Electronic Supplementary Information

Optical Readout of Charge Carriers Stored in a 2D Memory Cell of Monolayer WSe_2

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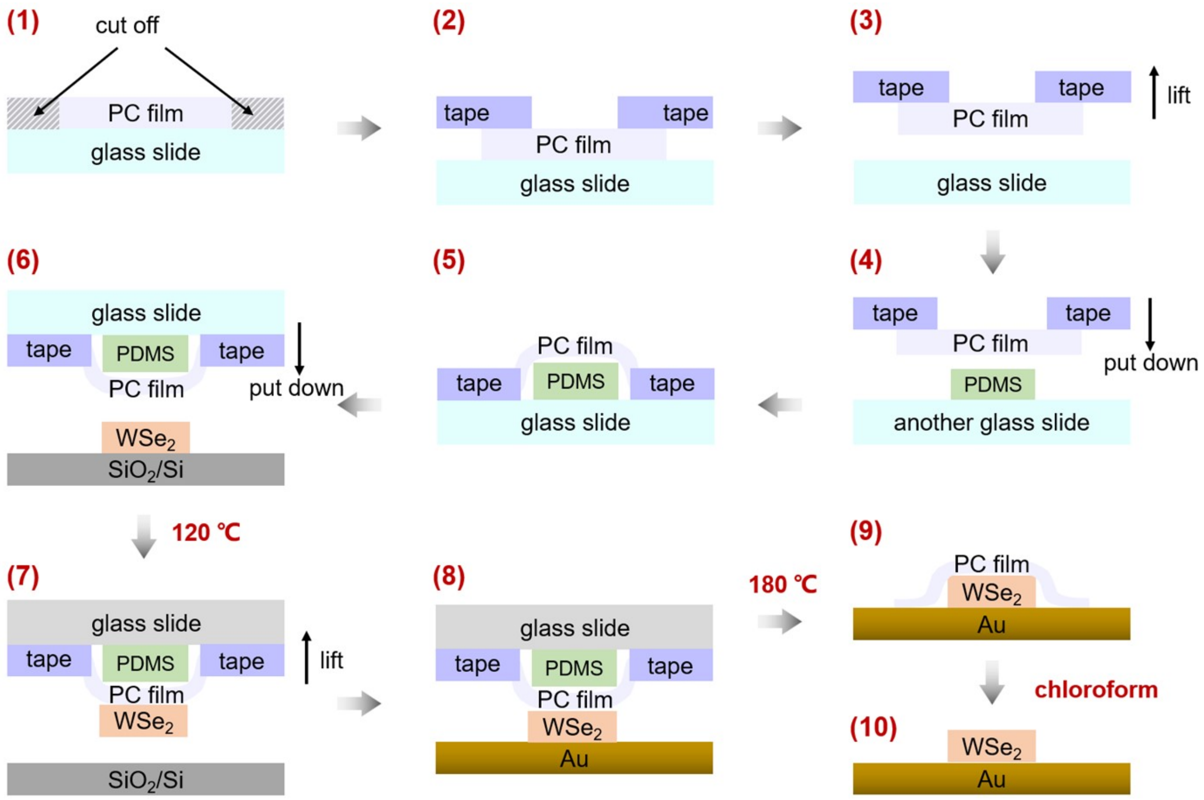

Fig. S1 Schematic diagram for the fabrication process of a 2D WSe_2 memory cell (see detailed descriptions in the sample preparations section of the main text). Of special note is that the PDMS film used here is pre-cleaned by plasmas to increase the surface viscosity, so that it can be tightly attached to the PC film for the eventual obtainment of a wrinkle-free WSe_2 monolayer. In the plasma-cleaning process, the glass substrate with a PDMS film on top was first placed inside a reaction cavity, which was then pumped to the vacuum with a pressure value of 100 pa. Under the continuous O_2 flow at the speed of 50 mL/min, the plasma generator was started to create a high-voltage AC (alternate-current) field between the two electrodes of the reaction cavity. This electric field could accelerate the free electrons to a high energy, which was sufficient to excite the O_2 molecules for the generation of plasmas. During the 3-5 s cleaning time, the high-energy plasmas reacted with the organic contaminants or collided with the micro-sized particles on the PDMS surface to yield various volatile materials. These volatile materials would be pumped out of the cavity together with the O_2 flow, leaving behind a PDMS film with the high surface cleanness and activity.

