Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp568-569

A-6-2

Conducting filament engineering by triple-layer RRAM for uniform resistive switching

Daeseok Lee[1], Jaesung Park[1], Sangsu Park[2], Jiyong Woo[1], Euijun Cha[1], Sangheon Lee[1], Yunmo Koo[1], Kibong Moon[1], Jeonghwan Song[1], and Hyunsang Hwang[1]

Department of Material Science and Engineering, Pohang University of Science and Technology, Pohang, 790-784, Korea[1]
Department of Nanobio Material and Electronic, Gwangju Institute of Science and Technology, Gwangju, 500-712, Korea[2]
Phone: +82-54-279-5123, Fax: +82-54-279-5122, e-mail: hwanghs@postech.ac.kr

1. Introduction

Recently, in filament type random access memory (RRAM), variability of switching parameters is one of significant obstacles to commercialization. Thus, various approaches have been proposed to improve the variability of switching parameters. Especially, a lightning-rod effect which is a control of filament dissolution region was proposed as a simple and effective approach [1]. According to previous researches, switching uniformity of various parameters such as read resistance (R_{read}), set voltage (V_{set}), and reset current were significantly improved by decreasing reset bias (V_{reset}). It can be explained by narrower physical gap between an electrode and conducting filament by the decreased V_{reset}. Since the switching non-uniformity comes from the random formation of conducting filament path in the physical gap, we can improve switching uniformity by minimizing the physical gap (lightning-rod effect). However, the resistance ratio (on/off ratio) which determines operation window is degraded due to the reduced physical gap, as shown in Fig. 1. This relation can be defined as a trade-off between the lightning-rod effect (narrower physical gap) and on/off ratio. Therefore, to improve uniformity with reasonable on/off ratio, we need to optimize both the lightning-rod effects and the resistance ratio.

Based on the previous papers, inserting additional layer can improve on/off ratio [2]. Thus, we inserted additional layer into typical bi-layer structure RRAM. Moreover, TiO_x layer which could lead to non-linear LRS was employed as an interlayer for non-linear resistive switching [3]. The mechanism of triple-layer RRAM was proposed by the difference of oxygen vacancy concentration and chemical potential, as shown in Fig. 2(b) and (c). The layer having high chemical potential can resolve the conducting filament faster than low chemical potential layer [4]. Based on this mechanism, maximized lightning-rod effects can be achieved by resolving the filament at only one layer.

The proposed approaches are summarized in Fig. 2(a). To improve switching uniformity without on/off ratio degradation, electrical and structural optimizations such as a limited switching region (lightning-rod effect), bi-layer structure, and insertion of buffer layer were proposed.

2. Experimental

Fig. 3 shows process flow for sample A ($TE/Ta/HfO_x/BE$), B ($TE/Ta/TiO_x/HfO_x/BE$), and C ($TE/Ta/HfO_x/TiO_x/BE$). The TiO_x layer was inserted into the typical Ta/HfO_x RRAM. The HfO_x layer was deposited by atomic layer deposition (ALD) system at 250 ^{O}C. TiO_x and Ta layer were deposited by sputtering Ti_4O_7 and Ta targets respectively. Pt layer was deposited as a capping layer.

3. Results & Discussion

The effects of interlayer thickness on RRAM switching characteristics were evaluated for each sample. Fig. 4 and 5 show cycle-to-cycle and cell-to-cell thickness dependences of the sample B and sample C respectively. The on/off ratio and V_{set} were increased as the thickness of interlayer increased. The effects of interlayer on device variability were studied by comparing the distributions of R_{read} and V_{set}, as shown in Fig. 6. In both R_{read} and V_{set} cases, sample C showed the best switching uniformities among the samples. These results can be explained by applied bias condition and oxygen vacancy distribution of oxide layers. Fig. 7 shows the simple models of each sample. The sample A has higher amount of oxygen vacancy at interface between Ta layer and HfO_x layer due to the oxygen absorption of Ta layer. Moreover, in switching layer (HfO_x), oxygen vacancies can be generated more than other samples. It is because the bi-layer sample has thinner oxide layers than the triple-layer samples. Besides, to obtain the lightning-rod effects, the same V_{reset} was applied to all samples. From difference of thickness between bi-layer and triple-layer, filament of triple-layer is effectively less dissolved than that of bi-layer structure.

