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In situ TEM Observation of CBRAMs during Digital and Analog Switching

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Abstract

***In situ* TEM was performed for CBRAMs with abrupt and gradual switching characteristics. Filament formation was observed in abrupt switching of WO_X device. Small contrast change was observed in gradual switching of MoO_X device. The difference of structural change and switching characteristics are thought to be caused by difference in characteristics of Cu in WO_X and MoO_X.**

1. Introduction

Conductive Bridge RAMs (CBRAMs) have been studied and developed for next-generation memories. Generally, CBRAMs have two characteristics: gradual (or analog) and abrupt (or digital) switching characteristics. Those two switching modes should be properly designed for versatile applications. Therefore, CBRAMs using various materials have been studied for modulating switching characteristics. In this study, Cu-MoO_X CBRAM for which a gradual switching is expected due to the high rate diffusion of Cu in MoO_X[1] and Cu-WO_X CBRAM for which an abrupt switching[2] is expected will be discussed. By using *in situ* transmission electron microscope (TEM) method, relationship between switching characteristics and structural changes of analog/digital CBRAMs were investigated.

2. Experimental

Lateral-type CBRAMs were adopted as *in situ* TEM samples for getting a clear image of structural changes[3]. Firstly, 30 nm thick Cu and Pt electrodes with 50-100 nm gaps were patterned by electron beam lithography and lift-off process. Then, 30 nm thick MoO_X or WO_X switching layer was deposited by sputtering using a metal mask. Those CBRAMs were measured by multiple voltage sweeps and structural changes were observed by TEM during the measurement.

3. Results and Discussion

Measurement results of the WO_X sample are summarized in Fig. 1. Positive voltage applications on the Cu electrode caused an abrupt resistive switching as shown in Fig. 1(a). By continuing measurement, the resistance was decreased step by step. Resistance history of the WO_X sample is shown in Fig. 1(b). Resistance decreased by two orders of magnitude from the 1st to 32nd sweep, but there were no distinct structural changes, which corresponds to previously reported result[3]. Structural changes were observed in the 33rd sweep (Fig. 1(c)) in which compliance current was 50 μA. Figure 2 shows that dynamics of Cu filament formation from the Pt electrode (cathode) to the Cu electrode (anode) and “a” to ”d” in Fig. 1(c) correspond to Fig. 2(a) to (d). By increasing voltage, rapid current jump occur at 1.8 V (Fig. 1(b)). Interestingly, there were no big structural changes in the CBRAM sample (Fig. 2 (a) and (b)). After current reached compliance current, the contrast of the Cu electrode became bright and precipitate started to appear at the edge of the Pt electrode (Fig. 2(c)). Then, filament grew from the cathode to the anode (Fig. 2(d)), which corresponds to the electrochemical switching model as generally accepted.

On the other hand, the MoO_X sample showed a gentle resistive switching and structural changes. Positive voltage application on the Cu electrode caused gradual resistance decrease (Fig. 3(a)) compared with that of the WO_X sample. By continuing measurements, the resistance decreased gradually (Fig. 3(b)). The resistance decreased by three orders of magnitude from the 1st to the 101st sweeps, but there were no distinct structural changes. At the 102nd sweep shown in Fig, 3(c), very faint contrast changes occurred at the gap between electrodes (Fig. 4).

Differences of switching characteristics and structural changes in the WO_X and the MoO_X sample were thought to be derived from difference in diffusion of Cu. The diffusion rate of Cu must be lower in WO_X than in MoO_X, so that it caused local structural changes like filament formation in the gap and rapid resistive switching. On the other hand, the high diffusion rate of Cu in MoO_X caused Cu diffusion throughout the MoO_X layer with a small structural change and gradual resistive switching.

