

Supporting Information

The Coexistence of Threshold and Memory Switching Characteristics of ALD HfO₂ Memristor Synaptic Arrays for Energy-Efficient Neuromorphic Computing

Haider Abbas,^a Yawar Abbas,^b Gul Hassan,^c Andrey Sergeevich Sokolov,^a Yu-Rim Jeon,^a

Boncheol Ku,^a Chi Jung Kang,^d and Changhwan Choi ^{*a}

^aDivision of Materials Science and Engineering, Hanyang University, Seoul 04763, Republic of Korea.

^bDepartment of Physics, Khalifa University, Abu Dhabi 127788, United Arab Emirates

^cCentre for Advanced Electronics & Photovoltaic Engineering, International Islamic University, Islamabad 44000, Pakistan

^dDepartment of Physics, Myongji University, Gyeonggi-do 17058, Republic of Korea

**Corresponding author's e-mail: cchoi@hanyang.ac.kr*

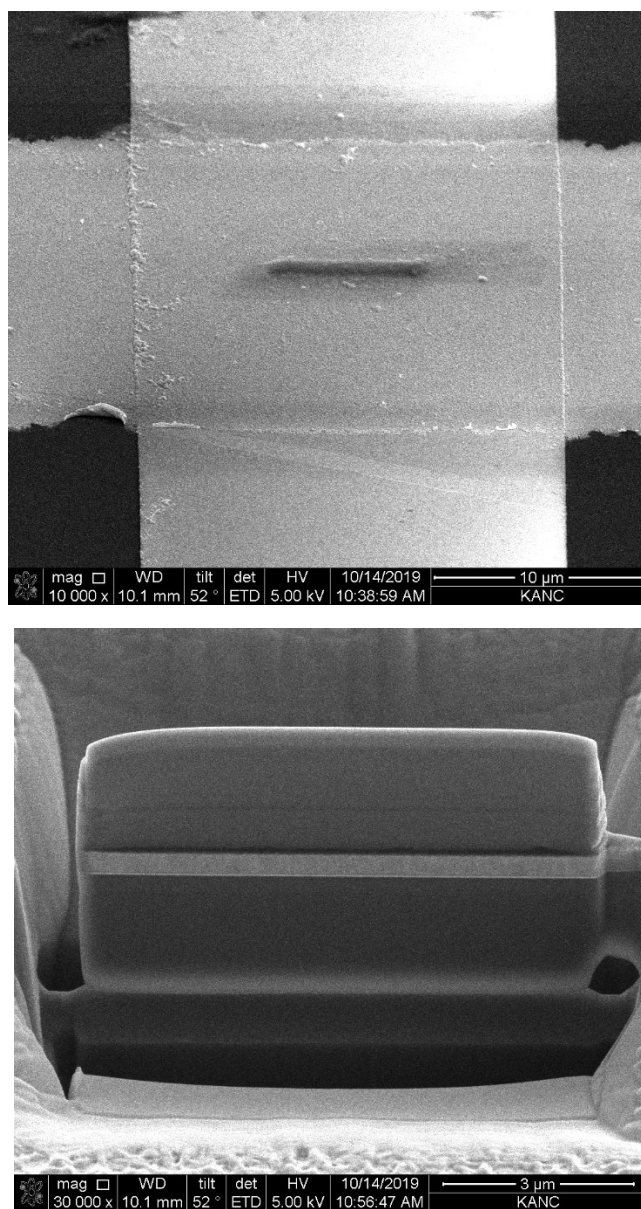


Figure S1. The SEM images of the crosspoint used for TEM analyses. The TEM sample was prepared via FIB at the center of a crosspoint.

