# Model-Assisted Analysis of Intermediate Resistive State Switching in Wafer-Scale Vertical $MoS_2$ Memristive Devices

M. Buttberg[(1,2)], Y. Fa[(3)], S. Menzel[(4)], and M. C. Lemme[(1,3)]

[(1)] Chair of Electronic Devices (ELD), RWTH Aachen University, Aachen, Germany
[(2)] Institute of Materials in Electrical Engineering 2 (IWE2), RWTH Aachen University, Aachen, Germany
[(3)] AMO GmbH, Advanced Microelectronic Center Aachen, Aachen, Germany
[(4)] Peter Grünberg Institute 7 (PGI 7) and JARA-FIT, Forschungszentrum Jülich GmbH, Jülich, Germany

Wafer-scale Ag/2D-$MoS_2$/Pd memristors based on MOCVD-grown multilayer $MoS_2$ exhibit volatile and nonvolatile switching and show a robust intermediate resistive state (IRS) across the wafer. While the experiments reveal stable IRS behavior, set and reset voltages within $\pm 1$ V, endurance beyond 2500 cycles, retention exceeding $10^6$ s, and a yield of 98%, the origin of the IRS and its transition to the low resistive state (LRS) requires a mechanistic interpretation beyond purely electrical characterization. In this work, we therefore focus on model-assisted analysis of the switching dynamics. Two complementary electrochemical metallization (ECM) modeling approaches were applied to the measured current-voltage characteristics: an established 1D compact model and a 2D axisymmetric continuum model. The 1D model includes interfacial redox reactions, ionic hopping transport, tunneling current, and vertical filament growth with constant radius. It reproduces the transition from the high resistive state to the IRS, but fails to capture the subsequent IRS $\leftrightarrow$ LRS switching because the filament reaches a minimum gap and further resistance reduction is suppressed. In contrast, the 2D continuum model additionally includes arbitrary conductive filament growth, active electrode dissolution, tunnel-barrier heating, and mechanically induced stress. This approach reproduces the gradual IRS $\leftrightarrow$ LRS characteristics and explains the experimentally observed variability through physically motivated side growth. The simulations support a switching picture in which a vertical remnant filament first stabilizes the IRS, followed by lateral Ag filament growth along van der Waals gaps in layered $MoS_2$, which drives the transition toward the LRS. The combined experimental and simulation results thus identify anisotropic filament growth in a layered material system as the key mechanism governing multistate switching and synaptic functionality in these vertical memristive devices.

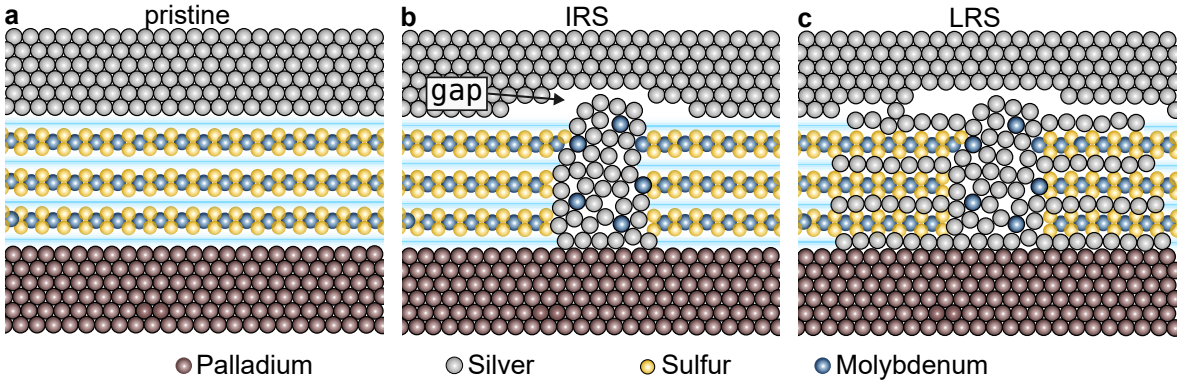


Figure 1: Schematic illustration of the 2D-$MoS_2$ ECM device in (a) pristine HRS, (b) IRS and (c) LRS. Adapted from [1], licensed under CC BY 4.0.

# References

[1] Y. Fa et al., Adv. Funct. Mater., 0, e26682, 2025.

[2] R. W. Ahmad et al., Neuromorph. Comput. Eng., 4, 034007, 2024.

[3] M. Buttberg et al., Adv. Mater. Technol., 11(1), e00837, 2025.