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Areal and Structural Effect on Oxide based RRAM cell for Improving Resistive Switching Characteristics

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Abstract

A new technical improvement in understanding the resistive switching characteristics in unipolar RRAM is investigated. It is possible to minimize reset current (I_{RESET}), set voltage variation and forming voltage ($V_{FORMING}$), which results in a wide sensing margin and high density application by using conducting filament (CF) minimized structure up to 10nm technology node. Its structural advantages enable I_{RESET} to be tuned with excellent manufacturability. Numerical simulation is also performed using random circuit breaker (RCB) model, showing that the proposed structure elucidates the resistive switching improvement.

Introduction

Recent advance in information technology (IT) gives spurs to development of the RRAM compared to other conventional memories. Among them, TMO based RRAM having unipolar resistive switching phenomenon is especially of interest because of its strong feasibility for high density application [1]. While there has been significant advance in developing high density memory field, there are still shortcomings such as limited understanding of switching mechanism, and relatively high switching current still needs to be improved [2]. In this study, we find that control of the contact area at resistive cell material/top electrode (TE) interface is eligible to reduce the I_{RESET}, set voltage distribution and $V_{FORMING}$, which are important factors in describing resistive switching characteristics. We also examine that this proposed structure in turn efficiently influences the CF results along with feasibility of low power RRAM [3]. Contact area can be defined identical to resistive cell size which is adjustable to deposition thickness. Effective numerical simulation is performed using RCB model to verify the proposed structure [4].

Discussions and results

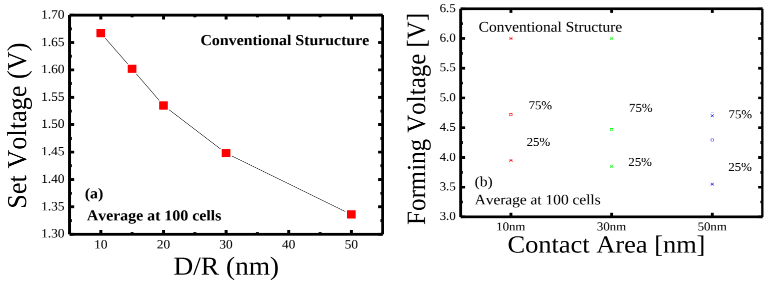
Set voltage (a) and $V_{FORMING}$ characteristics (b) as a function of device scaling in conventional structure are shown in fig. 1, and fig. 2 depicts the schematic drawings of contact area calculation of various structures. Contact area is reduced up to 79% at same design rule by using U-shape cell. Compared to the result when using the proposed structure, it makes not only the set voltage distribution controllable but also $V_{FORMING}$ to be reduced by enhancing CF controllability. In RCB model, I_{RESET} trends as a function of cell size under 50nm in conventional cell are shown in fig. 3. It shows that area control plays an important role in I_{RESET} reduction due to the remarkable decrease in total area of CF (A_{CF}) in sub nm level by using RCB model. Figure 4 shows the cross sectional TEM image of our proposed U-shape cell. The vertical stack of a resistive cell consists of a top electrode connected to Al metal line, a TiO_2 cell having U-shape structure vertically, and a bottom electrode connected to lower metal line. As previously mentioned in fig. 2, contact area 'a' can be easily tuned by adjusting deposition of resistive cell thickness, confirming how effective our proposed structure is. Figure 5 shows the I_{RESET} for 50nm, 20nm and 10nm U-shape cell (a) and I_{RESET} comparisons between conventional and U-shape cell (b). Reset currents of U-shape cell are lowered both to 20nm and 10nm cell size conditions in order to consider the structural effect of proposed structure. Effects on calculated total contact area as a function of I_{RESET} (a) and current-lateral contact area curves (b) of U-shape cell are also presented in fig. 6. Figure 7 shows the average of set voltage for 50nm, 20nm and 10nm U-shape cell (a) and 100 cells I_{RESET}- set voltage distributions between conventional cell and contact area split U-shape cells (b). Although set voltage still depends on a cell size even when using U-shape cell structure, there is a noticeable improvement in set voltage distribution as shown in fig. 7 (b). Figure 8 compares the programming voltage distributions for reset and set operations from 100 conventional and U-shape cells. The set voltage (a) and standard deviation of set voltage (b) for sub 10nm of 100 conventional cells and U-shape cells are also addressed in fig. 9. In the case of conventional cell, standard deviation of set voltage (σ) is changed from 0.37V to 0.44V as contact area decreases. However, σ of U-shape cell structure is only altered from 0.25V to 0.27V in the same condition. Forming voltage distributions of 100 conventional and U-shape cells are investigated (fig. 10) and 100 cells I_{RESET} - $V_{FORMING}$ distributions between conventional cell and contact area split U-shape cells are also examined (fig. 11). Better $V_{FORMING}$ and I_{RESET} level without photo-lithography problem can be achieved by using optimal U-shape cell. In the case of U-shape cell, especially in split 1 group, forming voltage distribution is dramatically improved compared to that of when using conventional cell. Figure 12 shows the optimal contact area of 100 U-shape cells for low $V_{FORMING}$. Some critical contact dimension fit to U-shape cell exists. This suggests that determining optimal process condition based on correct relationships between parameters is required to evaluate RRAM cell which shows superb sensing margin with low $V_{FORMING}$. Figure 13 shows the $V_{FORMING}$ for 20nm and 10nm of 100 average conventional cells and U-shape cells. The forming voltage level is supposed to increase as device scales of both structures in sub nm region. However, when using U-shape cell, forming voltage level is relatively low compared to that of when using conventional cell. This demonstrates that better CF controllability brings an advantage in total working voltage reduction. Resistance distributions for reset and set operations of 100 conventional cells and U-shape cells are illustrated in fig. 14. Localized CF path helps to improve sensing margin, indicating that reset resistance may deteriorate the CF originated from set resistance.