4. Summary

CBRAMs with abrupt switching (WO_X) and gradual switching (MoO_X) were investigated by i*n situ* TEM. The filament formation was observed in the WO_X sample with low diffusion rate of Cu and very small contrast change was observed in the MoO_X sample with a high diffusion rate of Cu. Difference in switching characteristics originated from property of the material was visualized as structural changes.

Acknowledgements

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References

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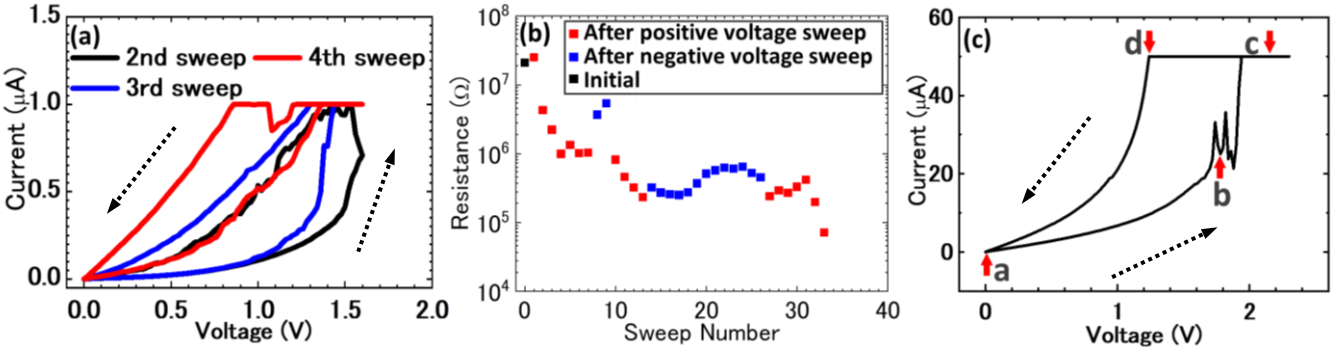

Figure 1 (a) *I-V* graph of the WO_X sample, where the horizontal axis denotes the potential of the Cu electrode relative to the Pt electrode. (b) Resistance change by multiple voltage sweeps for the WO_X sample. The measurement was conducted by using positive or negative voltage sweeps. Maximum voltages ranged from 0.6 to 2.3 V in the positive sweeps and -0.7 to -2.6 V in the negative sweeps. Compliance currents were increased up to 50 μA along with the resistance decrease. Black, red, and blue squares correspond to resistance in the initial state, after the positive voltage sweeps, and after the negative voltage sweeps. Resistances were determined from currents at 0.5 V in the backward sweeps. (c) *I-V* graph of WO_X in the 33rd sweep. "a" to "d" in the graph correspond to the measurement points of Fig. 2(a) to (d).

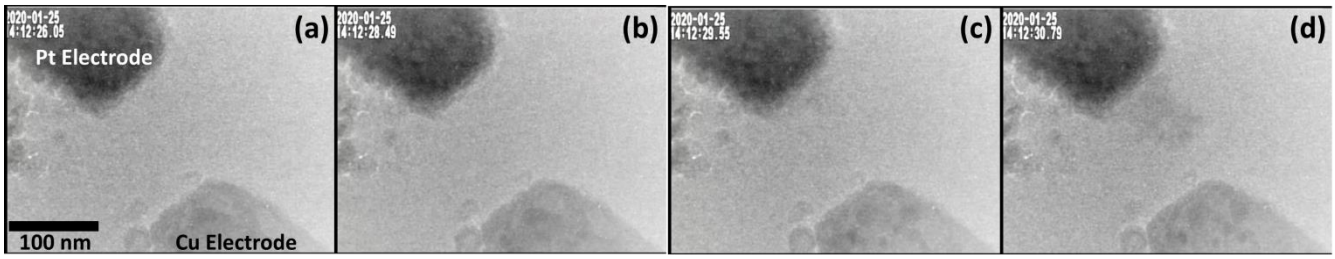

Figure 2 TEM images during the 33rd sweep of the WO_X sample at (a) 0, (b) 1.78, (c) 2.14 and (d) 1.24 V.

