Supplementary Information

Uniform self-rectifying resistive random access memory based on MXene-TiO_2 Schottky junction

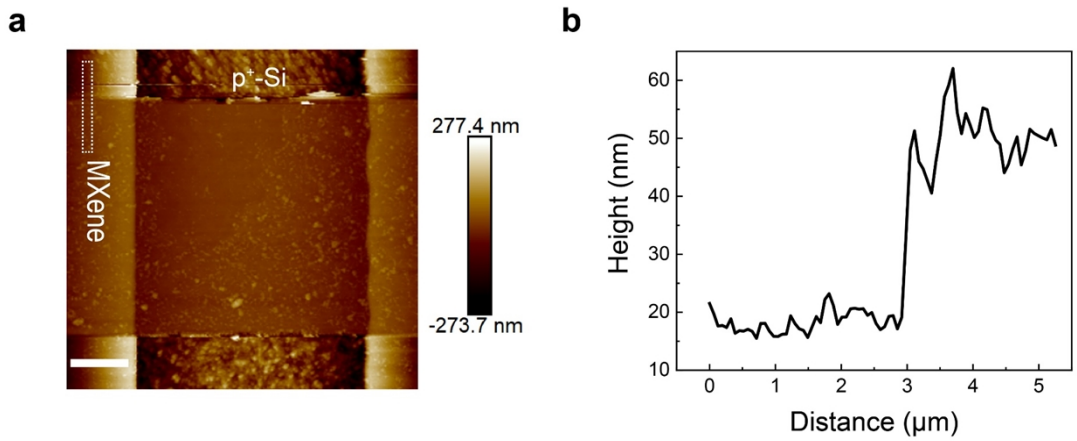
Chao Zang[1,2#], Bo Li[1,2#], Yun Sun[1*], Shun Feng[1,3], Xin-Zhe Wang[1,2], Xiaohui Wang[1,2*], Dong-Ming Sun[1,2*]

[1]Shenyang National Laboratory for Materials Science, Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang, 110016, China.

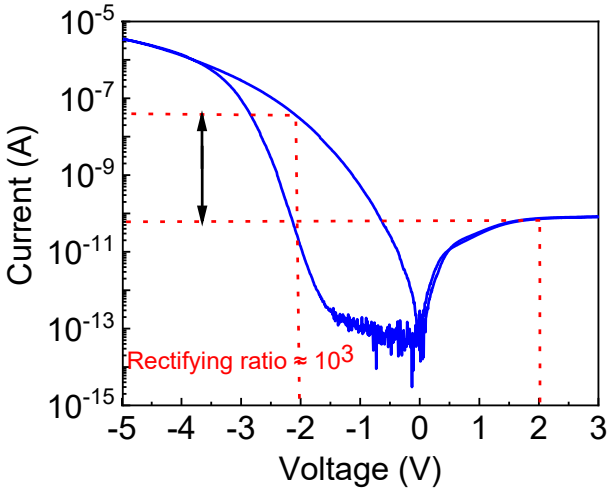
[2]School of Material Science and Engineering, University of Science and Technology of China, 72 Wenhua Road, Shenyang, 110016, China.

[3]School of Physical Science and Technology, ShanghaiTech University, 393 Huaxiazhong Road, Shanghai, 200031, China.

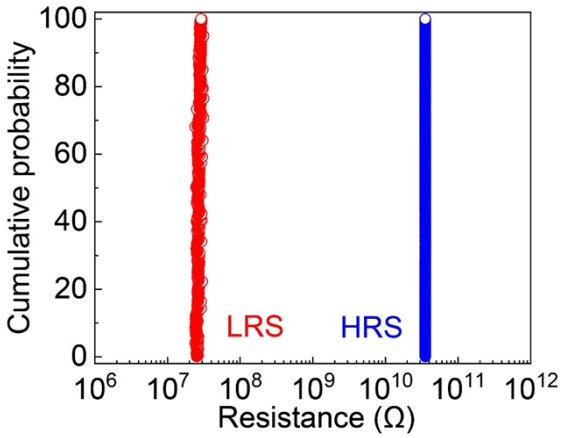
[#]These authors were equal major contributors to this work.



