Physical Chemistry Chemical Physics

Supporting Information

Title:

Multifunctional ferroelectric synaptic memristors based on HfAlOx with enhanced pavlovian learning and physical reservoir computing system

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Supplementary figures

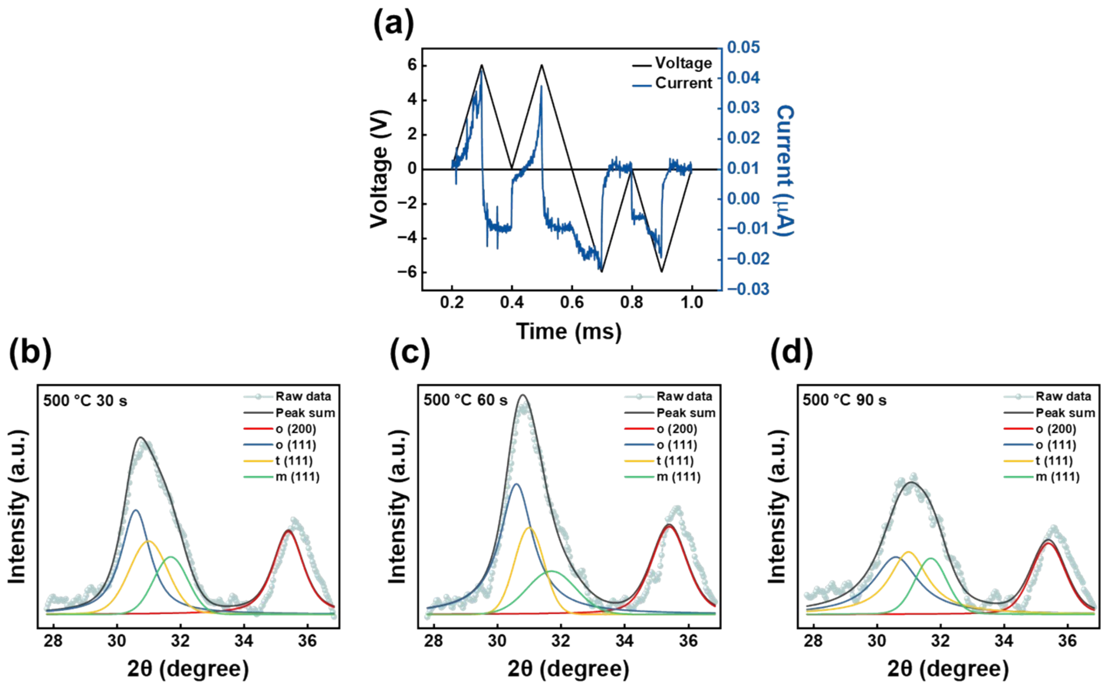

Figure S1. (a) Pulse scheme of PUND pulse and current response. Deconvoluted GIXRD spectra. Annealed for (a) 30 s, (b) 60 s, (c) 90 s.