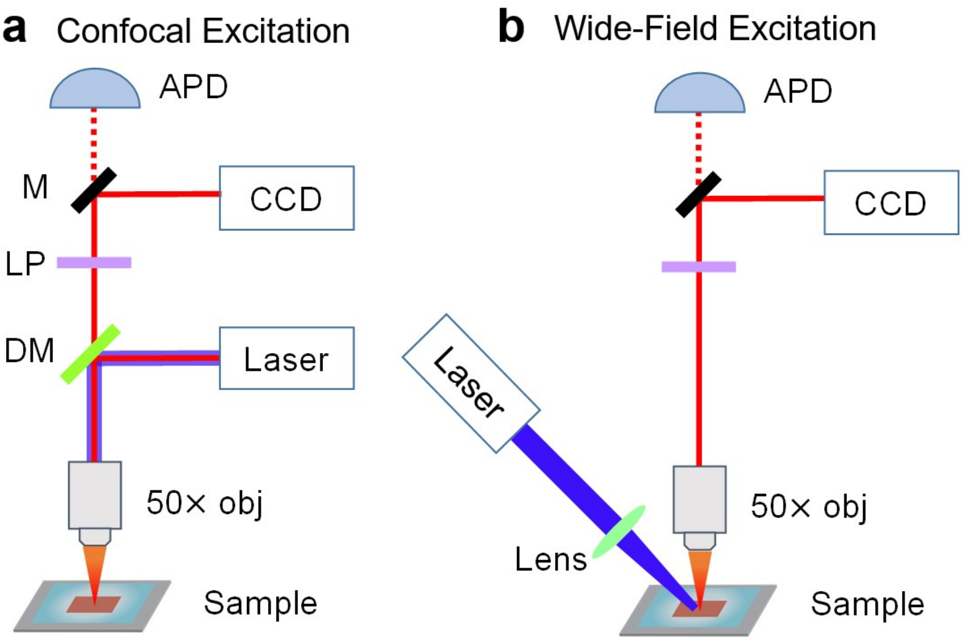

Fig. S2 Schematic diagrams for the optical measurements of 2D WSe_2 memory cells using the (a) confocal and (b) wide-field setups (see detailed descriptions in the optical measurements section of the main text). APD: avalanche photodetector; M: mirror; CCD: charge-coupled device; LP: long-pass filter; DM: dichroic mirror; obj: objective.