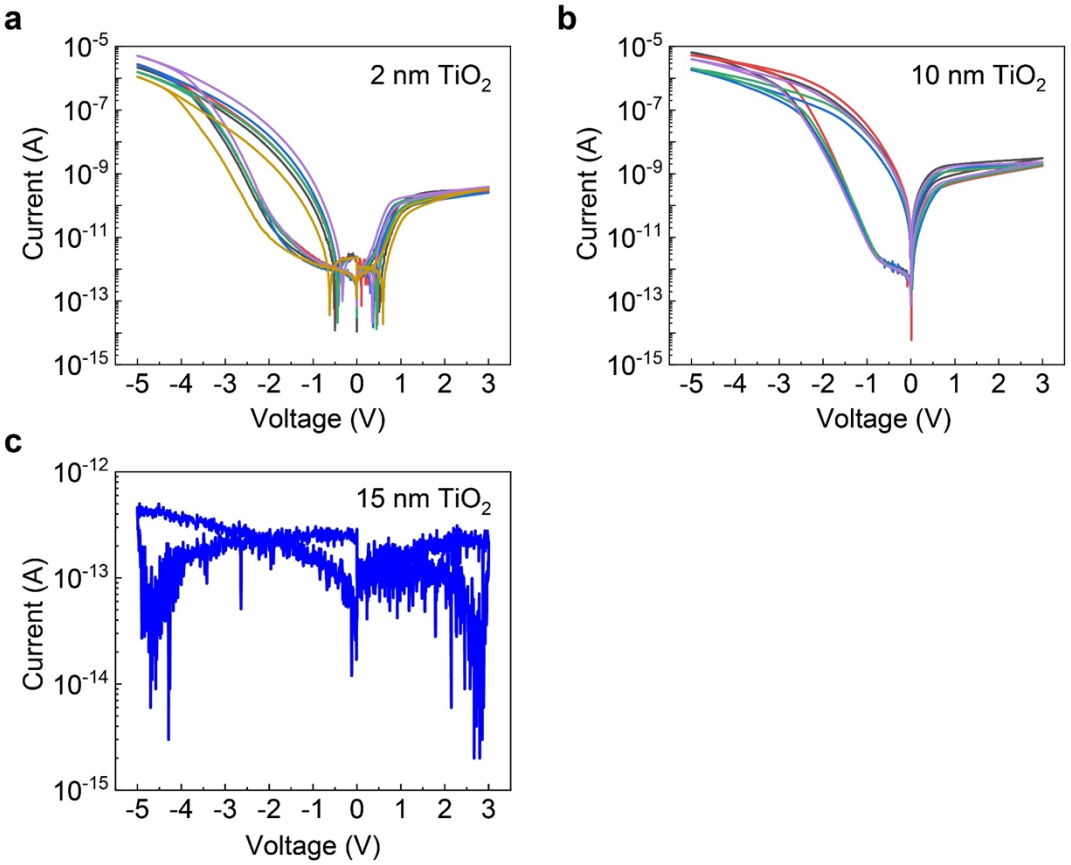
Supplementary Fig. 1 (a) AFM image of the morphology of MXene film. Scale bar, 2 μm. (b) Height profile along the white dashed line in (a), indicating a thickness of 25 nm MXene.