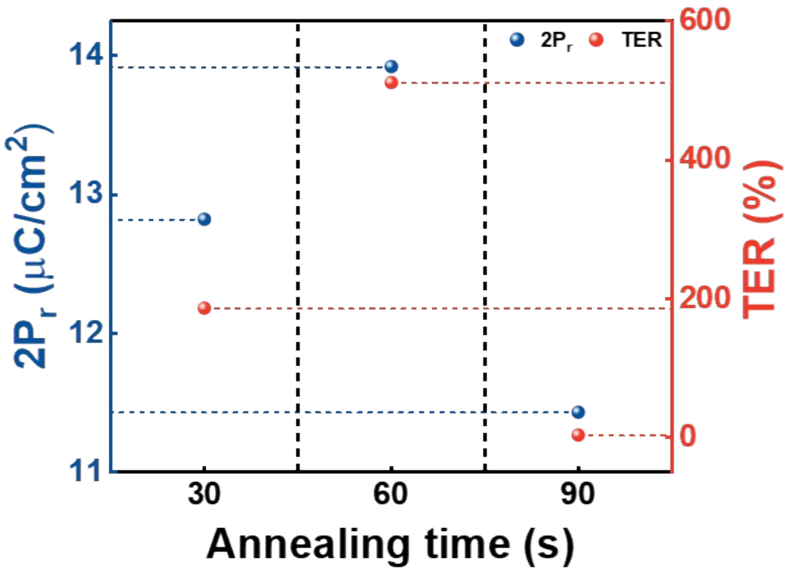

Figure S2. Variation of $2P_r$ and TER as a function of annealing time

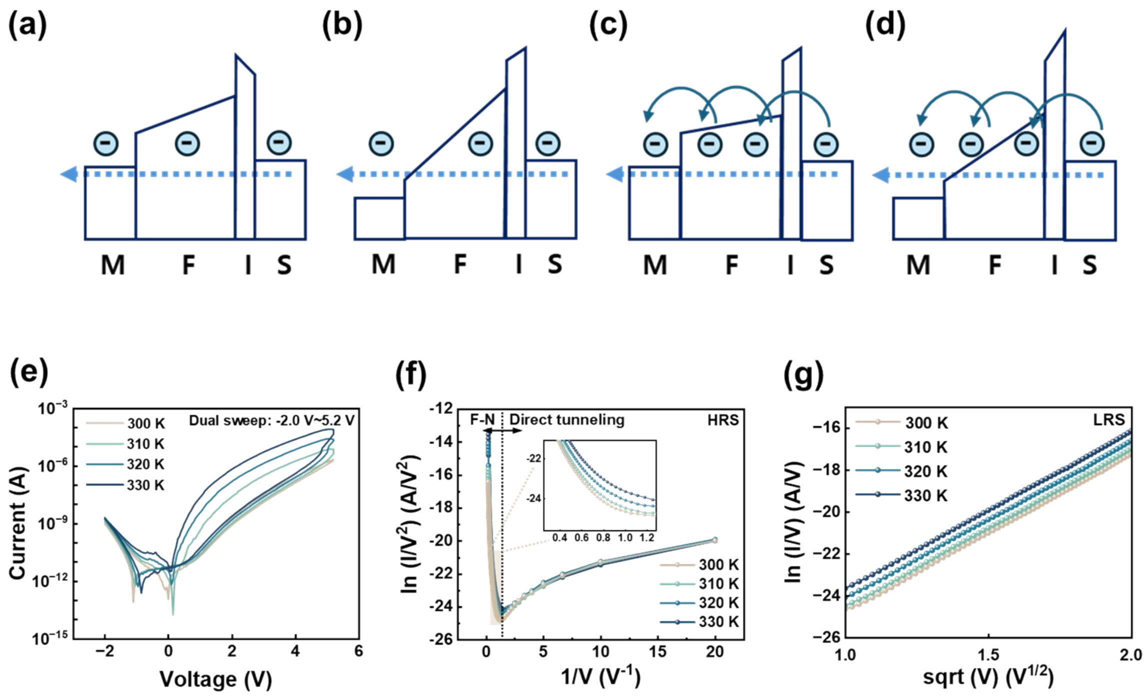

Figure S3. Energy band diagram in HRS state (a, b) and LRS state (c, d). (e) Voltage sweeps under 300 K-330 K in 10 K increments. (f) HRS state fitted curves. (g) LRS state fitted curves.