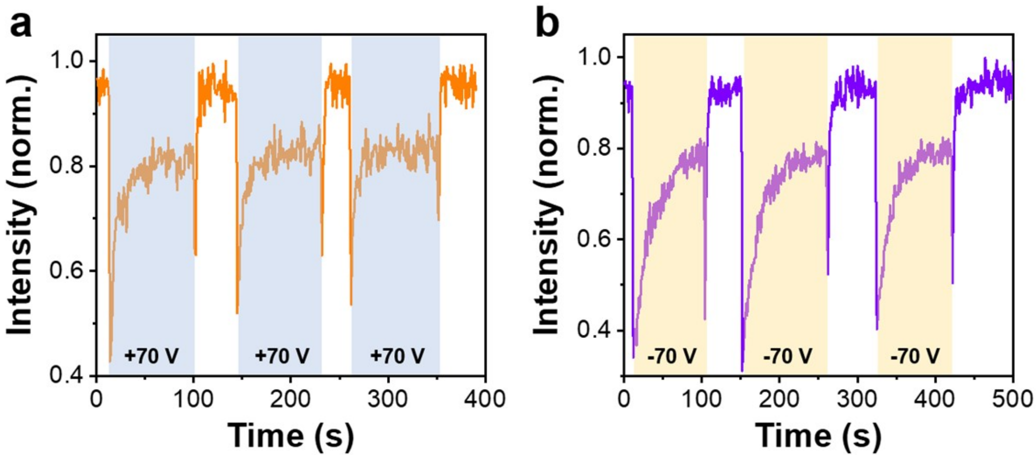

Fig. S3 Time-dependent PL intensities of WSe_2 measured when the external biases of (a) +70 V and (b) -70 V are first applied to and then removed from the electrode for several times. The PL intensity of WSe_2 stays at almost the same level when there is no external bias on the electrode, showing stable operation of the memory cell during the fast charging and discharging processes.

Positions	A_1	τ_1**(ns)**	A_2	τ_2**(ns)**
A	1.00	0.25		
B	0.77	0.43	0.23	1.45
C	0.85	0.16	0.15	0.92
D	0.80	0.40	0.20	1.43

Table S1 Fitting parameters for the PL decay curves of monolayer WSe_2. For position A, the PL decay curve is fitted by a single-exponential function of $A_1 e^{-t/\tau_1}$. For positions B-D, the PL decay curves are each fitted by a bi-exponential function of $A_1 e^{-t/\tau_1} + A_2 e^{-t/\tau_2}$.

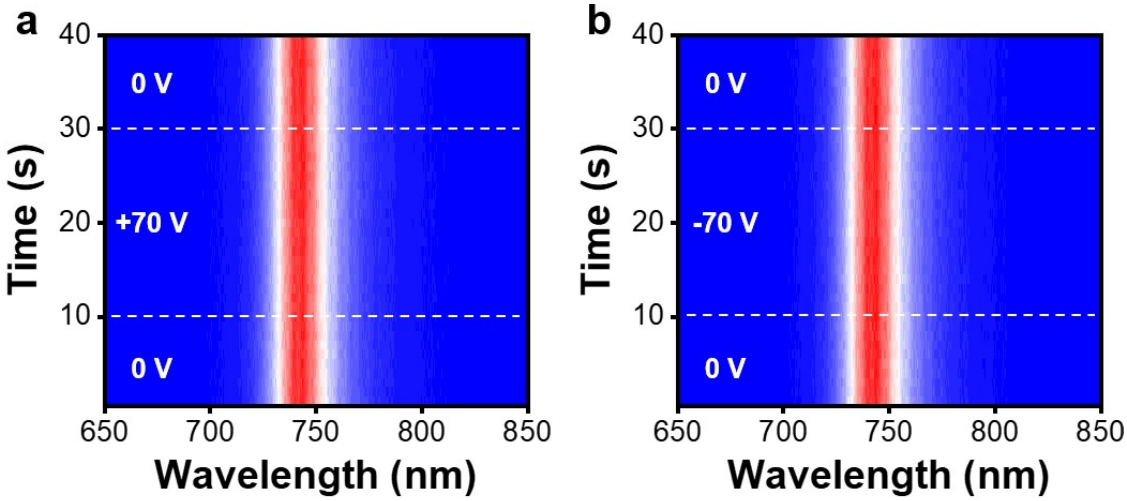

Fig. S4 Time-dependent PL spectral image measured for monolayer WSe_2 placed between two non-contacting electrodes. (a) A +70 V bias is applied to and then removed from the two electrodes at 10 and 30 s, respectively. (b) A -70 V bias is applied to and then removed from the two electrodes at 10 and 30 s, respectively.

