Ionic Relaxation–Driven Synaptic Behavior in 2D MXene-Based Neuromorphic FETs

Chen Yo Tsai,[1] Ming-Pei Lu,[2,*] and Ming-Yen Lu[1,3]
1. College of Semiconductor Research, National Tsing Hua University, Hsinchu, Taiwan
2. Taiwan Semiconductor Research Institute, National Institutes of Applied Research, Hsinchu, Taiwan
3. Department of Materials Science and Engineering, National Tsing Hua University, Hsinchu, Taiwan
**E-mail: mingpei.lu@gmail.com*

Two-dimensional (2D) van der Waals heterostructures have emerged as a promising platform for emulating biological synapses, offering a feasible route toward computing-in-memory (CIM) architectures to overcome the memory wall bottleneck inherent in the von Neumann architecture.[1,2] This work elucidates the ionic relaxation dynamics within 2D MXene Ti_3C_2 used as floating-gate in memory FETs, specifically investigating the impact of alkali cation species (Li^+,Na^+,K^+) on 2D floating gates, as shown in **Figure 1(a).**
In-situ Kelvin Probe Force Microscopy (KPFM) under varying DC biases provided direct visualization of surface potential shifts, confirming the out-of-plane migration of cations within the MXene lattice, as shown in **Figure 1(b)**. These experimental findings will further be supported by Scanning Transmission Electron Microscopy (STEM) and Density Functional Theory (DFT) calculations, which reveal the minimum energy pathways for out-of-plane ion transport. Electrically, the memory FETs successfully emulate essential synaptic functions, including excitatory postsynaptic currents (EPSC) and paired-pulse facilitation (PPF).
A finding, shown in **Figure 1(c),** is the relationship between ion mobility and synaptic learning efficiency. Although Li^+ exhibits superior transport kinetics and reduced steric hindrance, Na^+-intercalated devices demonstrated the most robust long-term potentiation (LTP). We attribute this enhanced performance to the slower ion relaxation kinetics of Na^+, which effectively suppress the rapid dissipation of programmed states observed in Li^+-based counterparts. These results highlight that enhancing carrier mobility alone is insufficient for optimized synaptic emulation, emphasizing the critical role of ion-species-dependent relaxation dynamics in the design of non-volatile neuromorphic electronics.

References

[1] Yu, Jinran, et al. " *Science Advances* 7.12 (2021): eabd9117.
[2] Sahu, Mousam Charan, et al. *Advanced Materials Technologies* 8.2 (2023): 2201125.

Figures

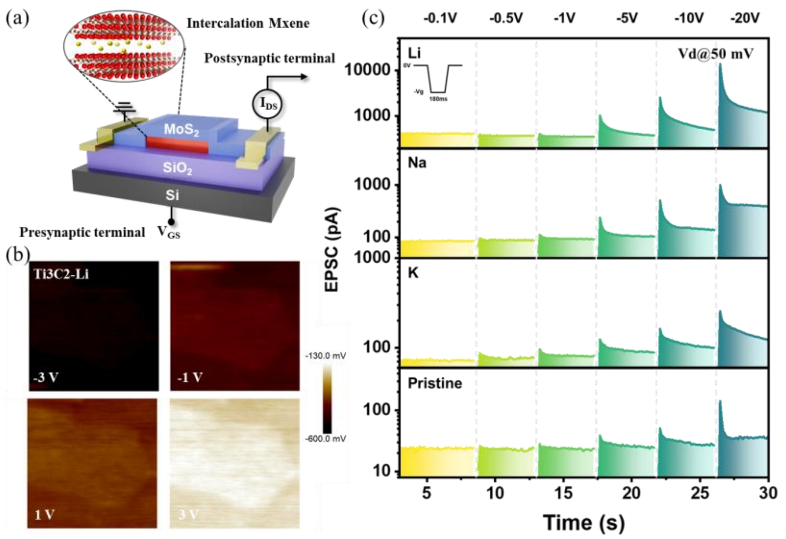

Figure 1: (a) Schematic illumination of the MoS_2/Ti_3C_2 heterojunction. (b) In-situ KPFM employed to visualize potential shifts and out-of-plane ion kinetics within the MXene lattice. (c) Transient current recorded under a 50 mV bias, highlighting the dynamic response to ionic-driven processes.