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# Elucidation of ReRAM Mechanism and Improvement of Memory Characteristics by HPHA

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## 1. Introduction

Resistance RAM (ReRAM) is one of the strong candidates for next generation memory with the scaling limit of conventional memories. It shows excellent characteristics, such as, low power consumption, high speed, and non-volatility. However, the most serious problem is the unclarity of exact mechanism.

In this study, we will focus on Pt and Nb doped $SrTiO_3$ (Nb:STO) interface for elucidating ReRAM mechanism. Based on the result, improved electrical characteristics will be presented.

## 2. Experimental

For the n-type semiconductor, we used a single crystalline Nb:STO (100) substrate, which was commercial available. The surface of the sample was ultrasonically degreased in trichloroethylene, acetone, and methanol solutions for 10 min., respectively. For compassion of other oxides, $Nb_2O_5$, $ZrO_x$, and Cr-STO films were deposited on heavy-doped n-type Si using pulsed laser deposition (PLD) system. Mesa structures with various sizes (30×30, 120×120, and 250×250 $\mu m^2$) were fabricated by photolithography and a liftoff process. Pt (100) was deposited on top of Nb:STO by radio frequency sputter. In order to improve memory characteristics, one sample was annealed in high pressure (10 atm) pure (100%) hydrogen ambient at 400 °C for 30 min. *I-V* and *C-V* characteristic curves were measured by the Agilent 4155C semiconductor parameter analyzer, and Agilent B1500 semiconductor parameter analyzer, respectively.

## 3. Results and Discussion

Figure 1 shows comparison of Nb:STO single crystal switching property with those of other oxides. It shows excellent reproducibility up to 95% and on-off distribution of more than two orders of magnitude.

Figure 2 shows hysteretic *I-V* characteristics of various top electrodes (TEs) with Nb:STO junction. The work functions of Ti and Al are 4.3 and 4.17~4.3 eV, respectively. That of Pt is 5.2 eV, which is typical deep metal work function and n-type semiconductor (Nb:STO) Schottky junction. While Ti/Nb:STO, and Al/Nb:STO junctions show no resistance switching behavior, Pt/Nb:STO shows good resistance switching behavior. Upper branch is the low resistance state (LRS) and lower branch is the high resistance state (HRS), respectively. Schottky junction with oxygen vacancy model was proposed to explain this phenomenon [1]. Schottky junctions with different size describe their behaviors very well as shown in Figure 3 [2].

Since oxygen vacancies play a crucial role in ReRAM mechanism, we proposed oxygen vacancies migration model as shown in the Figure 4. Oxygen vacancies with plus charges are piled up at the metal semiconductor interface as plus voltage is applied to TE. They lower the barrier height down, which make low resistance state (LRS). The opposite polarity pushes the oxygen vacancies away from the interface. They raise the barrier height up, which make high resistance state (HRS) [3].

To confirm the proposed mechanism, we measured *C-V* curve to check the barrier height change. Figure 5 shows $1/C^2$ - $V$ curve for the LRS and HRS state, respectively. Extrapolation of each line shows barrier height change. Inset of Figure 5 shows schematic diagram of measurement. Considering the Nb:STO is leaky oxide, we used high frequency of 1MHz.

Based on the mechanism, we increased oxygen vacancies with high pressure hydrogen annealing (HPHA) [4] by reduction of Nb:STO. Figure 6 (a) shows *I-V* characteristics of the samples for comparison. Figure 6 (b) shows XPS data of two samples, which show oxygen deficient region of Nb:STO surface.

Fig. 7 (a), (b), and (c) shows improved memory characteristics of HPHA sample, which is fast switching speed, durable endurance, and long retention, respectively.

## 4. Conclusion

We have investigated Pt/Nb:STO Schottky junction for elucidation of ReRAM mechanism. It can be explained by oxygen vacancy migration and Schottky barrier height change. We also improved memory characteristics with HPHA by using the result.

## Acknowledgements

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## References

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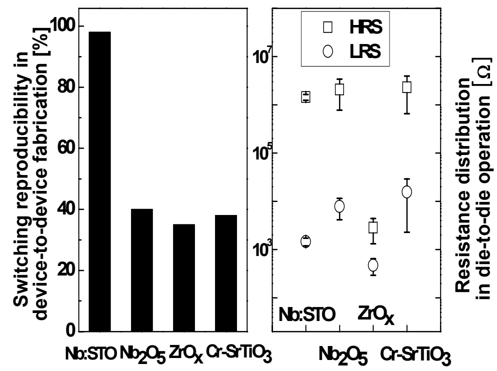


Fig. 1. Comparison of Nb:STO single crystal with other oxides.

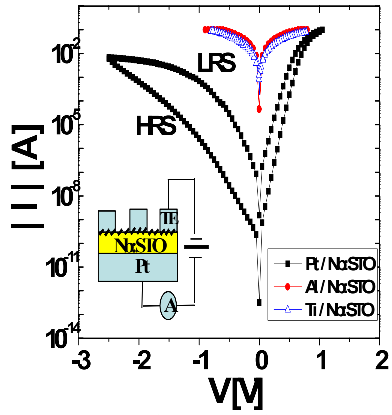


Fig. 2. Hysteretic *I-V* characteristic of various top electrodes (TEs). Only Pt/Nb:STO interface shows resistance switching.

