Bistable Resistance Switching Behaviors of SiO₂ and TiO₂ Binary Metal Oxide Films

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The bistable resistance switching characteristics of amorphous SiO₂ and poly-crystalline TiO₂ were investigated using Pt top and bottom electrodes sandwiched structure. Both films exhibit well defined switching characteristics. All device operation characteristic parameters such as forming, reset, and set voltages of TiO₂ are distinctly smaller than those of SiO₂, indicating that the values of these parameters can be related to the dielectric constant. From I-V curve analyses, it is found that the low resistance states of both films obey an ohmic conduction mechanism and the high resistance states show generation of a Schottky potential barrier. Regarding the mechanism for resistance switching of the binary oxide, it is suggested that the generation and annihilation of potential barriers accounts for the changes to the high resistance state and low resistance state, respectively.

Keywords: resistance switching, binary metal oxide, SiO₂, TiO₂

1. INTRODUCTION

Insulating binary oxides have attracted considerable interest with regard to their application as nonvolatile memory elements, the key technology for modern mobile electronic devices. In terms of meeting the requirements for next generation advanced devices, resistance random access memory (ReRAM) offers suitable properties such as low power consumption, high density, and high operation speed[1,2]. This memory is based on the resistance switching behaviors of insulators sandwiched between metal electrodes. Resistance switching phenomena have been found in various types of insulators including binary metal oxides[3,4], perovskite-type oxides[5], and even organic materials[6].

The choice of insulator is an important parameter for the device application, since the resistance switching characteristics depend on the energy bandgap and the dielectric constant of the insulator[7]. Binary oxide offers several advantages such as precise composition control and film quality with minimum complexity. The switching behaviors of a number of binary oxides have been widely investigated since the 1960s, and those of transition metal oxides including NiO[8,9] and TiO₂[10] have attracted interest because their switching properties are more universal than those of perovskite materials.

Titanium dioxide (TiO₂) is a versatile material that forms in a number of crystalline phases. For example, crystallized anatase TiO₂ has a very large dielectric constant of more than 60 but a small bandgap of 3 eV. In contrast, silicon dioxide (SiO₂) is a widely employed material in electronics with a low dielectric constant of 3.9 and a high bandgap of 9 eV. A comparison of the universal resistance switching behavior of these two metal oxides, i.e., amorphous SiO₂ and polycrystalline TiO₂ films, having extremely different bandgaps and dielectric constants, would provide useful information for future research and applications. In this paper, the switching characteristics including operation voltage and resistance ratio of SiO₂ and TiO₂ films are discussed and the conduction mechanisms for bistable resistance states based on ohmic conduction and potential barrier are proposed.

2. EXPERIMENTAL

Bottom Pt electrode deposition was carried out on a p-type Si(100) wafer using a dc magnetron sputtering system with 4-inch diameter targets (99.95% purity). Two insulating SiO₂ and TiO₂ films were then deposited by the RF magnetron sputter system. The Pt top electrode was also deposited with the same fabrication process as the bottom electrode. All deposition processes were performed at room temperature with a base pressure of less than 1 × 10⁻⁶ Torr. Deposited

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insulators and electrodes were all 40 nm thick. Electrode patterning was performed by the conventional liftoff method. The resistance switching was measured using an HP4155A semiconductor parameter analyzer. This measurement was conducted in voltage sweep mode with current compliance at room temperature. If the devices failed to exhibit switching behaviors, a thermal annealing process in N₂ ambient was executed until resistance switching behavior appeared. Depth profile analyses using Auger electron spectroscopy (AES) and X-ray diffraction (XRD) were performed in order to identify the composition and crystalline structure of the insulators, respectively.

3. RESULTS AND DISCUSSION

The depth profiles of the devices with SiO₂ film after deposition are shown in Fig. 1(a). It is clear that the SiO₂ film is well defined on the bottom electrode. The amounts of silicon and oxygen in the insulators remain constant along their depths. For the SiO₂ and TiO₂ films, the resistance switching characteristics begin to appear after the annealing process at 500 and 800 °C, respectively. The crystalline structures identified by XRD were amorphous SiO₂ and poly-crystalline TiO₂ with a mixture of anatase and rutile phases after their respective annealing processes, as shown in Fig. 1(b). Recently, it has been reported that TiO₂ anatase nano-crystal plays a major role in high speed switching.

The bistable resistance switching behaviors of annealed SiO₂ and TiO₂ films including the forming process are presented in Figs. 2(a) and 2(b), respectively. First, a forming process is needed to bring about the resistance switching. This is accomplished by increasing the bias along the insulator until dielectric breakdown occurs. By setting the current compliance, the insulator breakdown is reversibly controlled at the breakdown voltage (Vᵢ). The values of Vᵢ are 18.1 and 6.1 V for SiO₂ and TiO₂ films, respectively, as shown in Fig. 2. For the forming process, a model has been proposed wherein a conducting filament forms as a leakage path in the

![Fig. 1. (a) AES depth profiles of SiO₂ film and (b) XRD spectrum of TiO₂ film. (A: anatase, R: rutile).](image)

![Fig. 2. I-V curves showing resistance switching behaviors of (a) SiO₂ and (b) TiO₂ films.](image)