Effect of firing atmosphere and bottom electrode on resistive switching mode in TiO$_2$ thin films

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Sol–gel deposited Ag/TiO$_2$/Pt tri-layers exhibit unipolar resistive switching (URS) with a negative turn-on voltage when fired in air. Variation in both the turn-on voltage and the on-state current at turn-off threshold is observed in successive current–voltage (I–V) measurements. Based on the same composition and processing flow, bipolar resistive switching (BRS) showing positive turn-on voltage by contrast is obtained by applying two alternative procedures: one procedure under oxygen ambience and another one in which indium–tin oxide is used as the bottom electrode. Conduction mechanisms induced by reduction/oxidation reactions explain how firing ambience and bottom electrode affect the switching mode, as well as the distinct turn-on voltage polarity. URS and BRS are related to the amount of ambient oxygen and the arrangement of internal oxygen vacancy, thus determining whether the direction-independent thermochemical heating or polarity-dependent electrochemical oxidation near the anode interface is responsible for the filament rupture. Additionally, the space-charge-limited transport is analyzed to examine how URS and BRS-activated samples significantly differ from each other. Importantly, the temperature-dependent I–V data helps to elucidate the dominant carrier behavior in the regime of low and high electric field.

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1. Introduction

Owing to its simple structure and fast switching speed, resistive random access memory (RRAM) has been investigated widely for its potential nonvolatile storage application in mobile devices [1,2]. Resistance switching (RS) phenomena have been observed in various perovskite and transition metal oxides [3–5]. Two conduction states can be obtained by applying an appropriate programming voltage sweep or pulse. The set operations switch a memory cell in its high-resistance state (off) to low-resistance state (on), while the reset operations restore the cell to off state. Notably $V_{\text{SET}}$ and $V_{\text{RESET}}$ denote switching voltages for the turn-on and turn-off processes, respectively, and $I_{\text{SET}}/I_{\text{RESET}}$ for the corresponding currents. Additionally, unipolar resistance switching (URS) represents RS achieved by $V_{\text{SET}}$ and $V_{\text{RESET}}$ of the same polarity, whereas bipolar resistance switching (BRS) displays polarity dependence [6,7]. URS and BRS differ in resistance ratio, magnitude and stability in the switching voltage and, especially, reset current [8]. This large reset current inhibits the integration of RRAM devices, which are frequently observed in URS. BRS has a more stable current–voltage hysteresis and does not require the current compliance settings during turn-on transition [8].

The filament model stipulates that the formation and rupturing of conductive paths in an insulating matrix are responsible for the RS effect. The driving mechanism of URS differs from that of BRS in the set/reset process by thermal reduction/oxidation (redox) or that by the electrochemical migration of oxygen ions, respectively [9]. For BRS, bias polarity indicates whether the charged particles are attracted or repelled at electrode interface, while the reset process induced by Joule heating appears to be directionless for URS. The current compliance setting in URS is always higher than that in BRS [8–11]. The on state is a low-resistance state accompanied by the reduction reaction at $V_{\text{SET}}$. $V_{\text{SET}}$ polarity denotes a higher potential at the top or bottom side. Whether the defect has a positive valence into (or negative valence out of) the thin film, at the top or bottom side, depends on the $V_{\text{SET}}$ polarity. Oxygen-related defects, such as oxygen ions or vacancies, generally dominate the carrier transport in metal oxides. $V_{\text{SET}}$ polarity also helps to determine which one is the plausible one. Carrier transport arising from cation or anion migration leads to conduction of different activation energies [12,13]. This feature illustrates how electrode materials affect the RS mode in addition to the high or low Schottky barrier by work function difference [11]. Influenced by composition, fabrication, and electrode property,
References