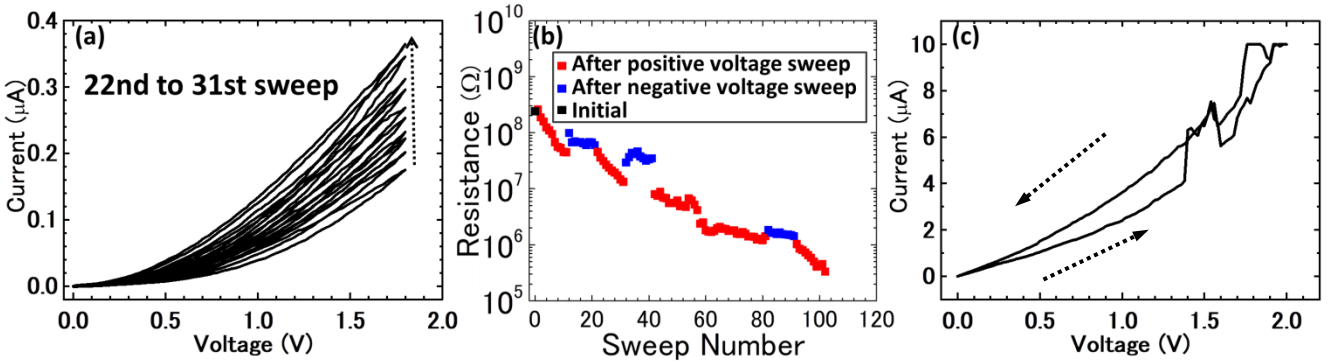

Figure 3 (a) *I-V* graph of the MoO_X sample, where the horizontal axis denotes the potential of the Cu electrode relative to the Pt electrode. (b) Resistance change measured by multiple voltage sweeps for the MoO_X sample. The measurement was conducted by using positive or negative voltage sweeps. Maximum voltage ranged from 1.8 to 2.0 V in positive sweeps and -1.8 to -2.0 V in negative sweeps. Compliance currents were increased up to 10 μA along with the resistance decrease. Resistances were determined from currents at 0.5 V in the backward sweep. Black, red, and blue squares correspond to resistance in the initial state, after the positive voltage sweep, and after the negative voltage sweep. (c) *I-V* graph of the MoO_X sample in the 102nd sweep.

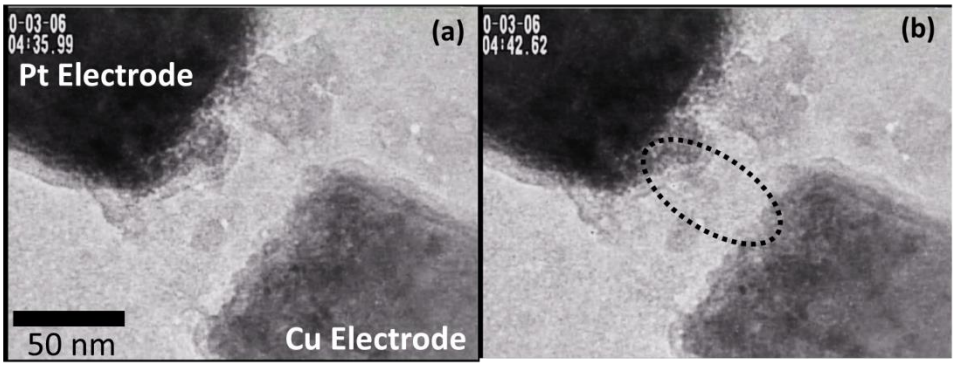

Figure 4 TEM images (a) before and (b) after structure changes in the 102nd sweep. Small contrast change was seen in the dotted area of (b). Note that the roughness of the electrodes was due to imperfection of the lift-off process.