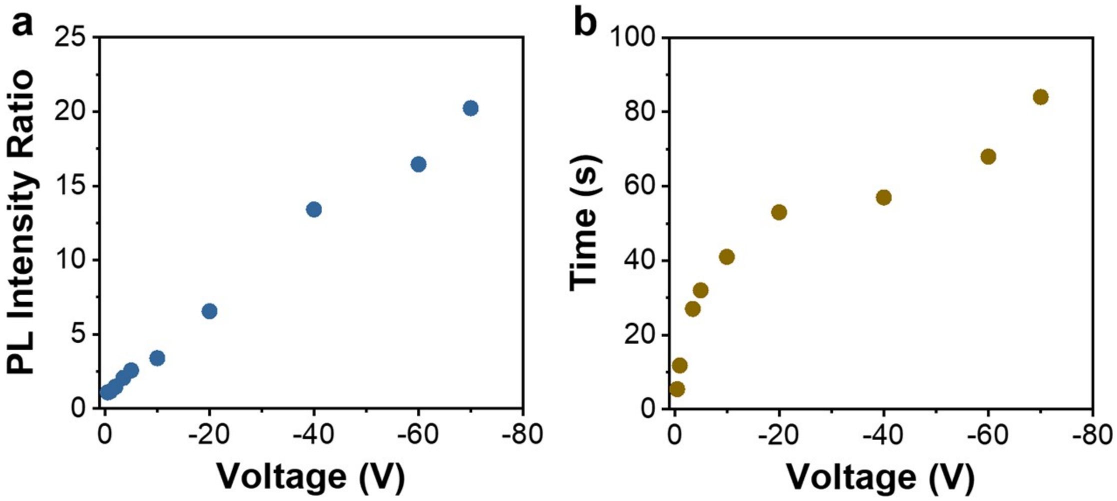

Fig. S5 (a) The ratio of WSe_2 PL intensities measured before and right after an external bias from -0.5 to -70 V has been applied to the electrode. A larger PL intensity ratio corresponds a more negatively-charged WSe_2 monolayer. (b) Electron retention time measured after an external bias from -0.5 to -70 V has been applied to the electrode.

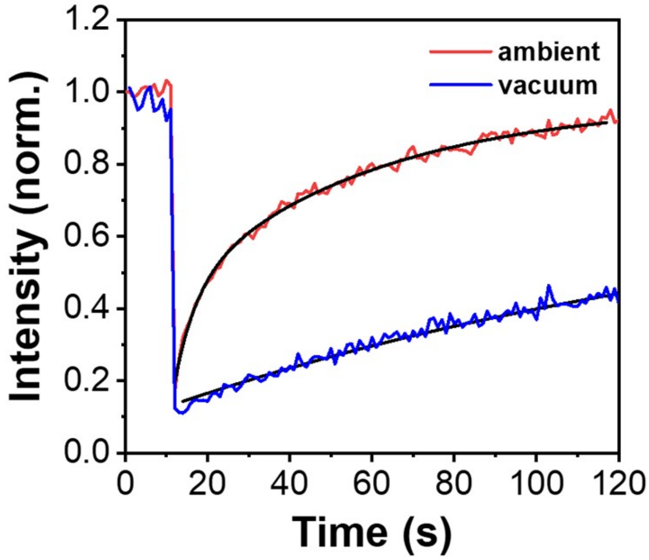

Fig. S6 Time-dependent PL intensities measured under the ambient and vacuum conditions for the same monolayer WSe_2 before and after an external bias of -10 V is applied to the electrode at 10 s, where the exponential fittings yield the electron retention times of ~27 and ~163 s, respectively. The above measurements are performed at room temperature, with the monolayer WSe_2 being excited at ~30 W/cm^2 by a pulsed 405 nm laser.