Conclusions

Areal and structural effects of proposed novel U-shape structure are systematically elucidated by using RCB model. Compared to conventional structure, proposed structure is more adequate in improving I_{RESET}. In particular, set voltage distributions and $V_{FORMING}$ are minimized due to CF controllability and field enhancement, which are not obtainable from the conventional resistive cell structure. Increase in resistance ratio implies that reset resistance may deteriorate the CF originated from set resistance. The structural advantages of proposed cell make I_{RESET} easy to be controlled by excellent manufacturability.

References

[1] Y. Sakotsubo et al., *Symp. VLSI Tech. Dig.*, pp.87, 2010. [2] U. Russo et al., *IEEE TED*, vol.56, p.193, 2009. [3] K.C. Ryoo et al., *SSDM Tech.Dig.*,p.2010 [4] S.C. Chae et al., *Adv. Mater.* Vol. 20, p.1154,2008



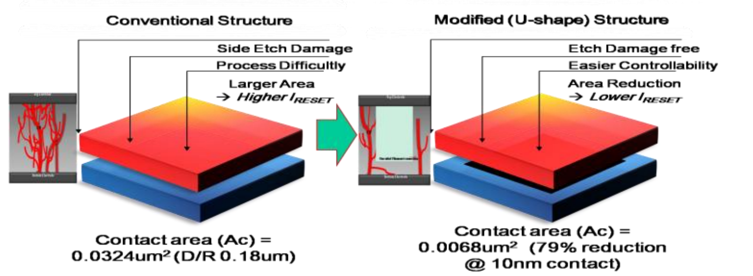
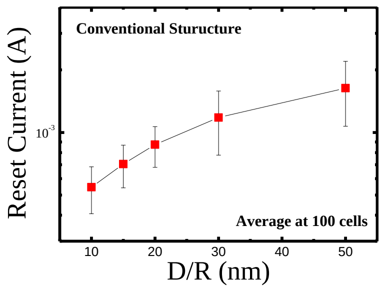
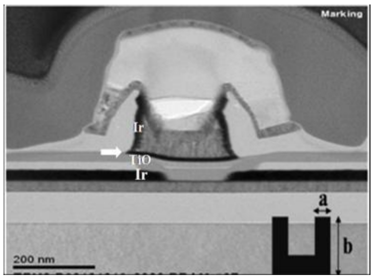


