Ion Migration Studies in Exfoliated 2D Molybdenum Oxide via Ionic Liquid Gating for Neuromorphic Device Applications

In this study, MoO_3 devices were exfoliated and successfully metalized by applying bias voltage through two different ILs where the I_d enhanced by 9 orders of magnitude. Metallization can be realized by sweeping gate voltages in a number of cycles, or applying a fixed bias over time. This process is reversible as the devices can be tuned back to an insulator by applying negative bias. We attribute this controllable electrical property change to the migration of oxygen and lithium ions for the groups using normal IL gating and lithium IL gating, respectively. The migration of lithium is much faster than oxygen, and thus the current modulation occurs much faster. ToF-SIMS result confirms the control of the ion migration in gating process. Results of short-pulse tests also illustrate the synaptic plasticity for neuromorphic computing elements. Some key figures with captions are shown below.

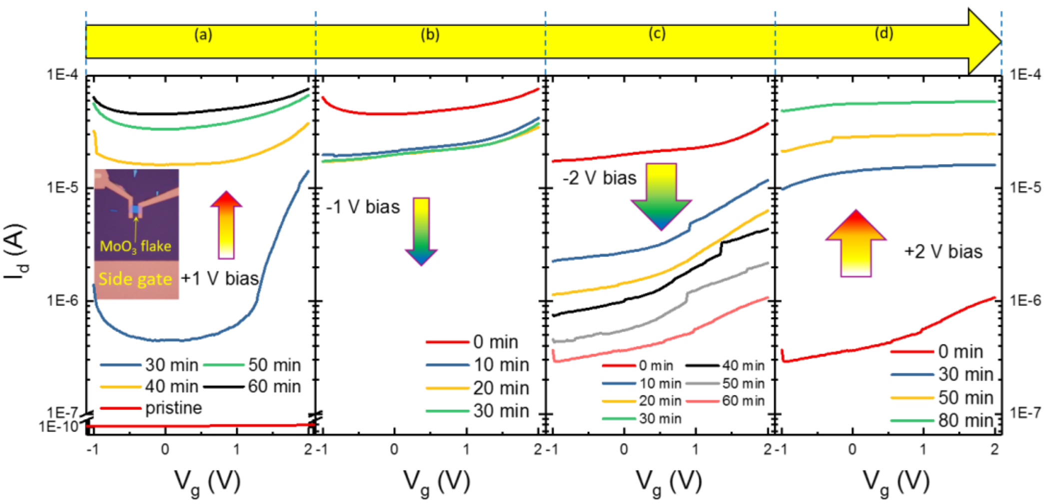

Figure 2. Metallization of a typical MoO_3 device through IL bias over time. The insulator-to-metal transition is reversible and the transfer curves measured at each gate voltage/time increment are shown from left to right: +1 V IL bias for up to 60 min (a), -1 V bias for up to 30 min (b), -2 V bias for up to 60 min (c) and +2 V bias for up to 80 min (d). The original off-to-on current ratio of the I_d is ~ 10^6 and the reversible switching range was from ~ 60 μA to 300 nA. All measurements were conducted with V_{sd} = 1 V. An optical micrograph of a MoO_3 side gate device is shown as an inset in (a).

