Temperature Dependence of Resistance in Conductive Filament Formed with Dielectric Breakdown of Ni/TiO_2/Pt structure

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A resistive switching (RS) memory has been expected to be a next-generation memory owing to its high density, low power, and high speed. The structure of the RS memory is simple, similar to a capacitor consisting of two electrodes and an insulator. Various insulator materials have been reported for the RS memory, such as NiO [1], TiO_2 [2], and Al_2O_3 [3]. The mechanism of the reversible RS phenomenon has been considered in terms of the formation and rupture of filaments, such as a metallic conduction filament and an oxygen vacancy filament. TiO_2 is one of the frequently reported materials with oxygen vacancies [2]. However, the physical properties of the conductive filament have not been well understood.

In this study, we investigated the RS mechanism by evaluation of current-voltage (*I*-*V*) characteristics and measuring the temperature dependence of resistance in the low resistance state (LRS).

The fabricated RS memory device has a simple cross-bar structure formed on a thermally oxidized Si substrate. First, we deposited a Pt layer (25 nm) as a bottom electrode with a thin Ti adhesion layer by DC sputtering. Then a TiO_2 layer (20 nm) was deposited on the bottom electrode as an insulator layer by the DC reactive sputtering of titanium in an argon and oxygen mixture (1 : 1). Finally, a Ni layer (40 nm) was deposited as a top electrode by DC sputtering. The electrical measurements of the RS memory were carried out by a two-probe method at room temperature in air, where the current is limited to 100 μA to prevent the complete dielectric breakdown of the device. The temperature dependence of resistance was measured with a four-probe method.

Figure 1 shows the RS characteristics of the Ni/TiO_2/Pt device in the unipolar operation method. As the applied voltage swept to 3 V, the device current abruptly increased, indicating that the transition from the HRS to LRS occurred (SET process). Although the applied voltage was swept again from 0 to 2.4 V, the current abruptly decreased to a low value, which corresponded to the reset process. The resistance ratio of high resistive state (HRS) and LRS is as large as five orders of magnitude with 1 V readout bias. The device was reversibly switched between the HRS and LRS by dc voltage in the same voltage direction, which was called the unipolar operation mode.

To clarify the conduction mechanism of the filament, the temperature dependence of the resistance for the LRS was investigated. The resistance in the LRS decreases proportionally to temperature, indicating that the conductive filament is metallic, as shown in Fig. 2. The inset figure shows *I*-*V* characteristics of the LRS at 300 and 9.8 K. The both *I*-*V* characteristics with the linearity support the suggested metallic filament. Temperature coefficient of resistance (TCR) is 1.2×10^{-3} K^{-1} at 285 K, which is much smaller than the value of pure Ni (6.7×10^{-3} K^{-1}). It is suggested that the conductive filament composed of oxygen vacancies [4].

We discussed a model of switching mechanisms based on the RS characteristic, suggested mechanisms of electrical conduction of filaments. Then, a high voltage is applied to a device, a soft breakdown of an insulator, which is introduced defects in TiO_2 layer. Current with a high density flows into the connected defects as the conduction pass. Then, conductive filament was formed by the oxygen vacancies in an insulator. This hypothesis agrees with the temperature dependent of resistance in LRS, which is oxygen vacancies, and the unipolar RS characteristics. Further discussions will be shown in the workshop.

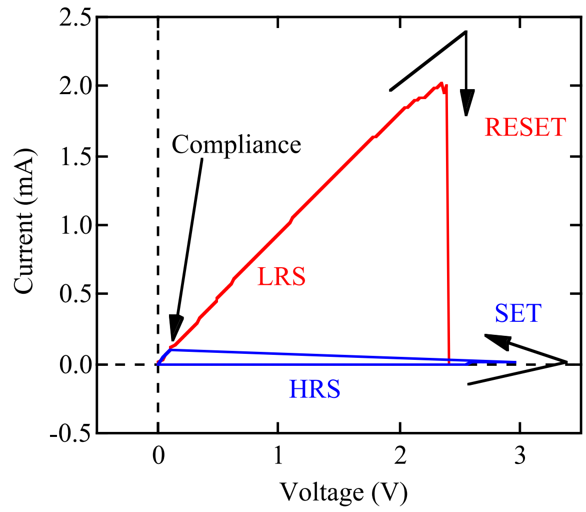

Fig. 1. Typical unipolar RS characteristics of the Ni/TiO_2/Pt structure. The current compliance value during the set process is 100 μA for unipolar RS.

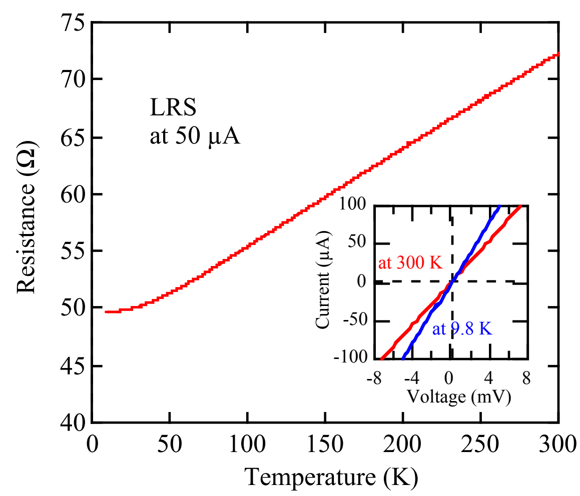

Fig. 2. Temperature dependence of resistance in the LRS. The inset figure shows *I*-*V* characteristics at 300 and 9.8 K, respectively.

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