Solid-state reactions in resistive random access memory (ReRAM) induced by electric filed and process atmosphere

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ReRAM, resistive random access memory, is considerably investigated as a strong candidate for high-speed and low-power nonvolatile memory. The operating performance of ReRAM is now undisputedly being developed to a practical level. A very simple memory element structure and materials used for ReRAM can boost up this trend because of their affinity with the conventional semiconductor manufacturing technologies. Simply stated, the memory element of ReRAM consists of transition metal oxide (TMO) layer and electrodes. Sometimes an oxygen reservoir layer is introduced between these TMO layer and electrode. As a result of recent intensive research activities on ReRAM, there are various factual data showing that the mechanism of the nonvolatile resistance change in ReRAM is the redox (oxidation and reduction) reactions in solids.[1] In other words, the resistance of ReRAM decreases when the TMO layer is reduced, while it increases when the TMO layer is oxidized. In this contribution, we will bring experimental evidences on such redox reactions in ReRAM.

The ReRAM memory element in the integrated memory array having a 1T-1R (1 transistor – 1 ReRAM) cell configuration fabricated using a 50 nm generation production technology was used in this experiment. Firstly, we confirmed the reproducible resistive switching. Then, the ReRAM element in LRS (low resistive state), HRS (high resistive state), as well as IRS (initial resistive state) were arranged and selected for EDX (energy dispersive X-ray spectroscopy) analysis with cross-sectional TEM (transmission electron microscope). We especially focused on the EDX signal intensity profiles of Oxygen and the metal element in the TMO layer represented by *M*. Henceforth, $I_{\mathrm{EDX}}(M)$ and $I_{\mathrm{EDX}}(\mathrm{O})$ denote the EDX signal intensity of Oxygen and *M*, respectively. With reference to the peak position of $I_{\mathrm{EDX}}(\mathrm{O})$, a marked variation of the integrate intensity ratio $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$ was observed depending on the resistive states. Figure 1 shows the values of $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$ in the as prepared state, LRS, and HRS. With a change in the resistance state, the values of $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$ also changes. This result can be reasonably attributed to the redox reaction in ReRAM. Compared to the as prepared state and HRS, the value of $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$ in LRS is the lowest, indicating that the TMO layer is in the reduced state. In addition to the variation of $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$, those signal profiles such as the distance between peak positions of $I_{\mathrm{EDX}}(M)$ and $I_{\mathrm{EDX}}(\mathrm{O})$ are changed. Such re-distribution of Oxygen in ReRAM is also considered to be one of the evidences for the redox reaction as the mechanism of resistance change inReRAM.

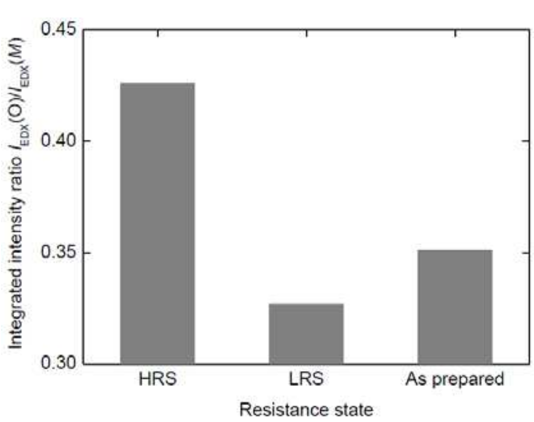

Fig. 1 $I_{\mathrm{EDX}}(\mathrm{O})/I_{\mathrm{EDX}}(M)$ in the as prepared state, LRS, and HRS.

In additon, related to the mechanism stated above, it is required to consider the impact of process atmosphere and temperature on TMO layer and electrodes. When we take Ta (tantalum) as an example, which is often used as an electrode material of ReRAM, the oxide and nitride of Ta are, respectively, insulating and metallic materials. Obviously, there are various thermal processes conducted in the oxidation, reduction, or nitriding atmospheres in the semiconductor manufacturing processes. Therefore, we investigated the impact of process atmosphere on the materials in ReRAM by using several spectroscopic techniques such as TEM-EDX, EELS (electron energy loss spectroscopy), and SIMS (secondary ion mass spectroscopy). Consequently, the thermally induced interfacial reaction at the TMO layer/electrode interface and the incursion of process gas species into ReRAM element were successfully detected. Such interaction between the ReRAM element and process gas species should be suppressed for the stable and reliable production of ReRAM.

References

1. H. Akinaga and H. Shima, “Resistive Random Access Memory (ReRAM) Based on Metal Oxides,” Special Issue of IEEE Proceedings “Nanoelectronics Research for Beyond CMOS Information Processing” 98, 2237 (2010).