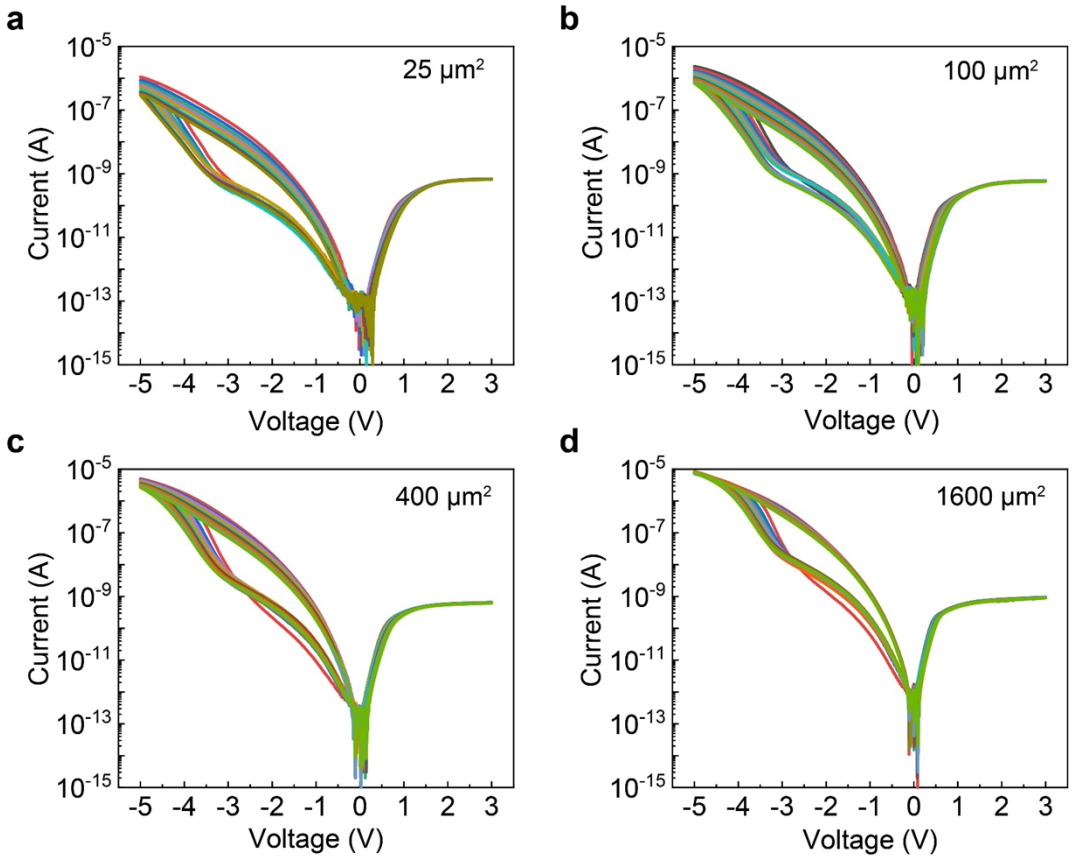
Supplementary Fig. 2 Typical *I-V* characteristic of an MXene-TiO_2-Si RRAM with a rectifying ratio of 10^3 obtained at 2 V and -2 V.



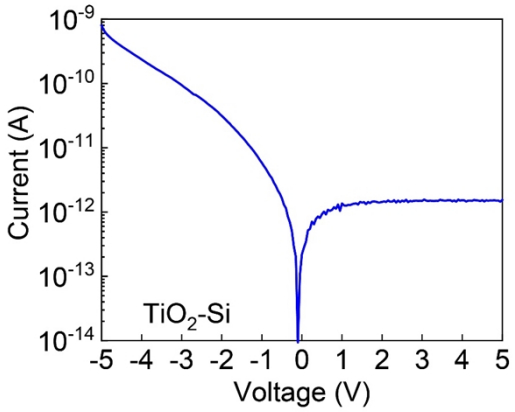
Supplementary Fig. 3 The read disturbance under 2 V/-2 V for HRS and LRS.



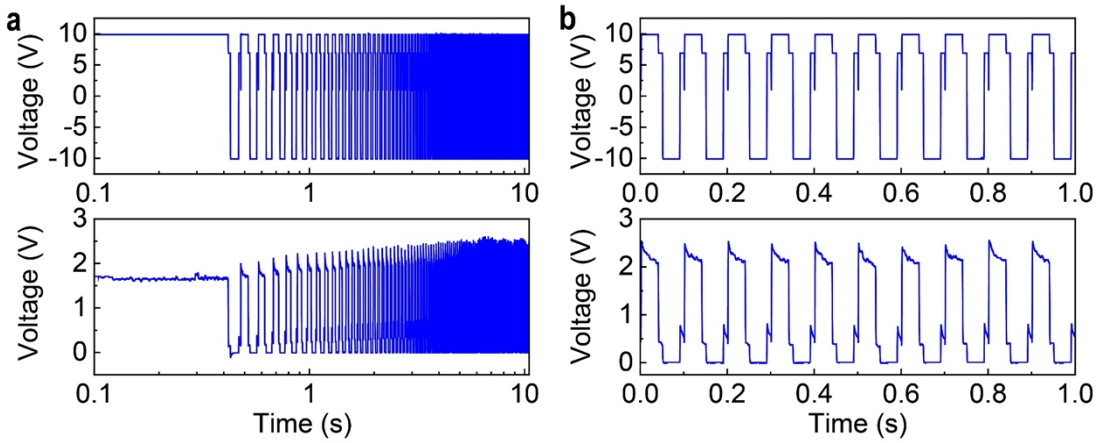
Supplementary Fig. 4 *I-V* characteristics of MXene-TiO_2-Si RRAMs with different thickness of TiO_2. (a) 2 nm, (b) 10 nm, (c) 15 nm.



