Microscopic model of the operation of the Single-chalcogenide X-point Memory

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The ovonic threshold switch (OTS) is an emerging device based on chalcogenide glasses such as sulfides, selenides, and tellurides. First discovered in the 1960s, the OTS is capable of threshold switching, where the current characteristics exhibit an abrupt transition from the off state to the on state at a characteristic threshold voltage V_T. OTS has attracted a widespread interest as a potential technology for selector devices in cross-points memory arrays [1]. Very recently, it has been shown that the threshold switching voltage V_T depends on the polarity of the applied field: a low V_T state (SET) is achieved when the programming and readout operations have the same polarity, while a high V_T state (RESET) when program and read occur in opposite polarities. This phenomenon paved the way for realizing a Single-chalcogenide Xpoint Memory (SXM), which operation is sketched in Fig. 1, and that relies on just a thin and confined film of chalcogenide glass that fulfills the roles of selector and storage elements. The characteristics of SXM fit well with the requirements for storage class memories, as they may combine the cost structure of a vertical 3D NAND with superior latency, endurance and bandwidth [2]. In this work, we provide a microscopic understanding of the polarity-dependent V_T by leveraging electrical and physical measurements, numerical simulations based on technology computer aided design (TCAD) and electronic structure calculations based on density functional theory (DFT). We developed a Graded Band Gap (GBG) model in which an inhomogeneous distribution of localized electronic states in the gap is established by the opposite effect of a strong electric field at the cathode and a high density of electrons in the conduction band at the anode (see Fig. 2). The model is suitable to reproduce several features of the programming window, including its dependence on temperature, thickness and composition of the chalcogenide alloy [3]. The microscopic understanding that we gained on the SXM operation lays the foundation for important improvements in the memory design and in the selection of better performing alloys for applications in enabling memory technologies.

References

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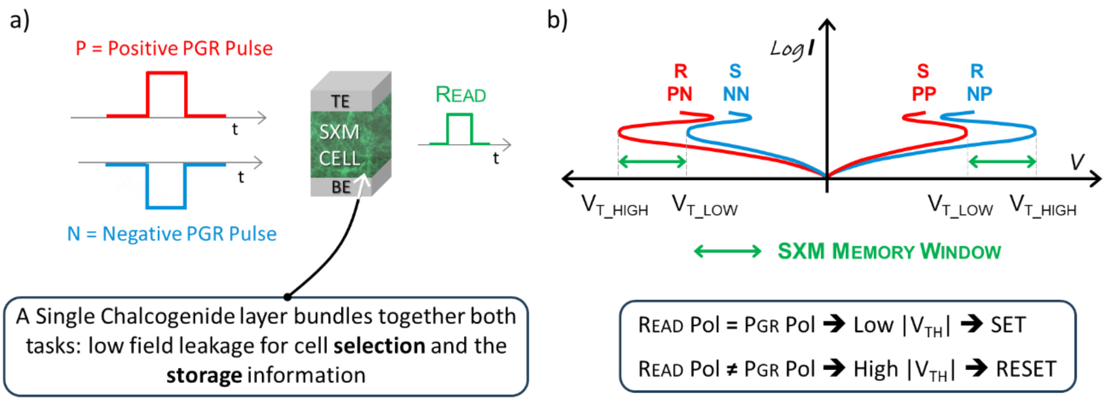

Fig. 1: a) Sketch of the operational principle of the SXM cell where a positive (P) and negative (N) programming (PGR) pulses with a positive (P) polarity readout pulse. b) I-V characteristics and V_Ts illustrating the different programming and readout polarities. V_T is higher when program and read occur in opposite polarity (NP and PN cases), while V_T is lower when program and read have concordant polarity (PP and NN). The different V_T provides the basis for the storage principle of the SXM device.

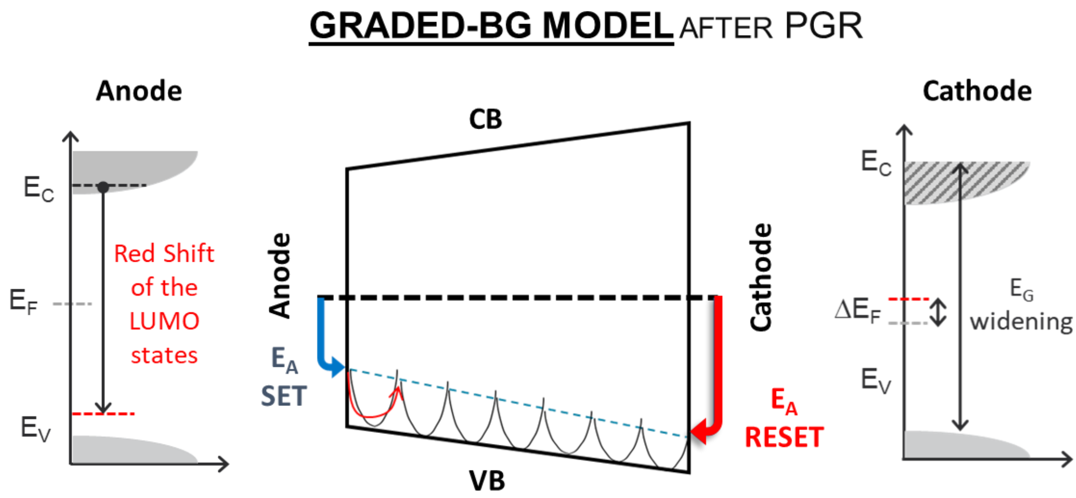

Fig. 2: Sketch of the Graded Band Gap (GBG) model responsible for SXM window with the two different activation energies (E_A) for hole injection at the anode and cathode. Atomistic simulation results shed light on what happens during the out-of equilibrium condition of switching when excess electrons populate the CB at the anode side, and a high electric field is generated at the cathode. The fast-quenching pulse freezes the out-of-equilibrium condition that shifts the LUMOs states closer to the valence band, facilitating hole injection from the anode side, and cleans-up the band gap from the homopolar defect states (dashed tail states) at the cathode side.

These processes lead to an effective Graded Band-Gap, briefly called GBG, that induce an asymmetry between the anode-side region and the cathode-side region that is the basis of our polarity driven model.