In sample B and C, both samples have the same thickness of oxide layer. However, due to the different fabrication processes, the sample C has more insulating layer than the sample B. In other words, the sample C has insulating TiO_x layer because the ALD process was conducted after the deposition of TiO_x layer in sufficient oxygen ambient. Contrast to the sample C, the sample B has defective TiO_x layer because no thermal process was conducted after deposition of the TiO_x layer. Thus, the sample C has an abrupt change of oxygen vacancy distribution which can play a role of filament dissolution region. Therefore, sample C has limited switching region leading to uniform resistive switching. The significantly improved switching variability was successfully achieved by the limited switching region in sample C.

4. Summary

To improve the variability of switching parameters, the effects of reset condition and TiO_x interlayer were investigated. To independently control both the switching uniformity and resistance ratio, we intentionally inserted TiO_x layer by sputtering Ti_4O_7 target. The sample having TiO_x interlayer exhibited improved switching uniformity and resistance ratio.

Acknowledgments

This work was supported by POSTECH-Samsung Electronics ReRAM Cluster Research and by R&D program of Ministry of Knowledge Economy.

References

[1] J.Park, et al., *EDL*, 32 (2011) 63

[2] L. Goux, et al., *VLSI* (2012) p.159

[3] J. J. Yang, et al., *APL* 100 (2012) 113501

[4] K. Kamiya, et al., *IEDM* (2012) p.478

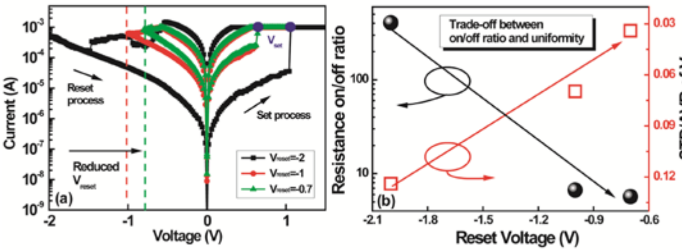

Fig. 1 (a) I-V characteristic of typical filament RRAM. Switching characteristics are strongly dependent on V_{reset}. (b) Reduced V_{reset} can improve uniformity, but degrade on/off ratio (trade-off of lightning rod effect).

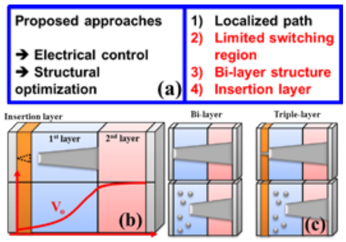

Fig. 2 (a) Summary of proposed approach by electrical and structural optimizations. (b), (c) Proposed Mechanism of triple-layer RRAM [4].

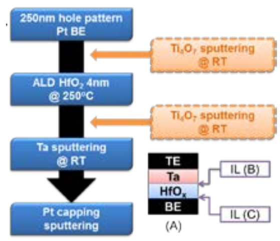

Fig. 3 Process flows for sample A (TE/Ta/HfO_x/BE), sample B (TE/Ta/TiO_x/HfO_x/BE), and sample C (TE/Ta/HfO_x/TiO_x/BE)

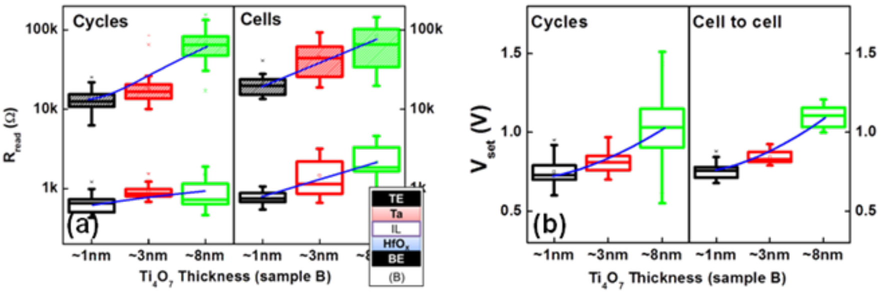

Fig. 4 Interlayer thickness dependence of sample B in (a) R_{read} and (b) V_{set} respects. As the thickness of interlayer increased, R_{read} and V_{set} were increased.