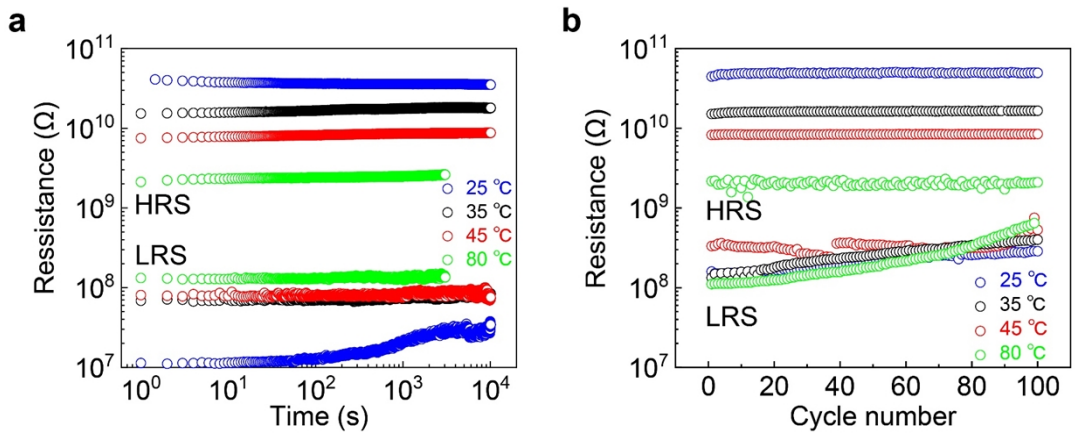
Supplementary Fig. 5 Typical *I-V* characteristics of MXene-TiO_2-Si RRAMs with different resistive area, indicating the bipolar SET and RESET processes. (a) 25 μm², (b) 100 μm², (c) 400 μm², (d) 1600 μm².



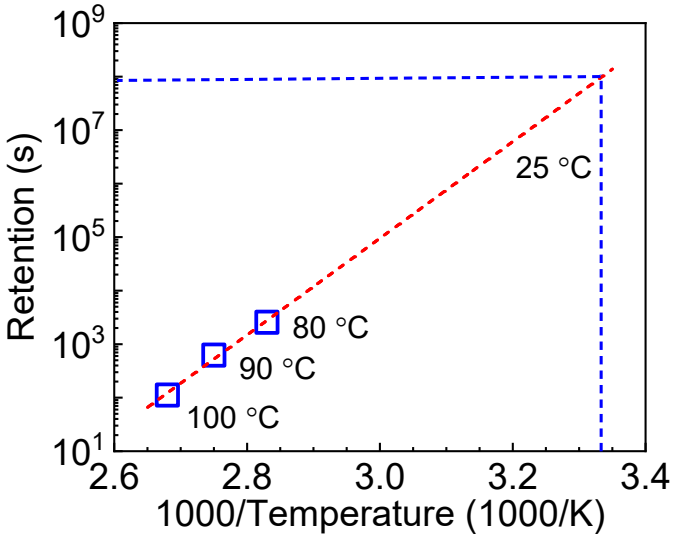
Supplementary Fig. 6 Typical *I-V* characteristic of TiO_2-Si junction.



