Modeling the Resistive Switching Process in Transition Metal Oxide Based Non-Volatile Memory Devices

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INTRODUCTION

Binary transition metal oxides TiO_x, NiO_x, HfO_x, AlO_x, TaO_x have been recently proposed as possible materials for embedded non-volatile memory modules. Currently, a major bottleneck in determining the scalability, retention and endurance of these devices, is the lack of detailed understanding of resistive switching mechanism. Generally, the process of forming in transition metal oxides systems includes either the diffusion of oxygen vacancies to cluster into filaments [1-5] or the diffusion of oxygen atoms away from the oxide region to form a thin interfacial reduced oxide. During electroforming, oxygen vacancies or ions are believed to drift due to the applied bias (Fig. 1), trap electrons or holes and facilitate the formation of vacancy ordered domains [4]. Then, during the reset process, the ordered vacancy domains are disconnected and a high resistance state is achieved. Another, slightly different mechanism is based on the potential barrier change between the electrode and the oxide by modulating the Schottky barrier height.

DISCUSSION

Filamentary models for transition metal oxides had been proposed theoretically [4] and the formation energy implications of a conductive filament channel formation corresponding to the "ON" state or LRS [6-8] was investigated (Fig. 2). The rupturing/dissolution process of the so formed filament, i.e. switching to the "OFF" state of the memory operation with HRS characteristics, is illustrated in Fig, 3. Preferential impurity doping [9] in these types of systems can favorably affect the transition process between the "ON" and "OFF" states (Fig. 4). In addition, the effect of electron and hole trapping during the switching process under applied electrical field were recently explained [10]. Hole injection into an oxygen reduced transition metal oxide that contain a formed filament were found to favor the dissolution, while electron injection induces filament formation, respectively. A schematic illustration of this process is shown in Fig. 5.

CONCLUSION

Atomistic modeling approaches based on quantum mechanical principles were used to elucidate the formation of filaments in ReRAM devices and a switching mechanism is proposed.

ACKNOWLEDGEMENT

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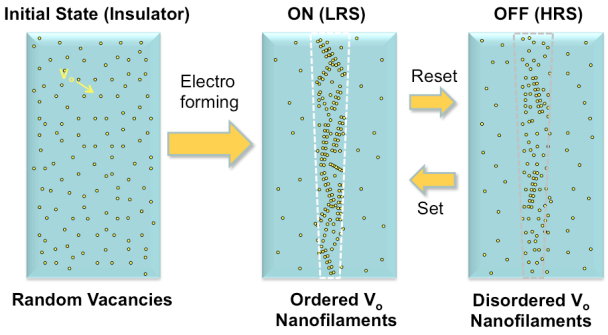

Fig. 3. Schematic switching model incorporating nano-filaments formation and disruption.

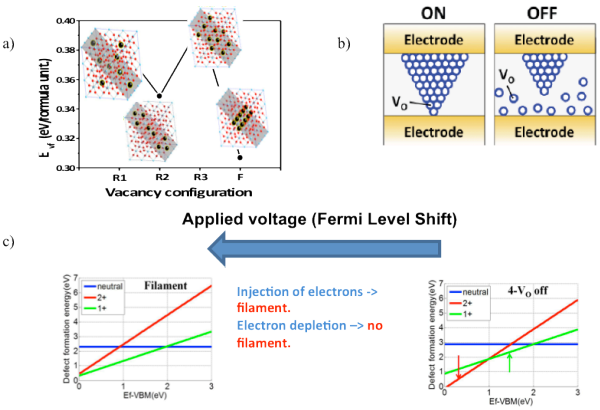

Fig. 2 a) Oxygen vacancy ordering is shown to be energetically favored over random configurations b) Schematic view of cohesion ("ON" state) to isolation ("OFF" state) transition of the filament formed by oxygen vacancies. c) The "ON"-"OFF" transition driven by the applied electric field induces filament stabilization/destabilization depending on electron or hole injection.

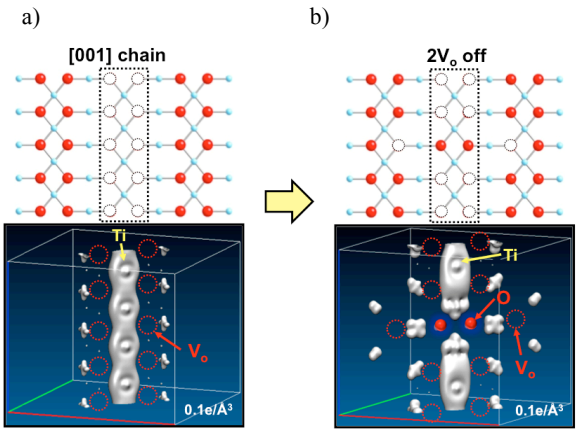

Fig. 3. Oxygen vacancy configurations and the corresponding partial defect charge densities. a) Ordered vacancy chain b) Disrupted oxygen vacancy chain.

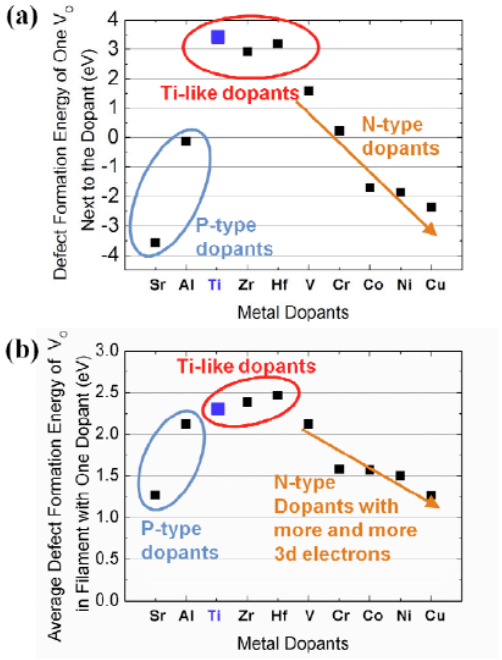

Fig. 4 a) Calculated formation energies of single oxygen vacancy next to different types of dopants. (b) Calculated average formation energies of oxygen vacancies in the filament doped with the metal dopants.

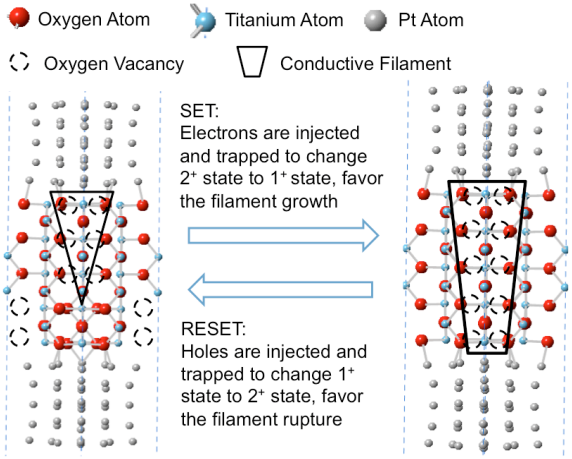

Fig. 5. Schematic view of electron and hole trapping process and their effect on the switching mechanism.