Area-dependent switching in IGZO/WO_x memristive devices: band alignment and M-CNN applications

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The reversible modulation of electrical resistance in metal oxides via electrically induced redox processes has attracted significant interest for applications in non-volatile data storage and neuromorphic computing [1]. Conventional metal-insulator-metal memristive devices typically operate via filamentary type switching, which requires an abrupt and stochastic electroforming process to create a conductive filament, thereby limiting their suitability for analog computing. In contrast, area-dependent switching devices lack local positive feedback driven by inhomogeneous Joule heating during the SET process, leading to switching across the entire device area [2]. As a result, they show gradual switching behavior, enabling more effective emulation of synaptic functionality in neural networks [3,4].

In this work, we investigate area-dependent resistive switching in W/WO_x/IGZO/Ti/Au devices. The full device stack can be fabricated at room temperature without high temperature processing, ensuring CMOS BEOL-compatibility. The devices exhibit gradual switching behavior and clearly distinguishable multilevel resistance states. Long term potentiation/depression measurements further demonstrate their potential for neuromorphic applications.

To understand the underlying switching mechanism, energy band diagrams are analyzed using numerical simulations, enabling identification of the dominant switching interface. The simulated band alignment is validated by in situ XPS band alignment at the WO_x/IGZO interface. Based on the extracted band profiles, the measured *I-V* characteristics are quantitatively described using the Tsu–Esaki tunneling model, explicitly accounting for the quasi-Fermi level distribution. The fittings of the experimental *I-V* relations show excellent agreement with both the experimentally determined band alignments from XPS and established literature values.

Finally, the applicability of these devices is evaluated in the context of the memristive device-based cellular nonlinear network (M-CNN) [5]. A simulation approach based on measured *I-V* characteristics is developed to assess device–circuit interactions. A symmetrized cell design is proposed to address limitations arising from asymmetric *I-V* characteristics, enabling controlled cell voltage and differential readout. The results demonstrate that gradual switching allows reliable mapping of input current levels while ensuring stable operation and reduced power consumption, highlighting the suitability of robust IGZO-based M-CNN implementations.

[1] D. Christensen et al., Neuromorp. Comput. Eng., 2(2), 022501, 2022

[2] R. Dittmann et al., Adv. Phys., 70(2), 155-349, 2021

[3] A. Gutsche et al., Front. Neurosci., 15, 661261, 2021

[4] M. Pereira et al., Adv. Electron. Mater., 6(10), 2000242, 2020

[5] Y. Wang et al., IEEE Trans. Nanotechnol., 24, 121–128, 2025