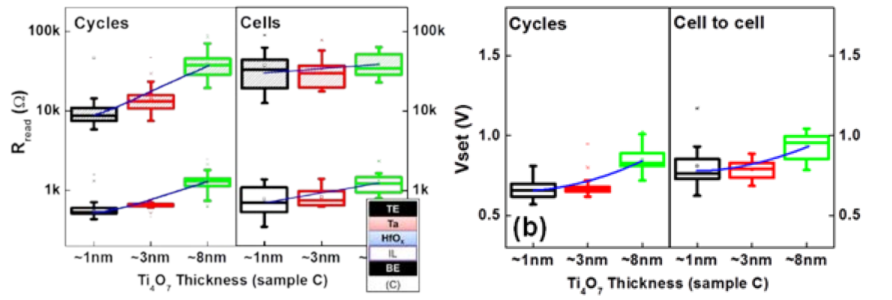

Fig. 5 Interlayer thickness dependence of sample C in (a) R_{read} and (b) V_{set} respects. As the thickness of interlayer increased, the sample C showed similar tendency with sample B.

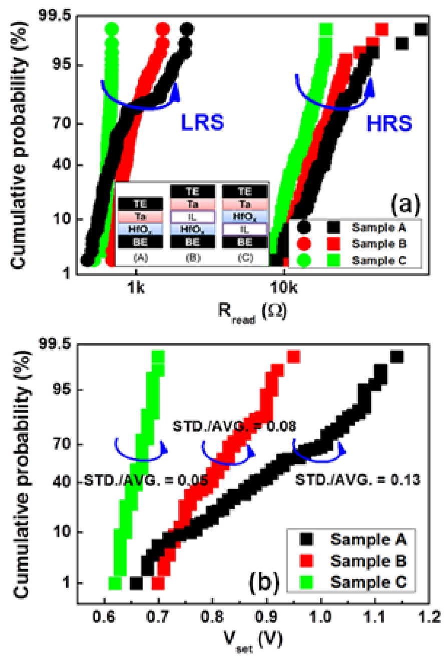

Fig. 6 Comparisons of distribution in (a) R_{read} and (b) V_{set}. Compare to bi-layer RRAM, triple-layer RRAMs showed more uniform distributions.

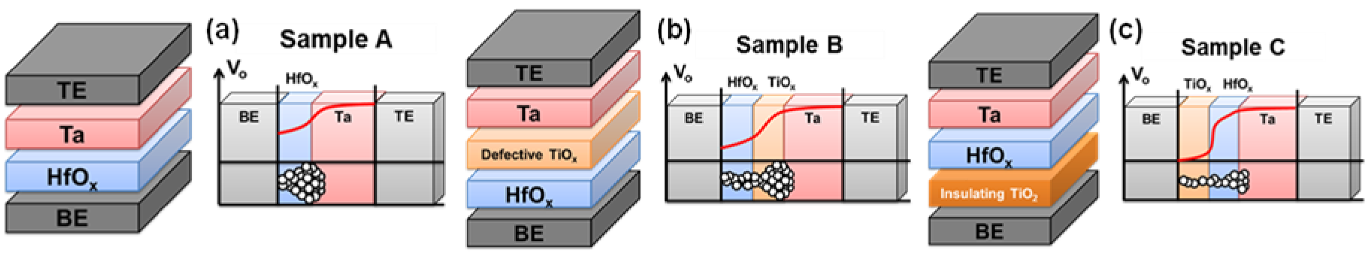

Fig. 7 Proposed simple models based on previously reported triple-layer RRAM mechanism [4]. Compare to typical bi-layer RRAM (a), the distribution oxygen vacancy can be abruptly changed in triple-layer RRAMs (b), (c). Because of different process condition, more insulating TiO_x layer which can limit oxygen vacancy generation can be formed in sample C. Thus, the sample C can have limited filament dissolution region leading to uniform resistive switching.