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Bipolar switching properties and electrical conduction mechanism of manganese oxide RRAM devices

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ABSTRACT

Electrical conduction mechanism and bipolar resistive switching properties of the manganese oxide thin films resistive random access memory (RRAM) devices for high resistive status and low resistive status (HRS/LRS) were investigated and discussed. The electrical and physical properties of post-treatment manganese oxide thin films for different oxygen concentration parameters were measured by x-ray diffraction (XRD) and operation current versus applied voltage (*I-V*) measurement. For *I-V* curves in different temperature, the ohmic conduction, space charge limited conduction (SCLC), schottky emission conduction, and hopping conduction mechanism of manganese oxide RRAM devices were discussed and verified in initial metallic filament path forming process. Finally, the excess oxygen ions, vacancy, and defect factor resulting in bipolar and unipolar resistive switching behavior of thin films RRAM devices will be explained and investigated by metallic filament path forming model.

1. Introduction

Recently, the non-volatile random access memory (NvRAM) and volatile random access memory (RAM) devices, such as ferroelectric random access memory (FeRAM), magnetron random access memory (MRAM), phrase random access memory (PRAM), flash memory, static random access memory (SRAM), and dynamic random access memory (DRAM) devices were widely discussed and investigated for applications in portable consumer electronic and wisdom industry electronic devices. However, the excellent non-volatile memory characteristics for the long retention, low power consumption, low operation voltage, high on/off ratio, read-out speed, and high storage capacity were major consideration selection parameters [1–8].

All of simply binary metal elements oxide, silicon-based, macromolecule, complex compound, and various oxide materials, such as ZnO, HfO, Gd:SiO_X, polymeric composites, $CaBi_4Ti_4O_{15}$, $Al_xZn_{1-x}O$, and $Pr_xZn_{1-x}O$ oxide thin films, were widely applications in unipolar and bipolar switching resistive properties of RRAM devices for the excellent non-volatile memory characteristics. In addition, bipolar switching properties and electrical conduction mechanism of manganese oxide RRAM devices will be discussed and obtained [9–15].

To investigate and discuss the bipolar resistive switching properties and electrical conduction mechanism of manganese oxide thin films, the Al/MnO_2/ITO structure device was fabricated for interface of indium tin oxide (ITO) and aluminum (Al) electrode. Besides, the ohmic conduction, space charge limited conduction (SCLC), schottky emission condition, and hopping conduction mechanism of the manganese oxide thin film RRAM devices for low resistive state (LRS) and high resistive state (HRS) was also fitting by *I-V* transferred curves fitting.

2. Experimental details

The metal-insulator-metal (MIM) structure samples were discussed for bipolar resistive switching properties of RRAM devices prepared by radio frequency (rf) sputtering technology in Fig. 3(b). The metal oxide target was placed near 5 cm away from the ITO substrate. To overcome the existence of oil pollution and prepared process, the particle and metal ion on ITO substrate were removed during standing clean process. In order to remove the defects and particle of metal target and obtain stable plasma during deposition time, pre-sputtering time of as-deposited thin films was maintained for 20 min under argon ambient. The optimal sputtering parameters, such as rf sputtering power of 160 W, chamber pressure of 10 mTorr, and the different

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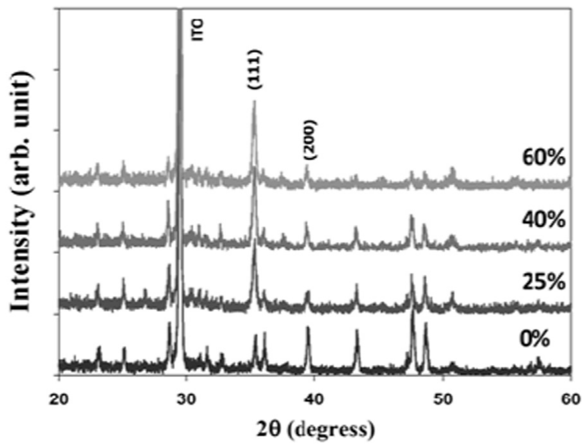

Fig. 1. The XRD patterns of the manganese oxide thin films for the different oxygen concentration parameters.

oxygen concentration parameters was used and prepared. And then, the manganese oxide\` thin film RRAM devices was treated by conventional furnace annealing (CFA) process for 400–500 °C in air. Each experimental parameters detail design and selection were considered and determined by grey entropy strategy of situation analysis method. To complete MIM structure of manganese oxide RRAM device, arrays of circular top contacts are formed by depositing an Al film with 500 nm thickness by dc sputtering technology. In addition, the different oxygen concentration effect of manganese oxide thin films is analyzed by the XRD measurement. The *I-V* bipolar switching properties of RRAM devices are obtained by Agilent B1500 semiconductor parameter analyzer.