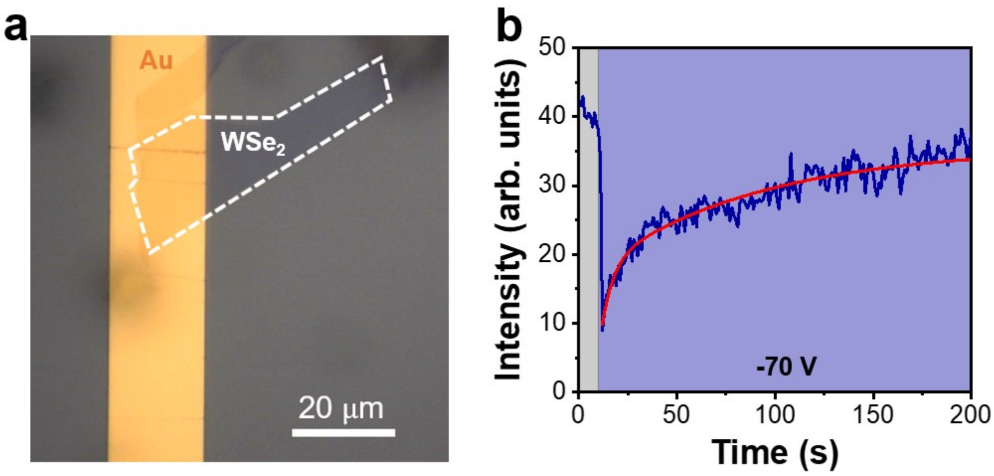

Fig. S7 (a) Optical image of a memory cell with only one electrode, above which a WSe_2 monolayer is partially deposited to serve as the channel material. (b) Time-dependent PL intensity measured at room temperature for monolayer WSe_2 before and after an external bias of -70 V is applied to the electrode at 10 s. The PL intensity rise curve measured during 10-200 s is exponentially fitted to yield an electron retention time of ~81 s.

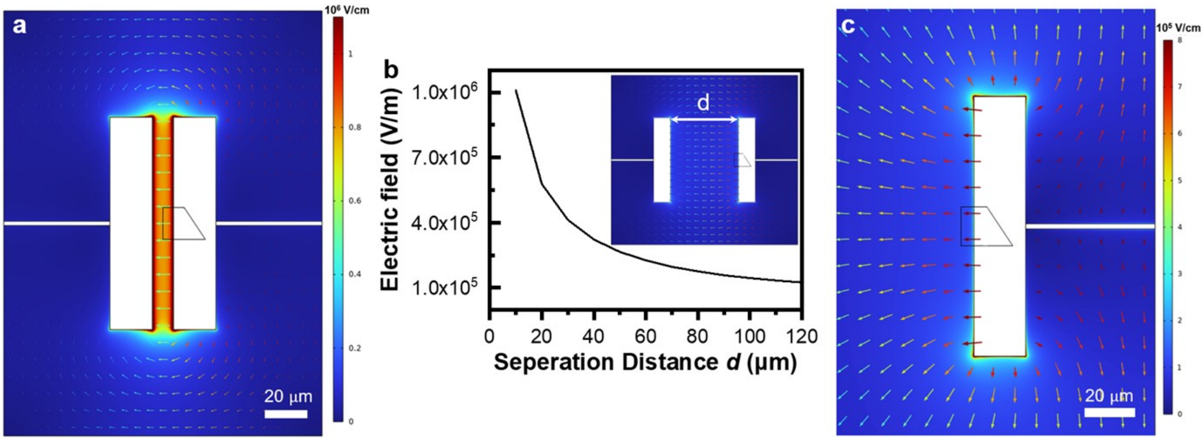

Fig. S8 (a) Simulated electric-field distribution around the two electrodes (white regions) being grounded (left) and biased at +10 V (right), respectively. The two electrodes are separated by 10 μm, and each of them has the width, length and thickness of 20 μm, 100 μm and 130 nm, respectively. The monolayer WSe_2 (black right-angled trapezoid) is deposited partially on top of the right electrode, while the average electric field estimated within its non-contacting area is ~1.00×10^6 V/m. (b) Average electric field simulated within the non-contacting area of monolayer WSe_2 as a function of the separation distance *d* between the two electrodes being grounded and biased at +10 V, respectively. Inset: Representative electric-field distribution simulated at *d* = 80 μm. According to these simulated results, the average electric field starts from ~10^6 V/m at *d* = 10 μm and decreases exponentially with the further increase of *d*. However, once *d* is larger than ~100 μm, this electric field would stay at almost a constant value of ~10^5 V/m. (c) Simulated electric-field distribution around the one electrode being biased at +10 V, with the grounded position being set at the source meter used in our experiment. The average electric field estimated within the non-contacting area of monolayer WSe_2 is ~1.46×10^5 V/m, which is confirmed by us to have the same charge injection efficiency as that of the ~10^6 V/m case (see Figure S7). The above simulations are performed by a finite-element method using the Comsol Multiphysics software.