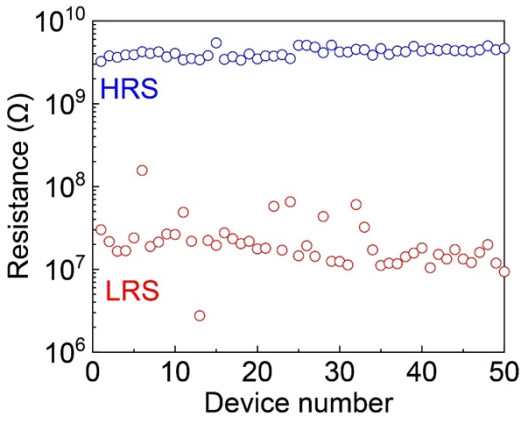
Supplementary Fig. 7 (a) Endurance test performed with more than 100 voltage sweep cycles in 10 s. (b) About 10 cycles in 1s cut from (a).



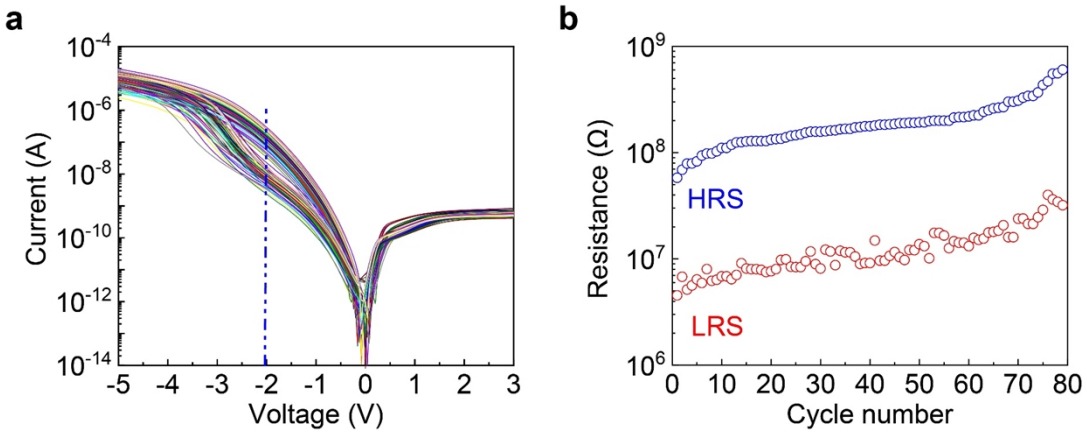
Supplementary Fig. 8 (a) Retention and (b) endurance characteristics at the different temperatures.



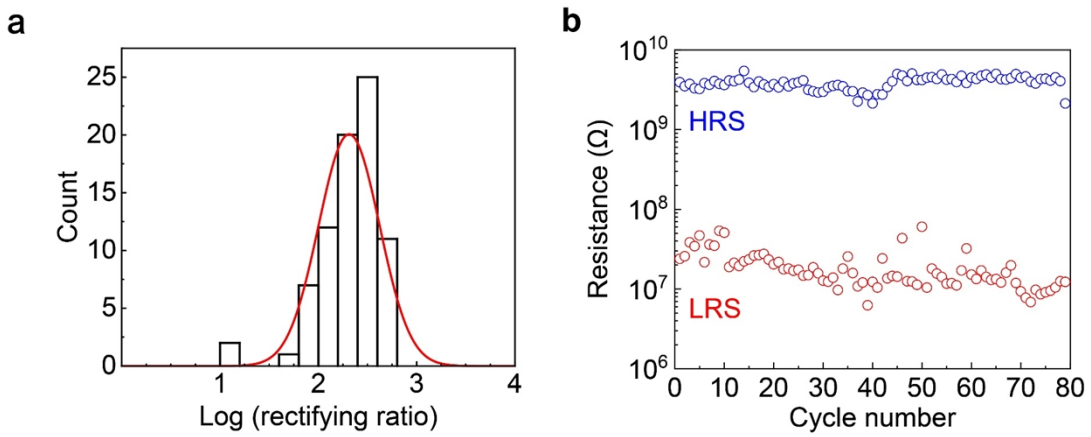
Supplementary Fig. 9 Temperature dependence of the retention time (s) follows the Arrhenius relation. Retention time at 25 ℃ are extrapolated from the linear fitting of measurement results (blue squares).



