Control of Switching Modes and Conductance Quantization in Oxygen Engineered HfO_x based Memristive Devices

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Hafnium oxide (HfO_x) based memristive devices have tremendous potential as non-volatile resistive random access memory (RRAM) and in neuromorphic electronics. Despite its seemingly simple two-terminal structure, myriad of RRAM devices reported in the rapidly growing literature exhibit rather complex resistive switching behaviors.

Using Pt/HfO_x/TiN based metal-insulator-metal structures as model systems, we show that, a well-controlled oxygen stoichiometry governs the filament formation and the occurrence of multiple switching modes. [1] The oxygen vacancy concentration is found to be the key factor in manipulating the balance between electric field and Joule heating during formation, rupture (reset), and reformation (set) of the conductive filaments in the dielectric. In addition, the engineering of oxygen vacancies stabilizes atomic size filament constrictions exhibiting integer and half-integer conductance quantization at room-temperature during set and reset. Identifying the materials conditions of different switching modes and conductance quantization contributes to a unified switching model correlating structural and functional properties of RRAM materials.

The possibility to engineer oxygen stoichiometry in HfO_x will allow creating quantum point contacts with multiple conductance quanta as a first step towards multi-level memristive quantum devices.

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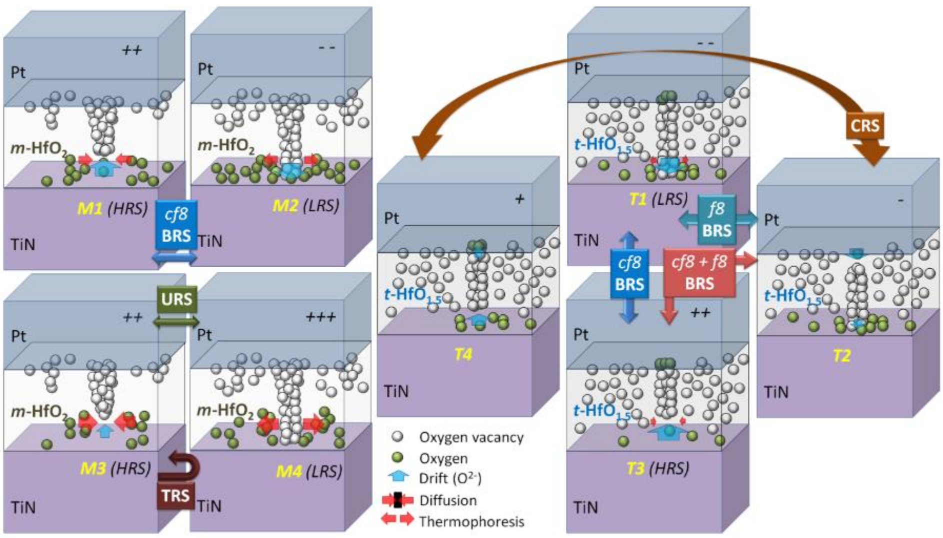

Fig. 1: A schematic qualitative model of switching modes in Pt/*m*-HfO_2/TiN (depicted by M1-M4) and Pt/*t*-HfO1.5/TiN (T1-T4). In the *m*-HfO_2 stack, the transition M1 ⇔ M2 corresponds to cf8-bipolar resistive switching (BRS); the transition M3 ⇔ M4 corresponds to unipolar resistive switching (URS), and M3 ⇒ M4 ⇒ M3 to threshold resistive switching (TRS). In the *t*-HfO_x stack, cf8-BRS is shown as T1 ⇔ T3, f8- BRS as T1 ⇔ T2 and complementary resistive switching as T4 ⇔ T1 ⇔ T2.