Observation of filament formation and rupture in Cu/MoO_x ReRAMs

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Resistive Switching RAM (ReRAM) has high potentials as a next generation nonvolatile memory. However, the operation mechanism has not yet been clearly understood in detail. To clarify this point, we introduced in-situ transmission electron microscopy (in-situ TEM). By means of this method, structural changes at a nanometer scale are observable during electrical measurements. In earlier reports, we have observed filament formation in NiO ReRAMs and Cu-GeS ReRAMs. In this work, we applied in-situ TEM to Cu/MoOx stacked ReRAMs and observed structural changes.

To fabricate Cu/MoOx ReRAM devices for in-situ TEM observation we used the ion-shadow method. (Figure 1) First, the thin film layers of Pt (100nm) / Cu (30nm) / MoOx (60nm) / TiN (10nm) were formed upon a heavily doped p-type silicon wafers. The MoOx insulating layer was prepared by reactive sputtering (Ar-O_2). After applying carbon mask particles over the deposited film surface, ion milling process (Ar+, 5 kV, 1 mA) was applied. During this process, the size of the mask particles gradually decreases and sharp needles are formed. (Figure 2) At the tips of the needles, ReRAM devices with a diameter of several tens or hundreds of nanometers are formed. (Figure 3)

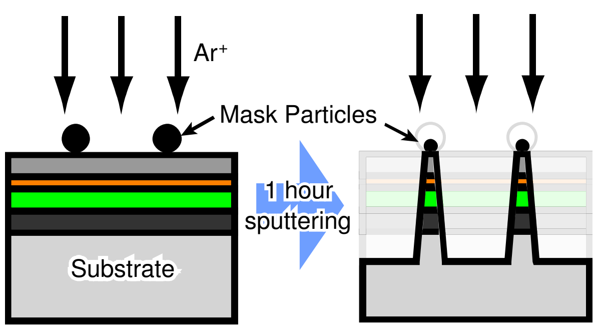

Fig 1. Schematic of the ion-shadow process.

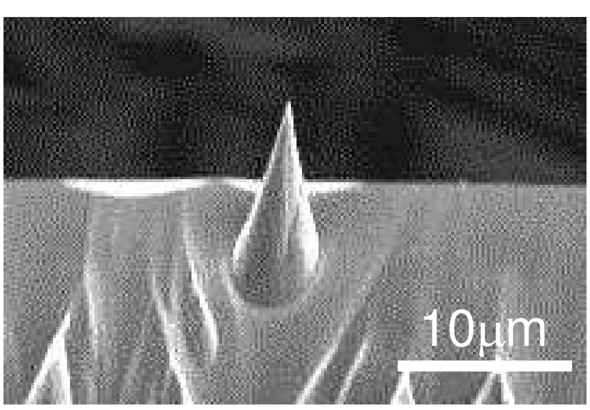

Fig 2. SEM image of the needle formed by the ion-shadow method. ReRAM layers exist at the tip of the needle.

Inside the TEM instrument, a Pt-Ir probe which is movable by a piezo actuator was used to make a contact to the Pt/Cu top electrode. Electrical measurements were performed by applying a voltage to the top electrode (via Pt-Ir probe) while the Si substarte was grounded. Simultaneously with the measurements, the TEM image was recorded by a CCD camera.

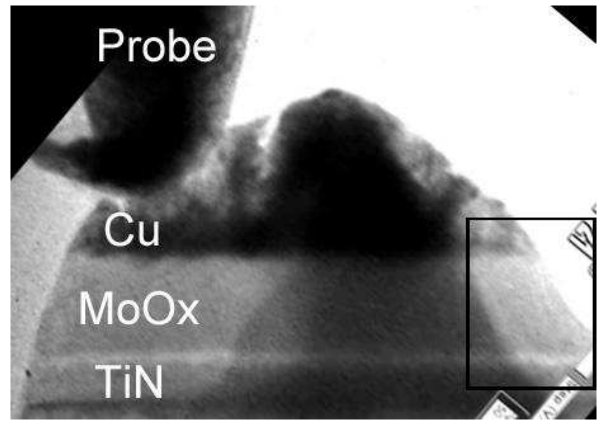

Fig 3. TEM image before resistive switching. (Square area shows the position of Figure 5)

By applying a positive voltage to the top electrode, resistive switching from a high-resistance state (HRS) to a low-resistance state (LRS) occurred (Figure 4(a)) at about +1.2 V and at the same time, a precipitation appeared near the bottom electrode inside the MoOx layer. (Figure 5(a)) Successively, a negative voltage was applied to the top electrode and switching from LRS to HRS occurred (Figure 4(b)) and the precipitation disappeared. (Figure 5(b))

Here, we succeeded to obtain a bi-polar resistive switching inside the TEM and observed appearing and disappearing of a precipitation. This precipitation seems to be working as a conducting filament, which gives a low resistance when it is formed and a high resistance when it ruptures.

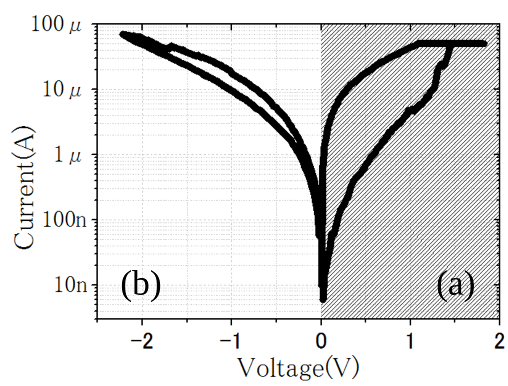

Fig. 4 I-V characteristics during resistive switching measured in the TEM instrument.

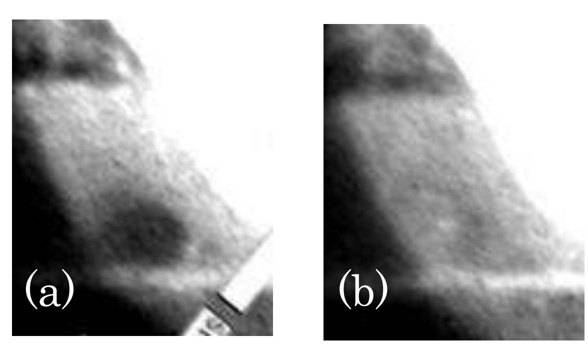

Fig 5. In-situ TEM image after resistive switching in (a) Low and (b) High Resistance States.