribute to the RS behavior. The other one is inert electrodes (such as Pt and Au), in which the electrode ions are stable and do not directly take part in the RS. For the active-layer materials in the RRAM memory cell, there are many more broadened selections. It can be organic matters, silicon, graphene, amorphous oxides, crystalline binary or complex oxides, and even organic–inorganic compounds [15].

Special choices of RRAM cell materials with specific cell fabrication technologies are revealed to strongly influence the memory performances. Among many active-layer candidates, perovskite oxides