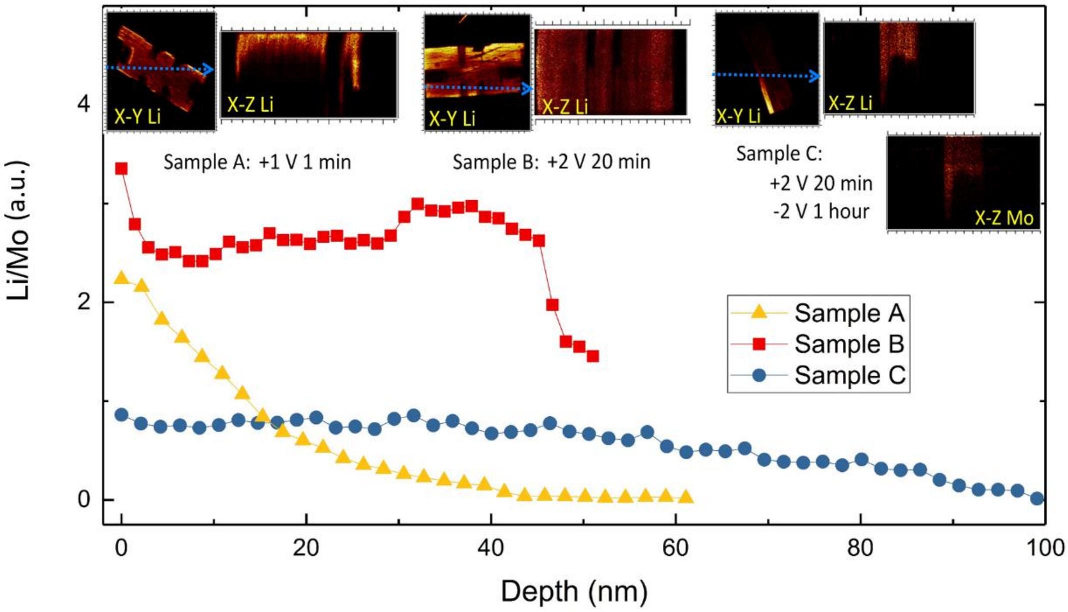

Figure 5. Quantitative analysis of the Li distribution along the depth of three devices after different LIL biasing process. Sample A was partially charged at +1 V for 1 minute; Sample B was charged at +2 V for 20 minutes; Sample C was initially charged at +2 V for 20 minutes, and then Li was extracted via a-2 V for 1 hour. The Li/Mo atom ratios was obtained from the intensity of 3D ion mapping images using ToF-SIMS. Thickness of Sample A, B and C is approximately 60 nm, 50 nm and 100 nm, respectively. Sample A is the same device presented in Fig. 4, with Li highly concentrated at the top surface of the sample. While other two devices exhibit comparatively uniform Li distribution along depth.

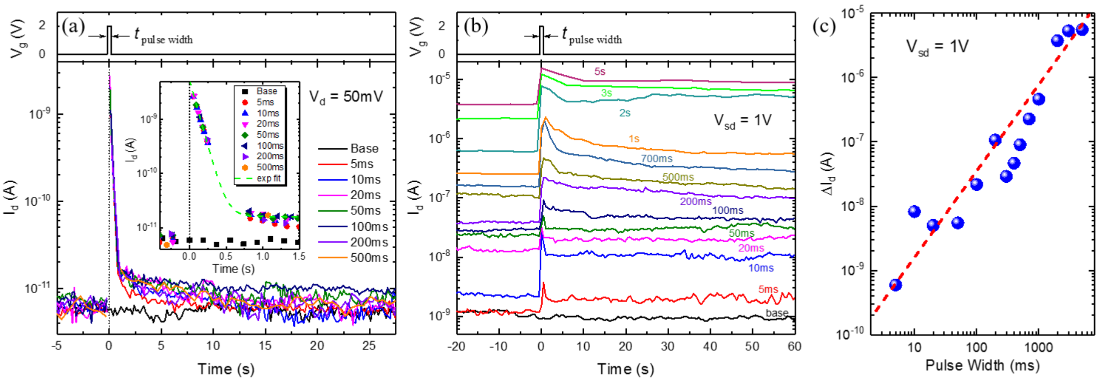

Figure 6. LIL short pulse measurement results under drain voltage of (a) 50 mV and (b) 1 V. 2V pulses through LIL side gate were applied on MoO_3 devices sequentially with increasing pulse widths. With V_{sd} = 50 mV drain voltage drain current increases instantly with the pulse and quickly decays; with an increased V_{sd} at 1 V, post-pulse drain current saturates at a higher compare to that measured before the pulse, leading to a long term change similar to a biological synaptic system. Inset in (a) zooms in a short time region near pulses, I_d after different pulses follows the same exponential decay. (c) plots the I_d incensement as the function of pulse width with V_d at 1 V, where $\Delta I_d = I_{d|t = 20s} - I_{d|t = -20s}$.