Room-Temperature TiOₓ Oxide Diode for 1D1R Resistance-Switching Memory

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Resistive-switching behaviors in transition metal oxides, such as NiO and TiO₂, have attracted great attention recently due to the potential for the next-generation nonvolatile memory applications [1, 2]. However, read disturbance due to the cross-talk among neighboring cells is a serious issue for the implementation of large memory array as shown in Fig. 1 [3]. Traditionally, a transistor can be added as a selection element in the memory cell, the so-called 1T1R (one transistor one resistor) cell, to prevent undesirable cross-talk, but at the expense of increasing cell size and high thermal-budget. Nevertheless, it is unfavorable in the high-density memory array where the unit cell size and the low-temperature three-dimensional stacking is of the concern. Recently, a compact 1D1R cell, which utilizes an oxide-based diode as the selection element to cut off the parasitic cross-talk, has been realized [4]. The ratifying pn junction formed by two different oxide layers, one n-type and one p-type, provides sufficient on-off ratio and current density, but the high turn-on voltage and high ideality factor are less than ideal. In this study, we demonstrate a high forward-current TiOₓ diode fabricated at room temperature by a very simple process. Finally, the switching behavior of the 1D1R cell will be discussed.

The oxide diode composed of the 80nm Pt bottom electrode, the 20nm TiOₓ oxide barrier and the 30nm Ti top electrode was deposited by an electron-beam evaporation system on the Ti/SiO₂/Si substrate. Before capping the top electrode, some TiOₓ/Pt samples were subjected to an additional 400°C annealing in O₂ ambient. In addition, to make the NiO memory cell, 50nm NiO was deposited on the Pt/Ti/SiO₂/Si substrate by dc reactive sputtering. During sputtering, oxygen content of (Ar+O₂) gases was kept at 5% at room temperature. The Pt top electrode was deposited on NiO by electron-beam evaporation to form the Pt/NiO/Pt structure.

The inset of Fig. 2 shows the cross-sectional transmission electron microscope (TEM) image of the fabricated oxide diode. In order to elucidate the effects of the oxygen vacancies in TiOₓ, X-ray Photoelectron Spectroscopy (XPS) has been performed to study the non-lattice oxygen and lattice oxygen. As shown in Fig. 2, the non-lattice oxygen, which increases both the density of oxygen interstitial and vacancy, exists in the as-deposited TiOₓ film. After 400°C annealing, the binding energy of oxygen peaked at 531 eV and the broaden tail from the non-lattice oxygen vanished. The oxygen vacancy acts as n-type dopant in TiOₓ and its concentration may significantly modulate the transport characteristics through the metal/oxide Schottky barrier [5]. Therefore, the as-deposited TiOₓ was employed in the diode to provide higher current density necessary for the NiO memory cell.

Considering the n-type behaviors of TiOₓ and the work function (WF) difference between Ti and Pt, a high forward current over 4 A/cm² was achieved at a forward bias of 1V as shown in Fig. 3. TiOₓ forms Ohmic contact at the interface with Ti and Schottky contact at the interface with Pt. Under forward bias, electrons inject easily through the Ti/TiOₓ interface, but are blocked due to the Schottky barrier at the TiOₓ/Pt interface under reverse bias. Clear ratifying characteristics with a rectification ratio of ~10⁴ at ±1 V and an ideal factor of 1.2 are demonstrated. The Schottky emission fitting in Fig. 4 confirms that at small forward bias (0.05-0.2V) additional build-in potential due to the WF difference between Ti and Pt, estimated around 0.8eV from the fitting, has to be overcome.

The switching characteristics of the 1D1R configuration in Fig. 5 were measured by externally connecting standalone Ti/TiOₓ/Pt diodes and Pt/NiO/Pt cells. Although the reset and set voltage is slightly higher in 1D1R than in 1R only (1.4V vs. 0.9V and 1.7V vs. 1.5 respectively), well-behaved resistive switching and high rectification behavior are clearly observed.
In conclusion, we have successfully fabricated a high forward-current oxide-based diode through a simple room-temperature process. Its compatibility with the NiO memory cell is verified. The result highlights the potential of future high-density and high-performance 1D1R RRAM.

References


