Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp889-890

# Observation and Distinction of e-RTN and GR-RTN in $TMO_x$-based RRAM

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***Abstract***—RTN resulted from the current path altering can be divided into two types: e-RTN and GR-RTN. In typical two-level RTN, GR-RTN and e-RTN can not be distinguished directly from the current levels and this hinders the accurate calculation of the trap location and energy level ($X_T$, $E_T$). In this work, three-level RTN in $TMO_x$-based RRAM was investigated. GR-RTN and e-RTN were both observed and can be distinguished clearly by the comparison among the three discrete current levels. Also, after discussing the bias dependency of time constants of the three-level e-RTN, the vertical location and energy level of the trap corresponding to this three-level e-RTN were finally tracked.

## I. Introduction

Random Telegragh Noise (RTN) is a useful tool for defect analysis, which can be used to track the defect location and energy level [1]. However, in typical two-level RTN, e-RTN and GR-RTN coexist and can not be distinguished directly from the current levels [2]. This hinders the accurate tracking of the defect, since the tracking technique is based on the electron emitting/capturing from the defect [3]. In this work, we systematically investigated the three-level RTN in $TMO_x$-based RRAM. We can clearly distinguish e-RTN from GR-RTN by comparing the three discrete current levels. After extracting the time constants of this three-level e-RTN under different voltage bias, vertical location and energy level of this trap corresponding to this e-RTN were tracked.

## II. Experimental

Fig.1 shows the schematic of 1T1R structure. The RRAM cell studied here was fabricated on the 28nm standard logic platform. Detailed information on integration process could be found in our previous work [4].

## III. Results and Discussion

Fig. 2a shows the physical mechanism accounting for the two-level random current fluctuation in Ox-RRAM. The origin of RTN is attributed to the random trapping and detrapping of carriers in traps located in the switching layer. There are two types of RTN: e-RTN, which is caused by the electron emitted/captured from/by the trap and GR-RTN, which can be attributed to the oxygen ion generated/recombined from/with the oxygen vacancy. However, we can not distinguish between e-RTN and GR-RTN in two-level RTN simply from the RTN signal shown in Fig. 2b. Fig. 3a&4a show three-level RTNs in time domain which are hardly observed. Different from two-level or four-level RTN which is due to one trap or two independent traps [5], the origin of three-level RTN is attributed to one trap interacting with two electrons or one oxygen ion and one electron. We found that two current differences ($\Delta I_1$, $\Delta I_2$) between the current levels have similar value in Fig. 3b. Hence, this three-level RTN is considered as a sequential two-electron capture and emission processes with one trap (Fig. 3d) and can be regarded as e-RTN [6]. Fig. 4b shows the other three-level RTN which is regarded as e-RTN and GR-RTN coexisting. The trap is reacted with both one electron and one oxygen ion as described in Fig. 4d. The power spectrum densities (PSD) of these two kinds of RTN (Fig. 3c&4c) also confirm that there is only one trap. For e-RTN, we defined Level 2 as the state in which the trap is empty, Level 1 defined as the state in which the trap is filled with one electron and Level 0 defined as the state in which the trap is filled with two electrons, respectively. Fig. 5a shows the time constants of different capture/emission processes. The bias dependency of time constants of this three-level e-RTN was depicted in Fig. 5b. Note that process 1 ($\tau_{c1}$,$\tau_{e1}$) and process 2 ($\tau_{c2}$,$\tau_{e2}$) have the same time constant variation rate, which confirm that there is only one trap [7]. The vertical location and energy level of the trap corresponding to this three-level e-RTN were then tracked (Fig. 5c).

## IV. Conclusion

In this work, we investigated the three-level RTN in $TMO_x$-based RRAM. GR-RTN and e-RTN were both observed and can be distinguished clearly by the comparison among the three discrete current levels. Furthermore, we discussed the bias dependency of time constants of the three-level e-RTN and the vertical location and energy level of the trap corresponding to this three-level e-RTN were finally tracked.