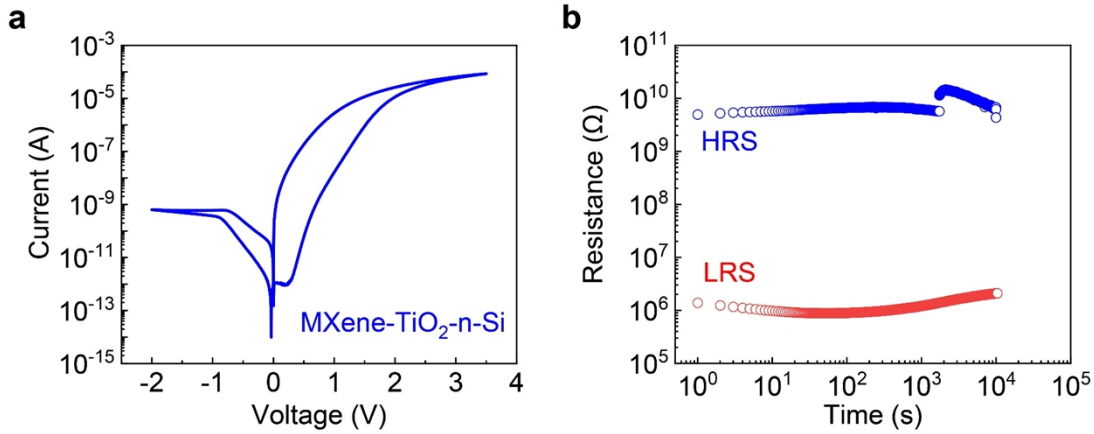
Supplementary Fig. 10 Device-to-device variation of HRS and LRS at the read voltage of 2 V, respectively.



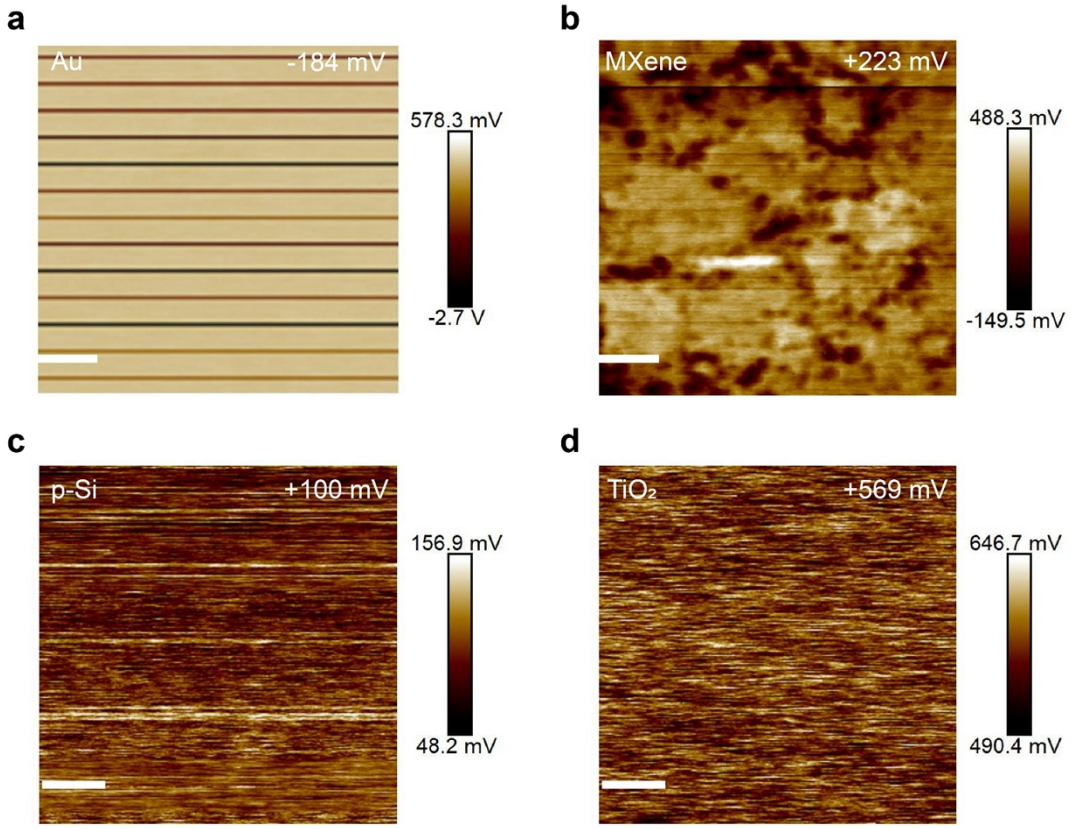
Supplementary Fig. 11 (a) The *I-V* characteristics of a single RRAM device with 80 cycles. (b) The extracted cycle-to-cycle distribution of HRS and LRS at 2 V read voltage. The resistance states can be also distinguished through the current on-off ratio more than 10