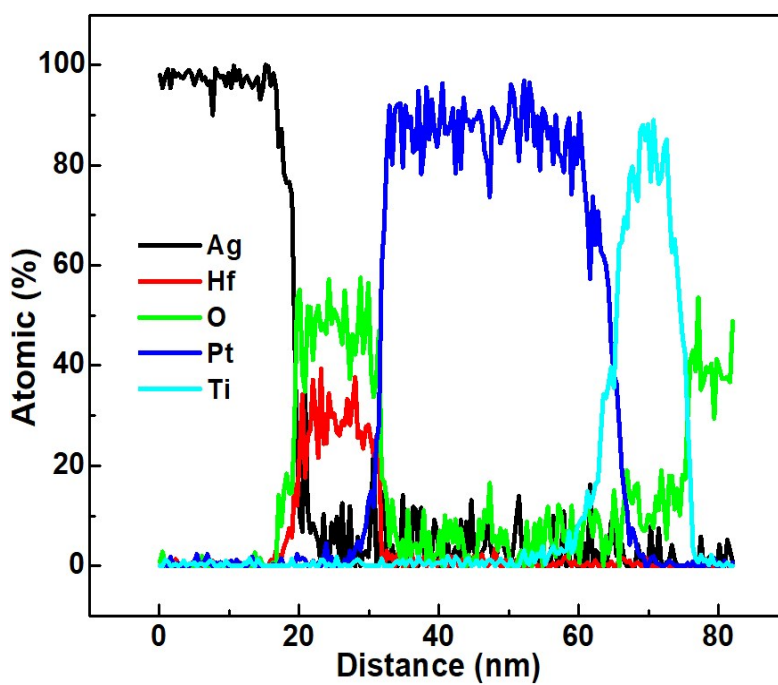
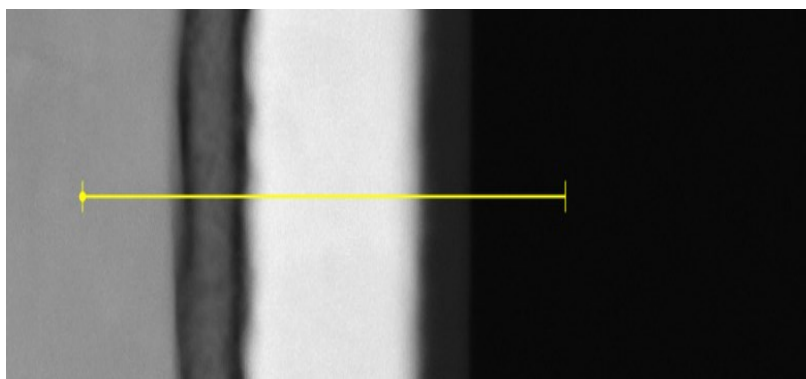


Figure S2. The elemental line EDS of the device carried out across the device at the indicated yellow line.