Fig. 1. Differences of set voltage (a) and forming voltage level (b) of conventional unipolar cell structure RRAM as a function of device scaling. Cell size is in inverse proportion to set voltage and $V_{FORMING}$ in conventional cell structure.

Fig. 2. Schematic drawing of calculated contact area of conventional cell and modified (U-shape) cell. Contact area is reduced up to 79% at same design rule by using modified cell structure.





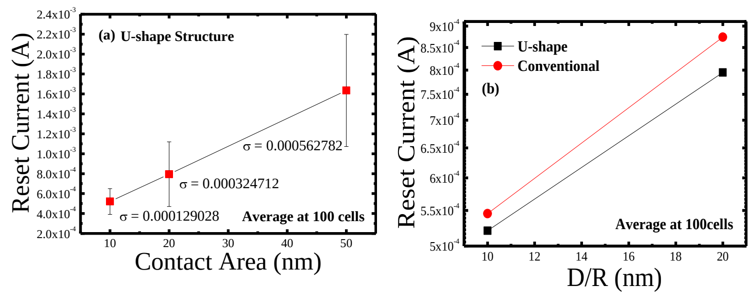
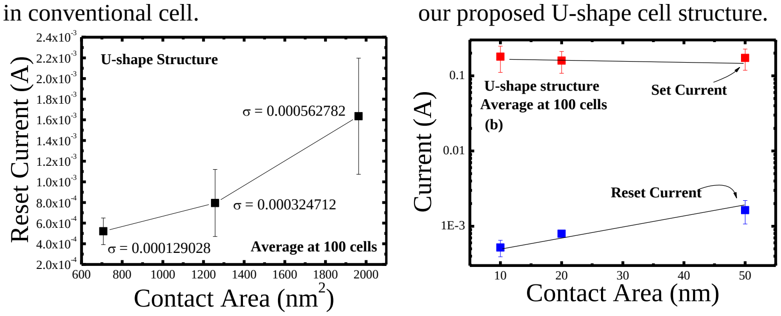


Fig. 3. I_{RESET} as a function of design rule in conventional cell.

Fig. 4. Cross sectional TEM image of our proposed U-shape cell structure.

Fig. 5. I_{RESET} as a function of contact area in U-shape cell (a) and I_{RESET} comparisons with conventional cell (b).



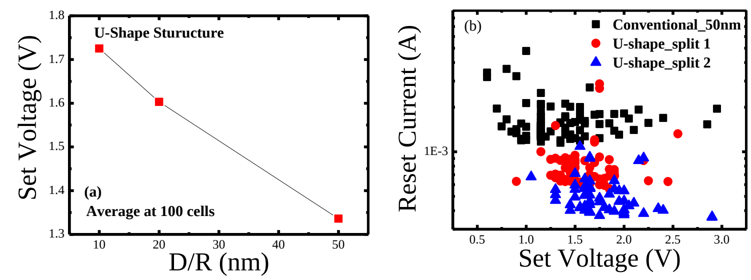
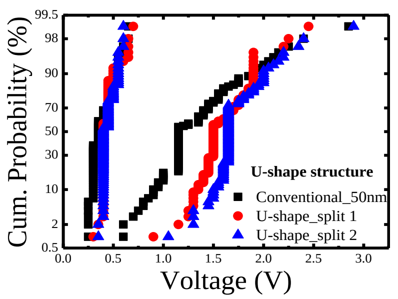
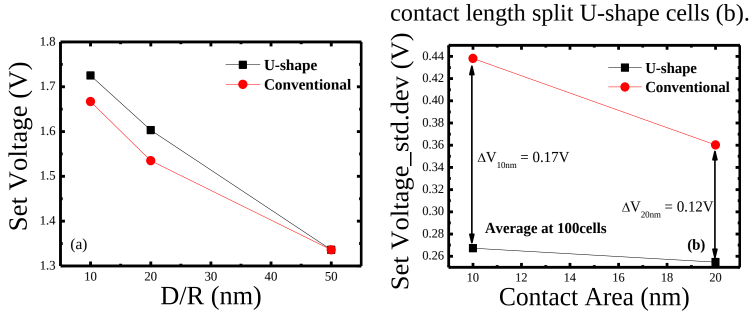