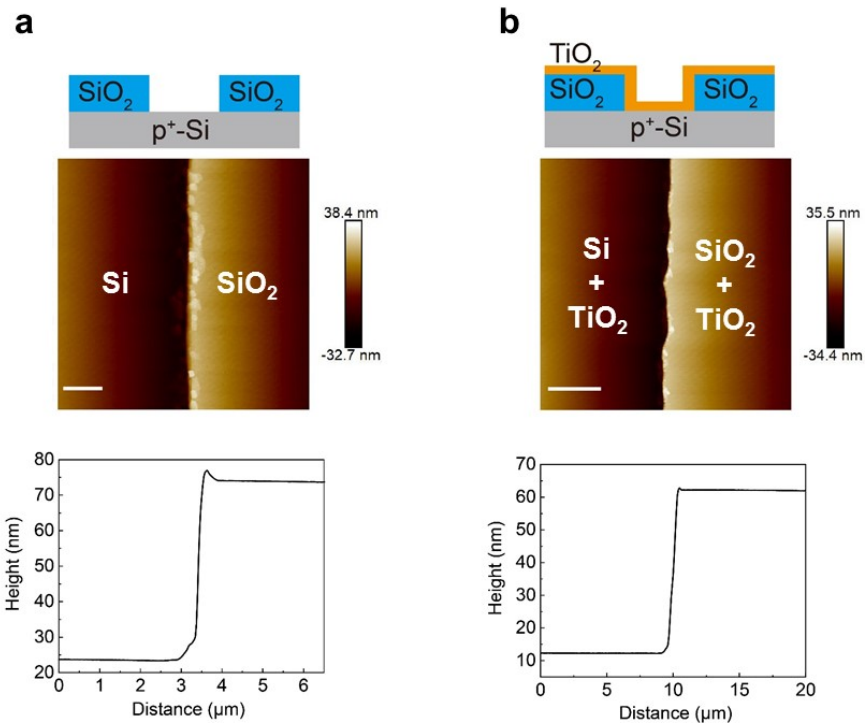
Supplementary Fig. 12 The statistical cycle-to-cycle variation of (a) rectifying ratio performed by a logarithmic operation and (b) HRS and LRS, respectively.