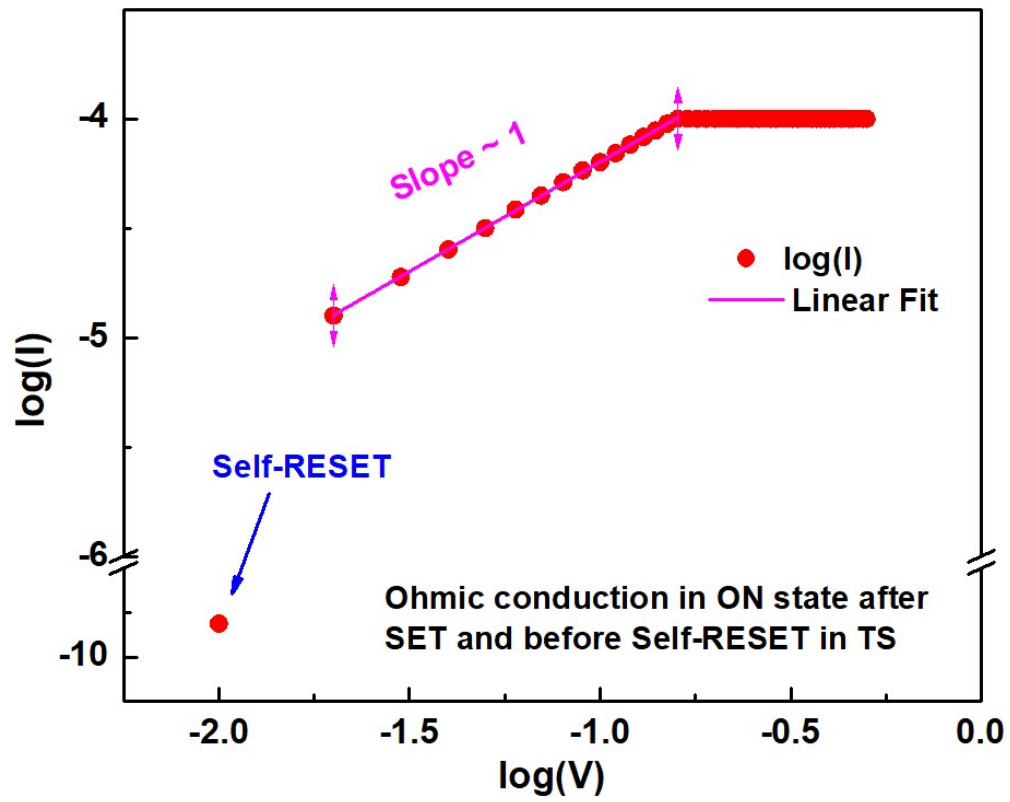


Figure S3. The $\log I$ - $\log V$ plot of the ON state in threshold switching.