Fig. 6. I_{RESET} – calculated total contact area curve (a) and set/reset current- lateral contact area curve (b) of U-shape cell.

Fig. 7. The average of set voltage for 50nm, 20nm and 10nm U-shape cell (a) and 100 cells I_{RESET}- set voltage distributions between conventional cell and contact length split U-shape cells (b).





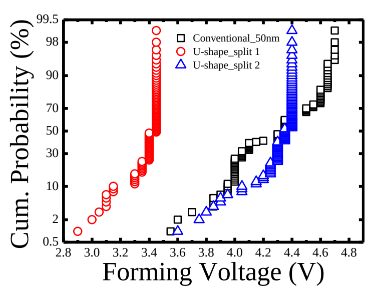
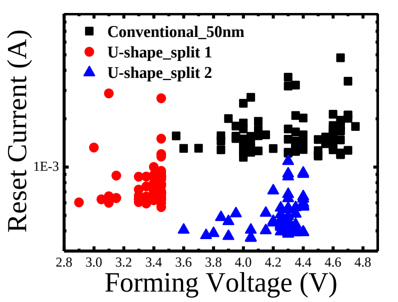
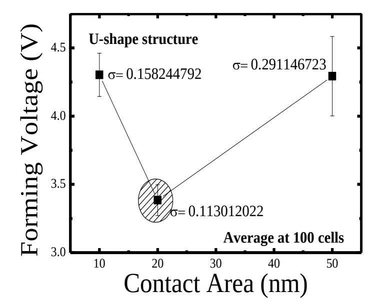


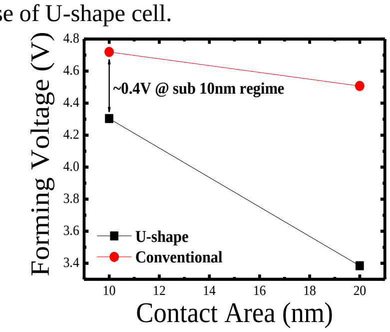
Fig. 8. Programming voltage distributions for reset and set operations from 100 conventional and U-shape cells.

Fig. 9. The set voltage (a) and standard deviation of set voltage (b) for sub 10nm of 100 average conventional cells and U-shape cells. The set voltage level increases as device scales in both structures. But set voltage is much lower with narrow distribution in case of U-shape cell.

Fig.10. Forming voltage distributions of 100 conventional and U-shape cells.







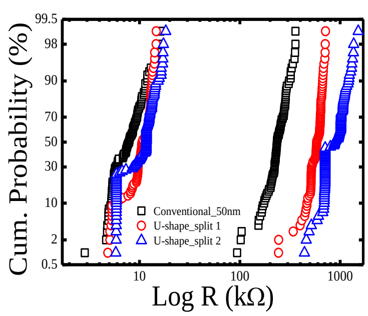


Fig.11.100cells of I_{RESET}- forming voltage distribution curve of various split cells.

Fig. 12. Optimal contact area of 100 U-shape cells for low $V_{FORMING}$.

Fig. 13. $V_{FORMING}$ for 20nm and 10nm of 100 a split cells.

Fig. 14. Resistance distributions for reset and set operations.