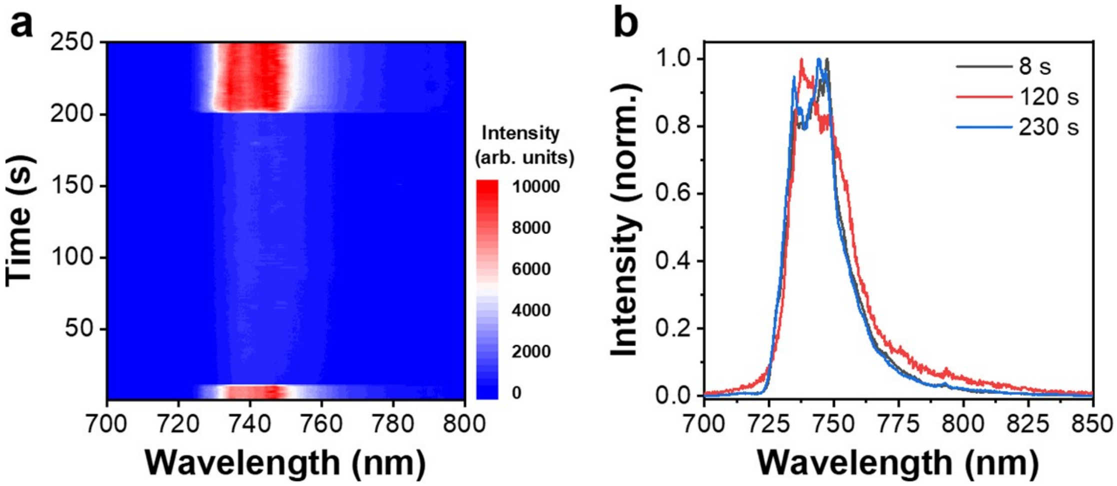

Fig. S9 (a) Time-dependent PL spectral image measured for monolayer WSe_2 at 4 K, wherein a -70 V bias is first applied to and then removed from the electrode at 10 and 200 s, respectively. (b) PL spectrum extracted from (a) at 120 s (solid red line), showing the emergence of a red-shifted component due to the more negatively-charged condition of monolayer WSe_2. For comparison, the PL spectra extracted from (a) at 8 (solid black line) and 230 s (solid blue line) are also provided, corresponding to the originally n-doped condition when no external bias is applied to the electrode.

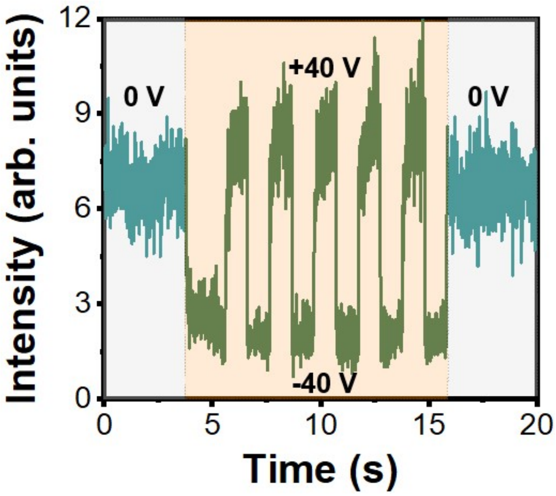

Fig. S10 Time-dependent PL intensity measured for monolayer WSe_2 under alternating applications of the ±40 V biases to the electrode.