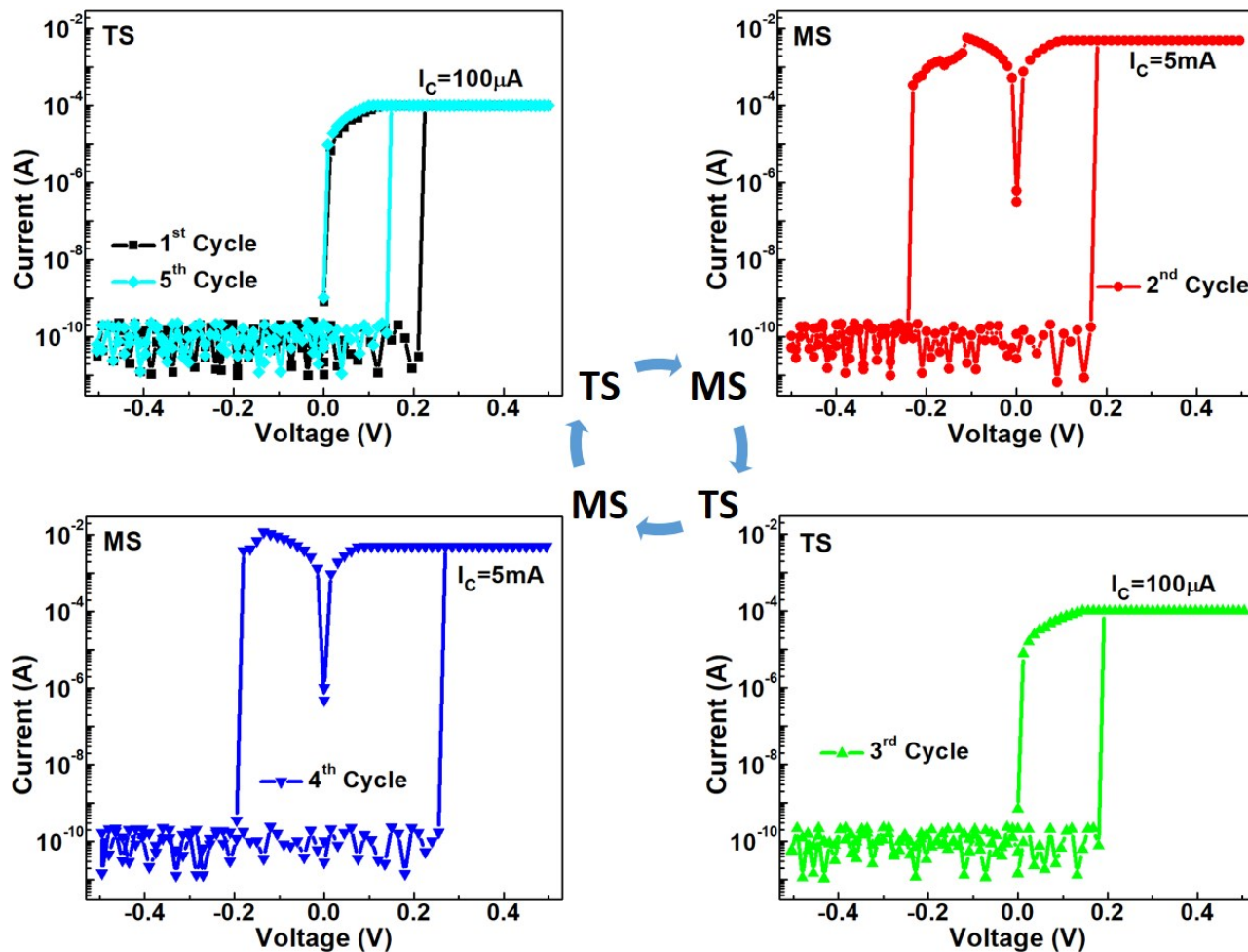


Figure S4. The Typical I-V characteristics of the device exhibiting the reversible transition and the coexistence of volatile TS and non-volatile MS behaviors. The device presented TS behaviors when operated with low I_C ($100 \mu\text{A}$), whereas, MS switching characteristics were observed at higher I_C (5 mA).

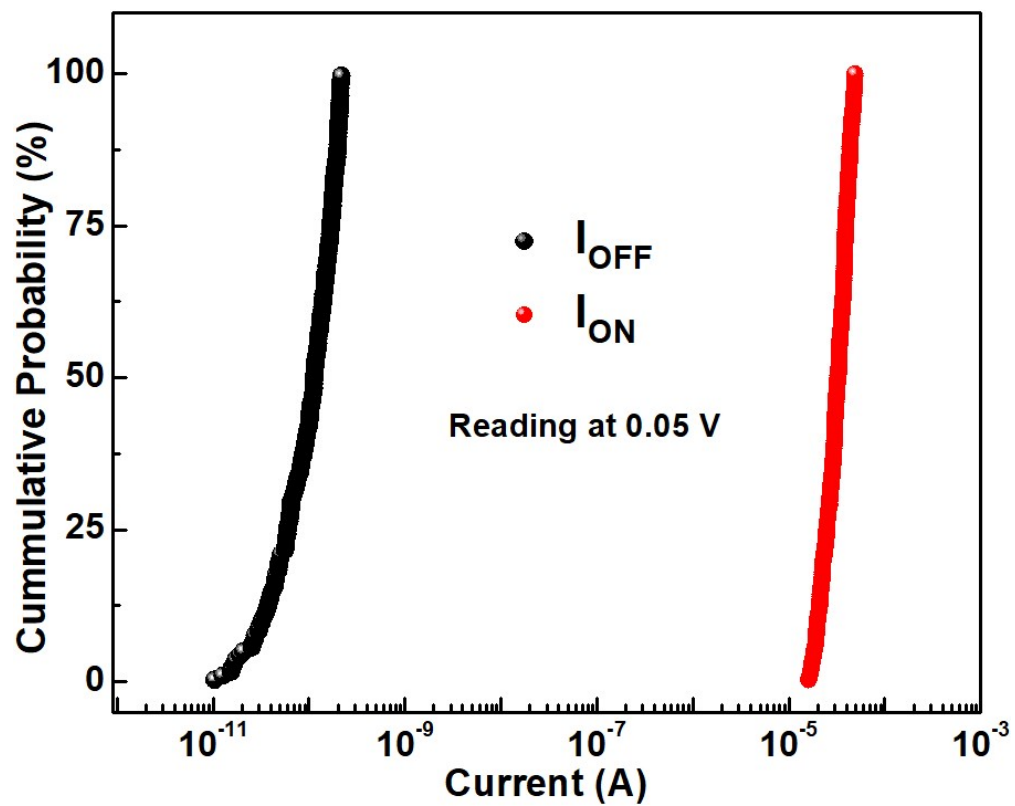


Figure S5. The cumulative probability plot of the OFF and ON currents for 300 repeated cycles in threshold switching.

