Two-Dimensional Semiconductor Nanoribbons for Neuromorphic Computing

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Engineering novel memory architectures is essential to the advancement of energy-efficient compact neuromorphic hardware [1]. In this work, we investigate that channel width scaling of tungsten disulfide (WS_2) nanoribbon transistors down to sub-100 nm to 10-nm shows dynamic analog memristive switching and tunable synaptic operations at room temperature [2]. The memtransistors exhibit filament-free reproducible switching with wide memory windows, stable endurance cycles, and bias-dependent multi-level conductance states. The voltage-driven migration of edge sulfur atoms provides a physically plausible microscopic mechanism for the observed memtransistive switching behavior. The nudged elastic band calculations demonstrate that sulfur migration is energetically more favorable at the W-edge than in the interior region of the WS_2 nanoribbon to form S–S dimers under an applied electric field. Beyond memory, the memtransistors emulate key neuromorphic behaviors, including short-term to long-term memory transitions, frequency-dependent learning, and controllable potentiation-depression, closely reflecting biological synaptic dynamics. By utilizing the gate terminal as a modulatory neuron, the devices further achieve heterosynaptic plasticity, Pavlov's associative learning, reliable multi-bit encoding and reservoir computing. These findings highlight the significance of ultra-scaled nanoribbon transistors for future in-memory computing architecture through miniaturized, multifunctional hardware.

References

[1] G. Indiveri and S.-C. Liu, "Memory and information processing in neuromorphic systems," Proc. IEEE, vol. 103, no. 8, pp. 1379–1397, Aug. 2015

[2] Md. A. Hoque, A. Y. Polyakpv, B. Munkhbat et al. "Ultranarrow Semiconductor WS_2 Nanoribbon Field-Effect Transistors," Nano Lett. 2025, 25, 5, 1750–1757.

Figures

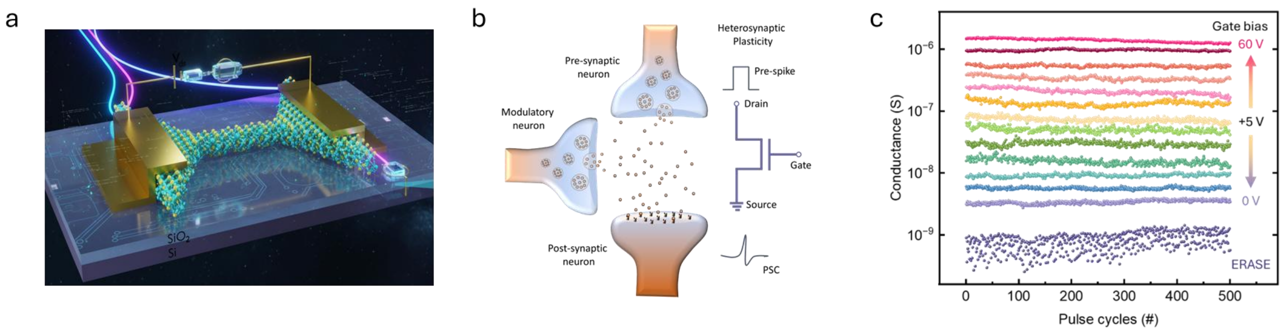

Figure 1: a Schematics of a WS_2 nanoribbon memtransistor. **b** illustration of the biological synapse and the memtransistor synaptic device, where alongside of drain/source terminals as pre/post synaptic neurons, gate can be used as an auxiliary modulatory neuron. **c** Conductance states recorded after each bias pulses under different gate bias conditions from 0 to 60 V. The above operations are carried out up to 500 cycles showing robust gate tunable heterosynaptic plasticity of nanoribbon memtransistors.