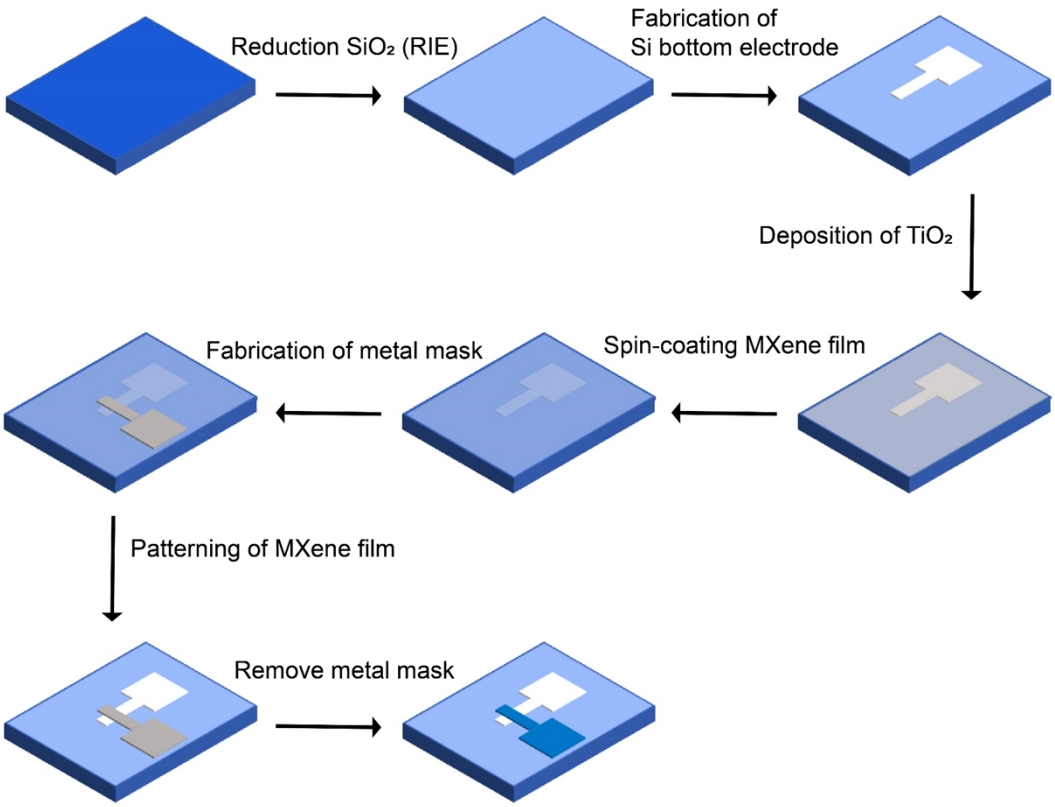
Supplementary Fig. 13 (a) Self-rectifying behavior and (b) retention characteristics of the MXene-TiO_2-n-Si.



Supplementary Fig. 14 The Kelvin probe force microscopy (KPFM) potential map images and numerical analysis of (a) Au (scale bar: 840 nm), (b) MXene (scale bar: 1 μm). (c) p^+-Si (scale bar: 1 μm) and (d) TiO_2 (scale bar: 1 μm). The potentials of Au, MXene, p^+-Si, and TiO_2 were −184 mV, +223 mV, +100 mV and +569 mV, respectively. The work function of Au is 5.2 eV. Therefore, the work function of MXene is 5.2 – 0.184 – 0.223 = 4.893 eV, p^+-Si is 5.2 – 0.184 – 0.1 = 5.016 eV and TiO_2 is 5.2 – 0.184 – 0.569 = 5.547 eV. (KPFM probe: SCM-PIT-V2, 0.01-0.025 Ohm-cm Antimony (n) doped Si).



Supplementary Fig. 15 The schematic, corresponding AFM and height of Si electrode (a) before and (b) afrer 5-nm-TiO_2 deposited by ALD. Scale bar, 1 μm, 4 μm.



Supplementary Fig. 16 Fabrication flowchart of MXene-TiO_2-Si self-rectifying RRAMs.

Table S1. Performance comparison about TiO_2-based RRAM devices.

Structure	on/off ratio	rectifying ratio	Retention (s)	endurance
$Ti/TiO_2/Pt$[1]	10^3	10^5		1000
$Cu/Ti/HfO_2/TiO_2/TiN$[2]	3×10^3			200
$TaO_x/TiO_2/TaO_x$[3]	10^3		10^4	10^{10}
$TiN/Ti/TiO_x/HfO_x/TiN$[4]	10^3		10^4	
$Pt/In,Sn_2O_3/TiO_2/Pt$[5]	160			40
$TiN/TiO_x/Al_2O_3/IrO_x$[6]	10	10	10^5	1000
$TiN/TiO_x/Al_2O_3/IrO_x$[7]	30			10^6
My work	**10^3**	**10^3**	**10^4**	**100**

[1] Appl. Phys. Lett. 2020, 96, 262901.

[2] Advanced Electronic Materials 2020, 6 (9), 2000488□.

[3] ACS Nano 2012, 6, 9, 8166–8172.

[4] Appl. Phys. Lett. 2012, 101, 103506.

[5] Appl. Phys. Lett. 2008, 92, 162904.

[6] IEEE Transactions on Electron Devices 2018, 65 (3), 957-962□.

[7] ACS omega 2017, 2 (10), 6888-6895□.