3. Results and discussion

Fig. 1 depicted the XRD patterns of the manganese oxide thin films for different oxygen concentration deposition parameters. In XRD analyzed, the preferred (111) and (200) peaks of polycrystalline structure thin films for 40% and 60% oxygen concentration were observed. For increasing crystal quality and relax strain of lattice, the (111) smallest full width at half maximum (FWHM) value was slightly increasing for increasing oxygen concentration parameters. Fig. 2(a) and (b) presented the surface micro-structure and cross-sectional morphology of the manganese oxide thin films for faceted and inhomogeneous grains in SEM images. The grain size and micro-

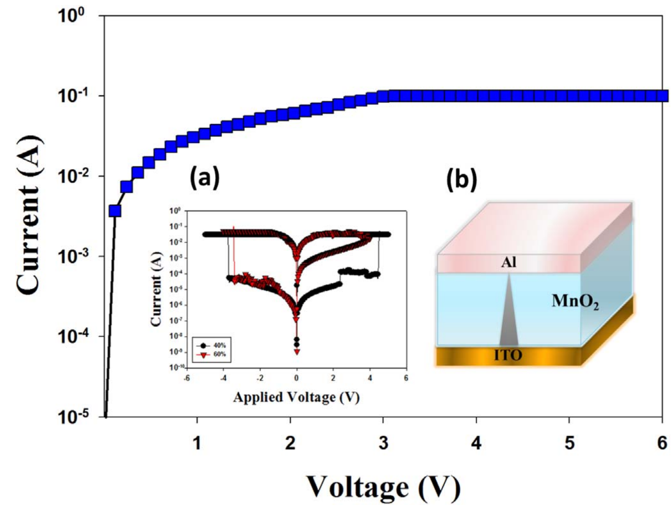

Fig. 3. Unipolar and bipolar switching curves of the manganese oxide thin films for different oxygen concentration parameters.

structure of as-deposited manganese oxide thin films for 40% and 60% oxygen concentration all was exhibited polycrystalline style. Besides, the electrical switching properties of CFA annealed-treated thin films were efficiently improved by thermal annealing treatment process. In our previous study, the polycrystalline grain structure and leakage current density of as-deposited oxide thin films were efficiently and apparently improvement in fill oxygen concentration deposition parameters. The lowing leakage current density caused by trap, defect and oxygen vacancy of as-deposited thin films was apparently decreased by the different oxygen concentration deposited parameters [16–19].

To define the forming process of 5 V, the *I-V* switching curves of the manganese oxide thin films RRAM device for HRS/LRS were presented in Fig. 3. The compliance current was 10 mA. For applied a high positive bias than the set voltage, the HRS of RRAM device was transferred to LRS was called set process. The operation current of RRAM devices for LRS continuously decreased to HRS for the applied negative bias over the reset voltage was called reset process. As shown in Fig. 4, the 100 cycles *I-V* switching curves of the manganese oxide thin films RRAM device for different oxygen concentration parameters were observed. In 40% oxygen concentration, the bipolar switching properties and high memory on/off ratio for LRS/HRS were observed in the applied voltage of 6 V. However, the manganese oxide thin films RRAM devices for 0%, 20%, and 60% oxygen concentration parameters

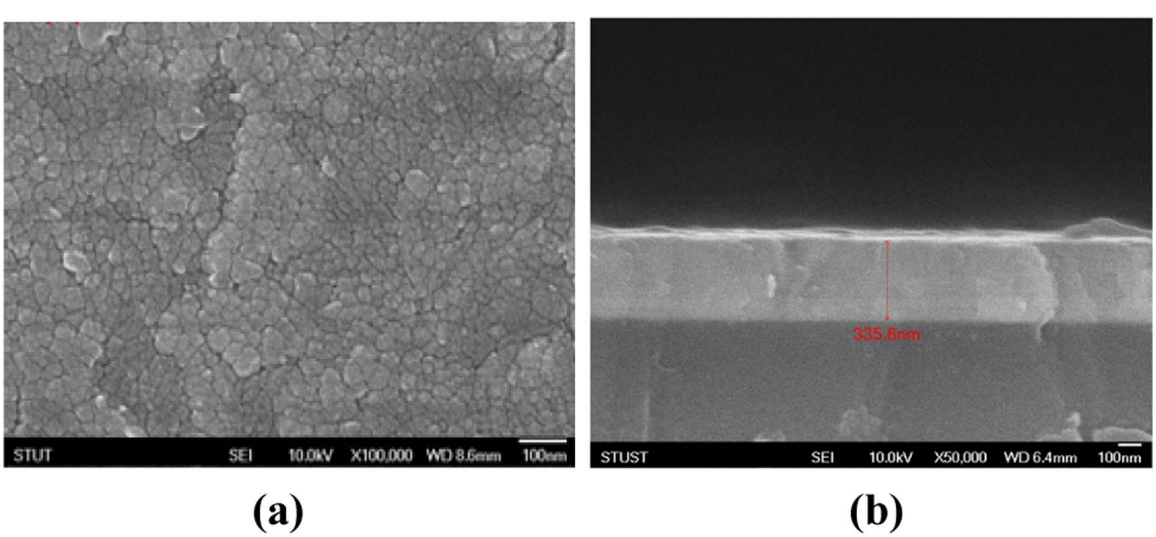

Fig. 2. The SEM images of the 40% manganese oxide thin films for (a) surface micro-structure, and (b) cross-sectional morphology.