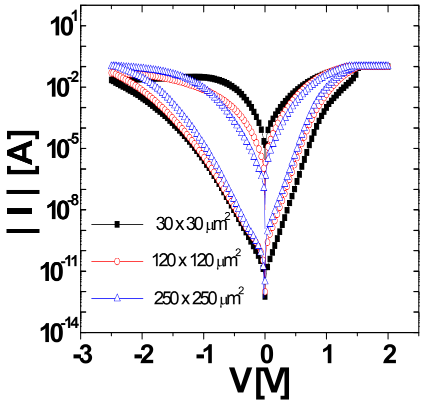


Fig. 3 Hysteretic *I-V* characteristics of different TEs in size.

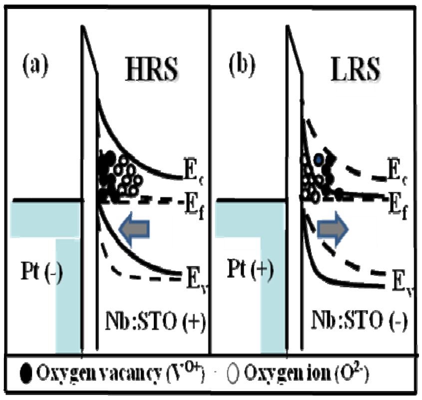


Fig. 4. Negative voltage applied on TE pushes oxygen vacancies away from the interface, which raise the barrier height (HRS). The opposite case makes LRS. The arrows indicate direction of oxygen vacancies.

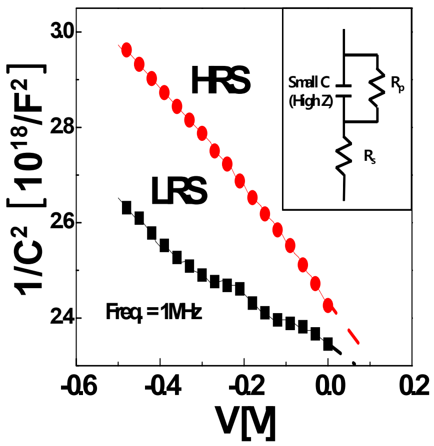


Fig. 5. *1/C²–V* curves of HRS and LRS, respectively. Extrapolations from the data show the barrier height changes. Inset shows schematic diagram of the *C-V* measurement.

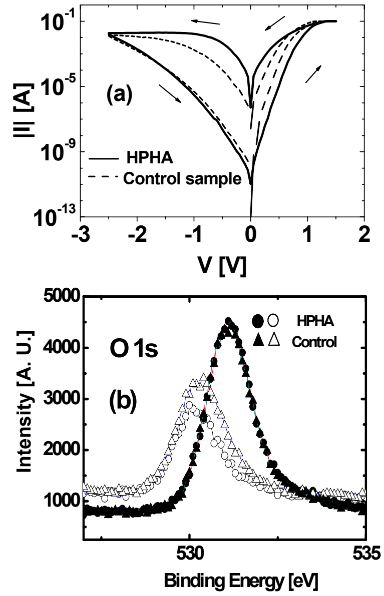


Fig. 6 (a) *I-V* curves of HPHA and control sample. (b) XPS O 1s peaks of HPHA and control sample, which shows oxygen deficient surface layer of HPHA sample.

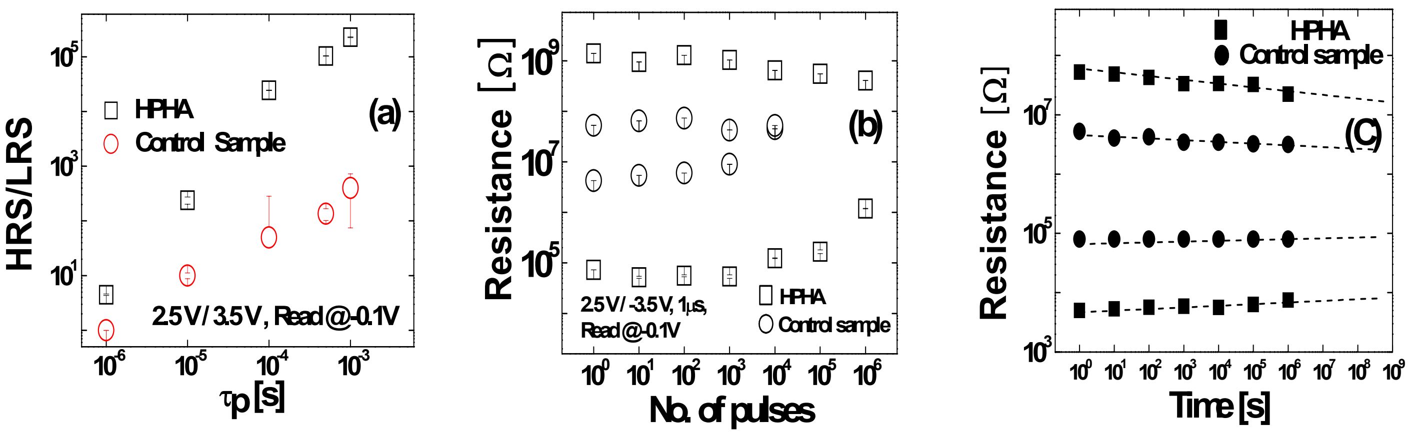


Fig. 7. Comparison of memory characteristics of control and HPHA sample. (a) Switching speed (b) Endurance test (c) Retention test. All measurements were performed by pulsed voltage stresses.