## Acknowledgment

This work was supported in part by the MOST of China under Grant 2016YFA0203800 and Grant 2016YFA020183 and in part by the National Natural Science Foundation of China under Grant 61522408, Grant 61334007, and Grant 61521064.

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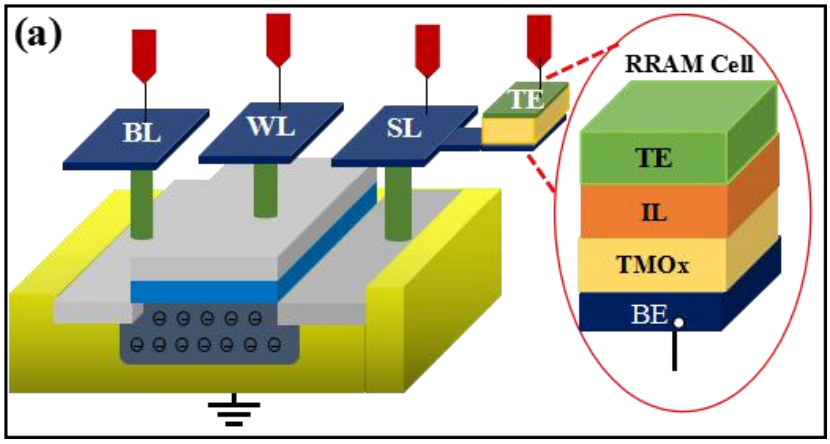


*Fig. 1 Schematic of the 1T1R structure.*

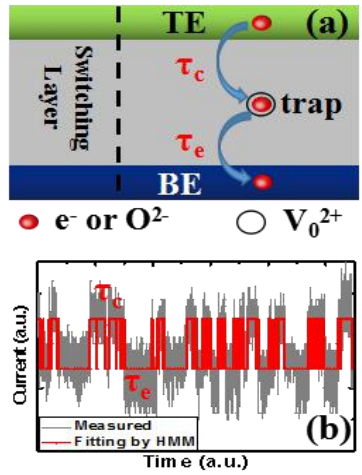


*Fig. 2 (a) Physical mechanism of two-level RTN. (b) RTN signal.*

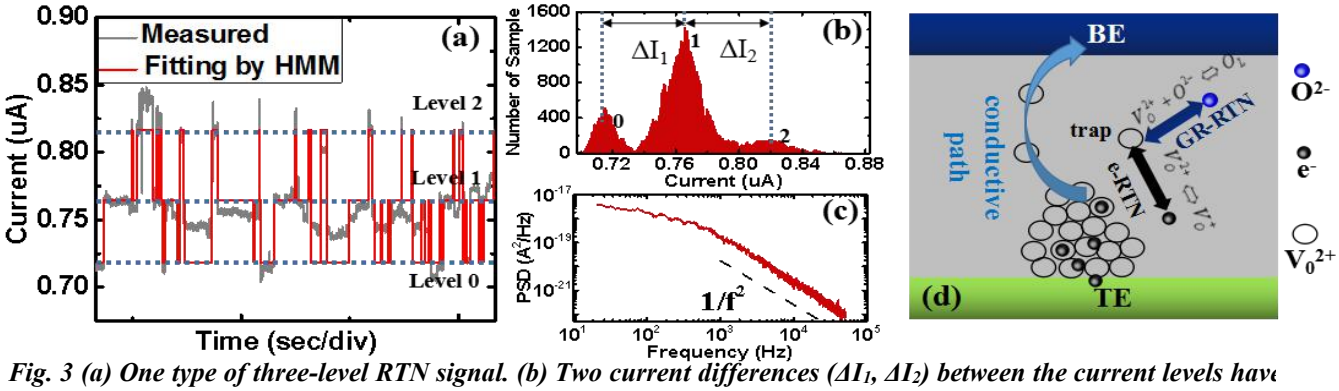


*Fig. 3 (a) One type of three-level RTN signal. (b) Two current differences ($\Delta I_1$, $\Delta I_2$) between the current levels have similar value. (c) The PSD of this RTN indicates that there is only one trap. (d) Physical mechanism of this three-level RTN which can be regarded as e-RTN.*