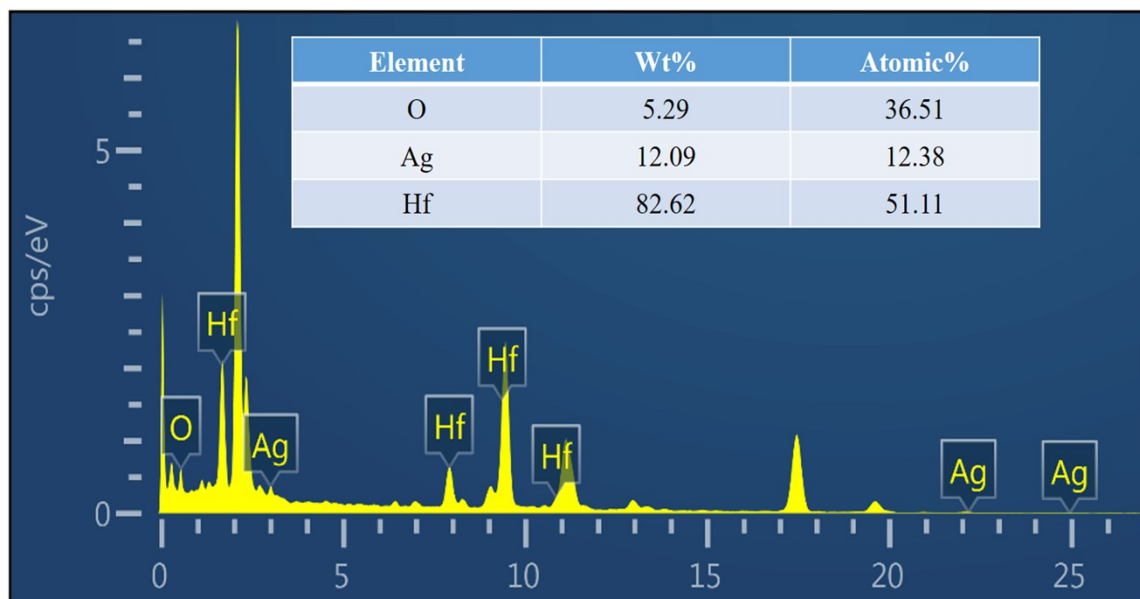


Figure S6. The EDS analysis carried out in the center of the CF region. The EDs confirms the presence of Ag in the CF.

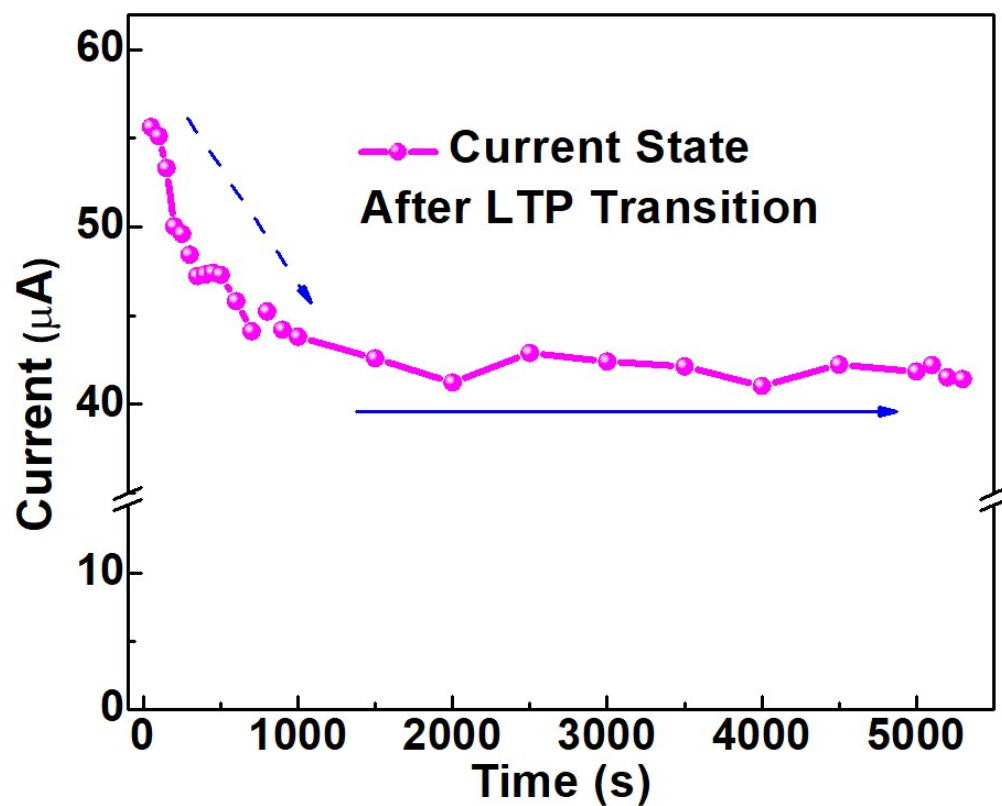


Figure S7. The longer time retention after application of 30 pulses (LTP transition). Negligible degradation in ON state is observed after the LTP transition.