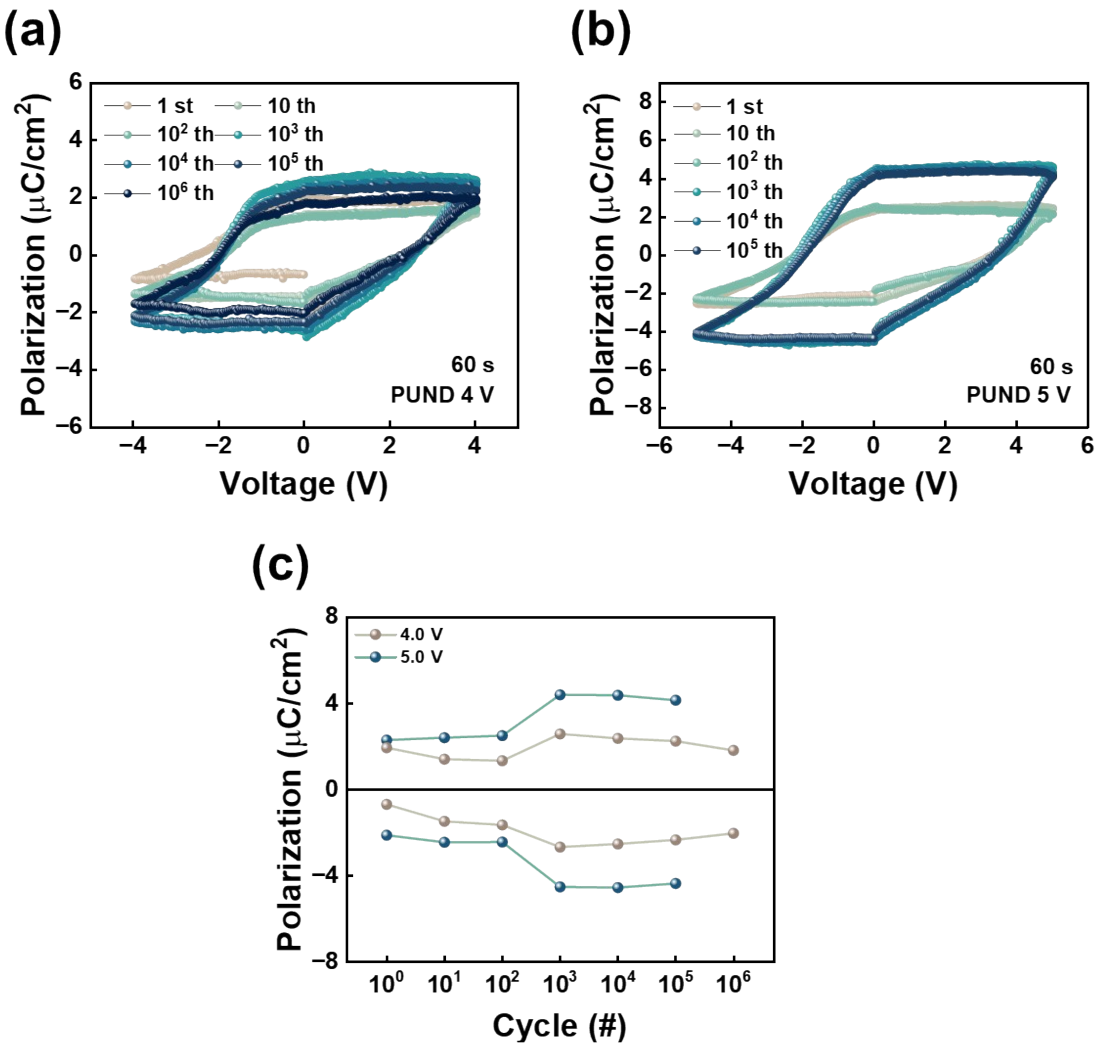

Figure S4. PV curves under repeated PUND cycling at (a) 4 V and (b) 5 V. (c) Polarization changes under ±4 V and ±5 V PUND cycling