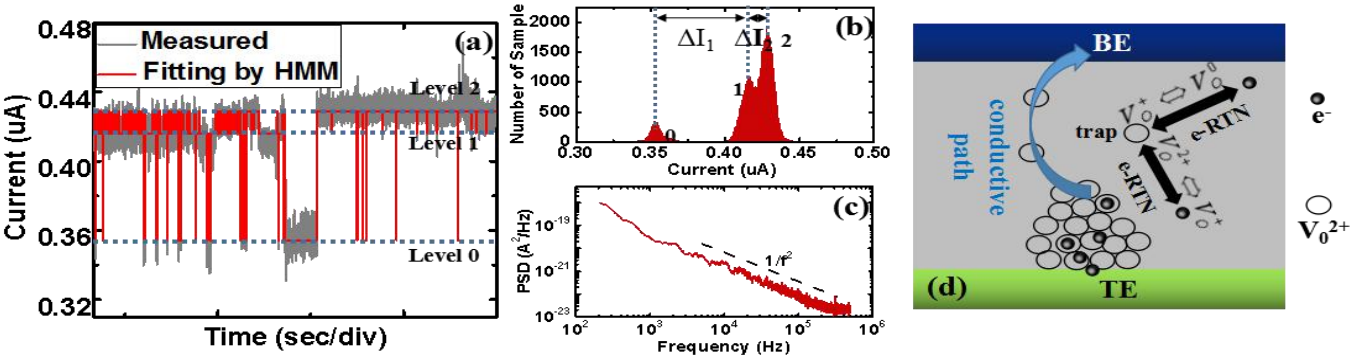


*Fig. 4 (a) The other type of three-level RTN signal. (b) Two current differences ($\Delta I_1$, $\Delta I_2$) between the current levels have different value. (c) The PSD of this RTN indicates that there is only one trap. (c) Physical mechanism of this three-level RTN which is regarded as e-RTN and GR-RTN coexisting.*

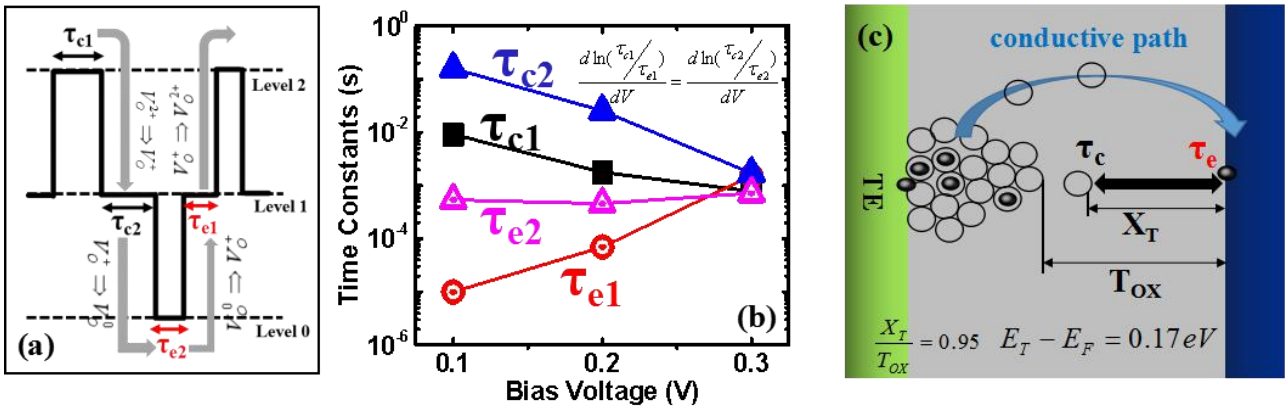


*Fig. 5 (a) Definition of time constants in three-level e-RTN. (b) Bias dependency of time constants of the three-level e-RTN. (c) The vertical location and energy level of the trap corresponding to this three-level e-RTN were tracked.*