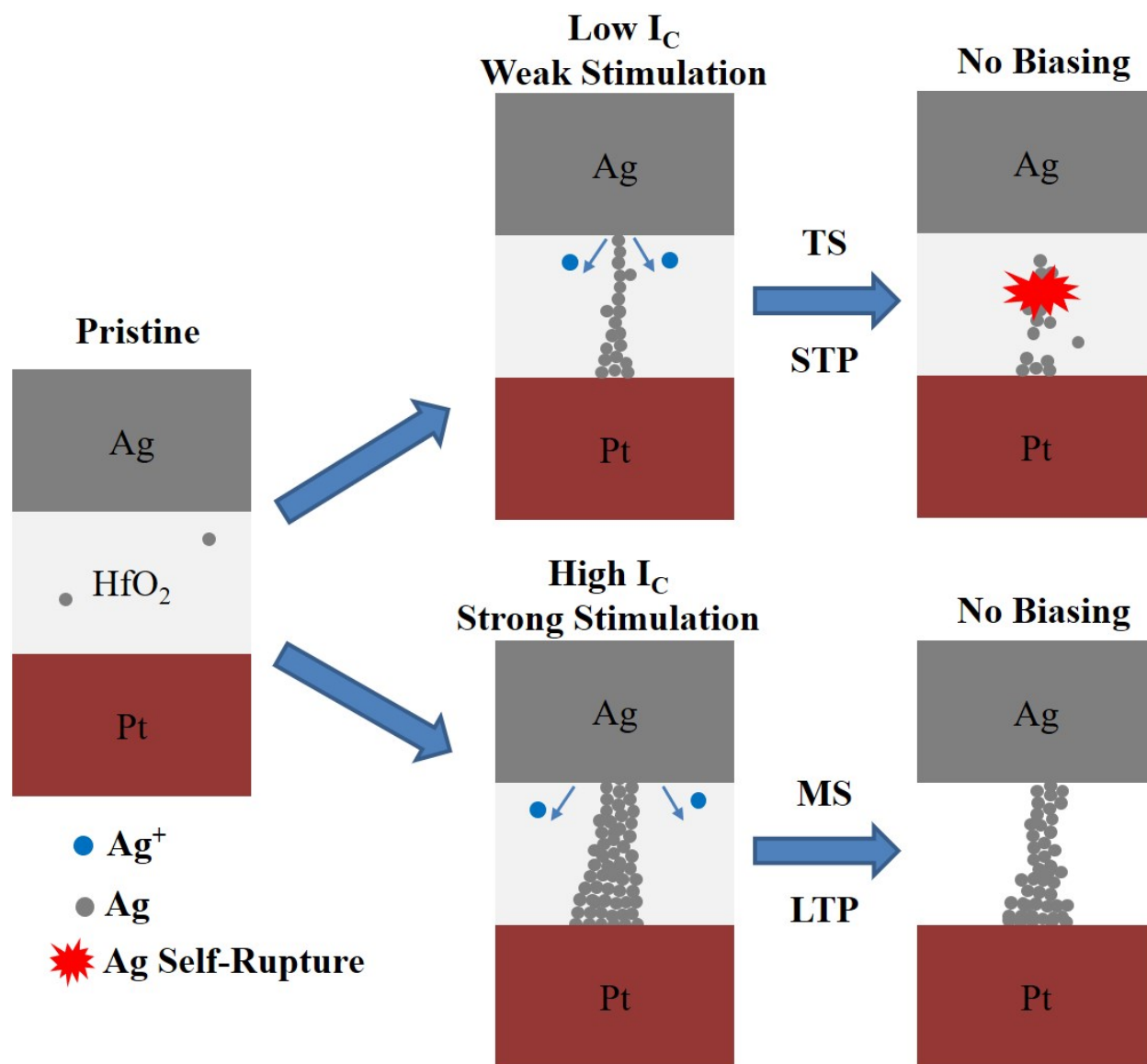


Figure S8. The schematic illustration of the switching mechanism. The device operated with low I_c or weak pulses results in the formation of a weak CF providing volatile TS or STP behavior whereas, high I_c operation or strong pulse stimulations form a thick CF providing nonvolatile MS or LTP behavior.

