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Resistive Switching in Transition Metal Oxide ReRAM Devices

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1. Introduction

As possible solutions for embedded non-volatile memory (NVM) modules, the resistive random access memory devices (ReRAM) for data storage had been gaining increased attention lately. The control of the resistance change process between the low resistance (LRS) and high resistance (HRS) states, induced repetitively in a metal–insulator–metal (MIM) stack, is one of the key aspects of their functionality. As for materials, the binary transition metal oxides, e.g., TiO_x, NiO_x, HfO_x, AlO_x, TaO_x have been specifically promising in terms of low cost, high scalability, and low power consumption characteristics. Nevertheless, in spite of the rapid rise in publications of ReRAM related research during the past couple of years, a major bottleneck in determining the scalability, retention and endurance of these devices, is the lack of detailed understanding of resistive switching mechanism. To address the critical issues of ReRAM operation, atomistic modeling approaches based on quantum mechanical principles are needed to achieve the optimization of material properties and structures of ReRAM cells, as well as of selection devices and memory array configurations.

2. Overview and current status

To explain the process of resistance change observed experimentally, various switching mechanisms were proposed and described in the technical literature. Generally, in transition metal oxides system such as TiO_2, HfO_2 and NiO the diffusion of oxygen vacancies to cluster and create filaments [1-5] or the diffusion of oxygen atoms away from the oxide region to form a thin interfacial reduced oxide, were proposed to initiate the forming and then control the switching process.

During electroforming, vacancies are believed to drift due to the applied bias, change their charge state and facilitate the formation of vacancy ordered domains [4]. A high density of vacancy concentration to form filaments is desired to achieve the “ON” -state conduction. 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 resistance change materials by modulating the Schottky barrier height. The proposed mechanisms promote the general belief that charge injection from the electrode results in trapping on defect sites. However, based on where the charge trapping sites are located, this can be a bulk like (filamentary) phenomena or an interface effect. In the later case the electrostatic barrier against introducing charges is altered in the course of the resistance change. Depending on the particular mechanism, the resistance change had been proposed to take place either locally or uniformly across the cross section of the device structure.

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. The rupturing/dissolution process of the so formed filament, i.e. switching to the “OFF” state of the memory operation with HRS characteristics, have been addressed also theoretically. Impurity doping in these types of systems may also favorably affect the transition process between the “ON” and “OFF” states. In addition, the effect of electron and hole injection on the switching mechanism had been addressed and the undergoing atomic and electronic processes under applied electrical field were explained [9]. 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. 1.

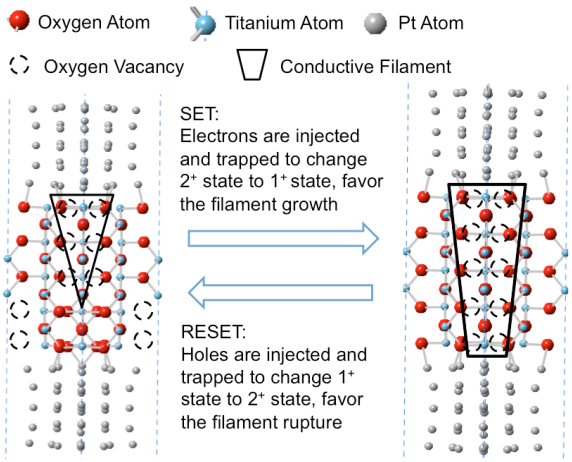

Fig. 1. Structural effects of electron and hole injection and their effect on the switching.

3. Conclusions

Several competing processes may undergo simultaneously at the microscopic level during the switching of ReRAM devices. Atomistic simulations based on density functional theory can provide an accurate description of the role of each component and describe the mechanism of ReRAM switching.

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