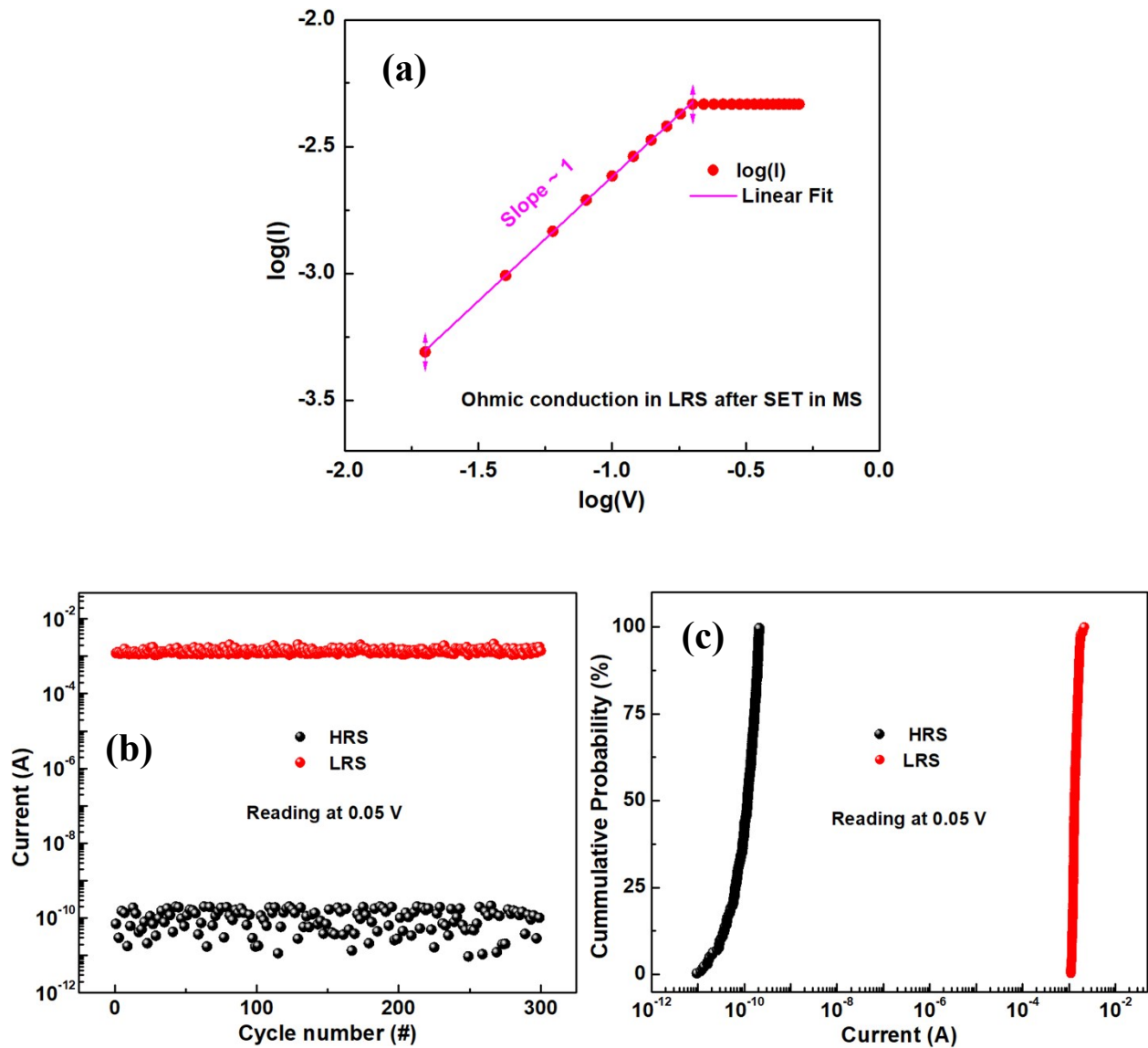


Figure S9. (a) The $\log I$ - $\log V$ plot of the LRS in memory switching. (b) The DC endurance characteristics of the device. (b) The cumulative probability plot of HRS and LRS for 300 repeated cycles.