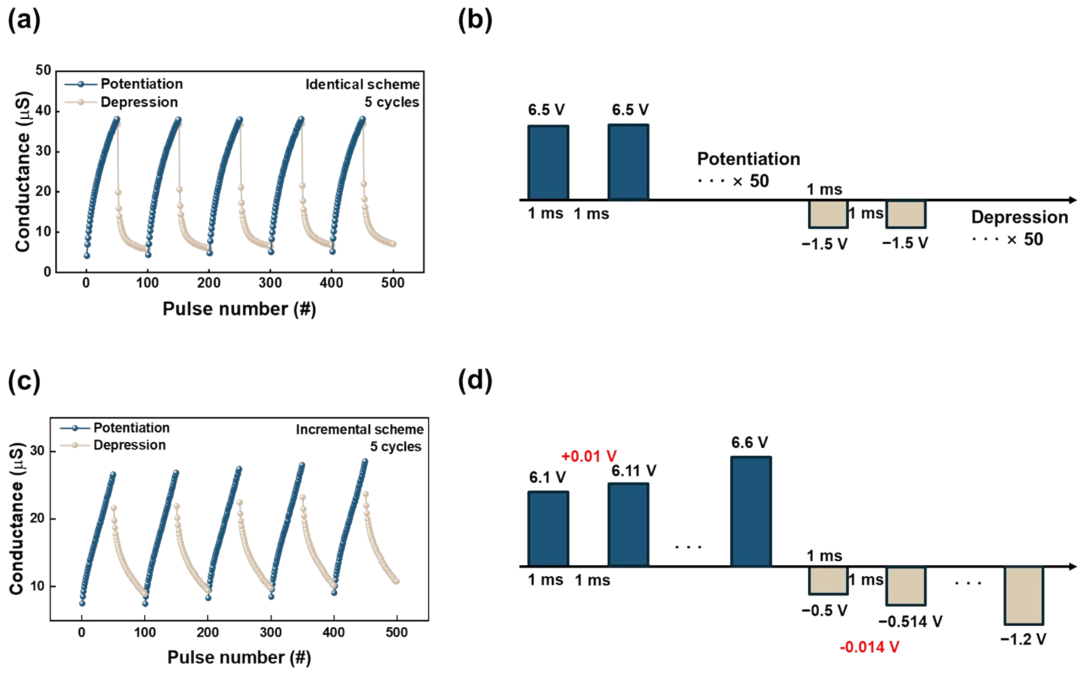

Figure S5. PD characteristics under different methods. (a) Identical PD conductance over 5 cycles. (b) Pulse scheme for the identical PD method. (c) Incremental PD conductance over 5 cycles. (d) Pulse scheme for the incremental PD method.

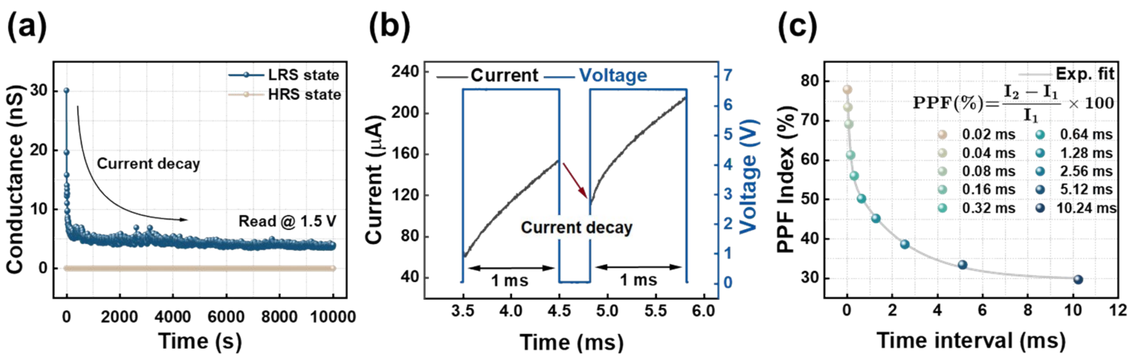

Figure S6. Retention and paired-pulse facilitation (PPF) characteristics. (a) Retention characteristics in the LRS state and HRS state. (b) Pulse scheme for two paired pulses and corresponding current response. (c) PPF characteristics as a function of the time interval between paired pulses.

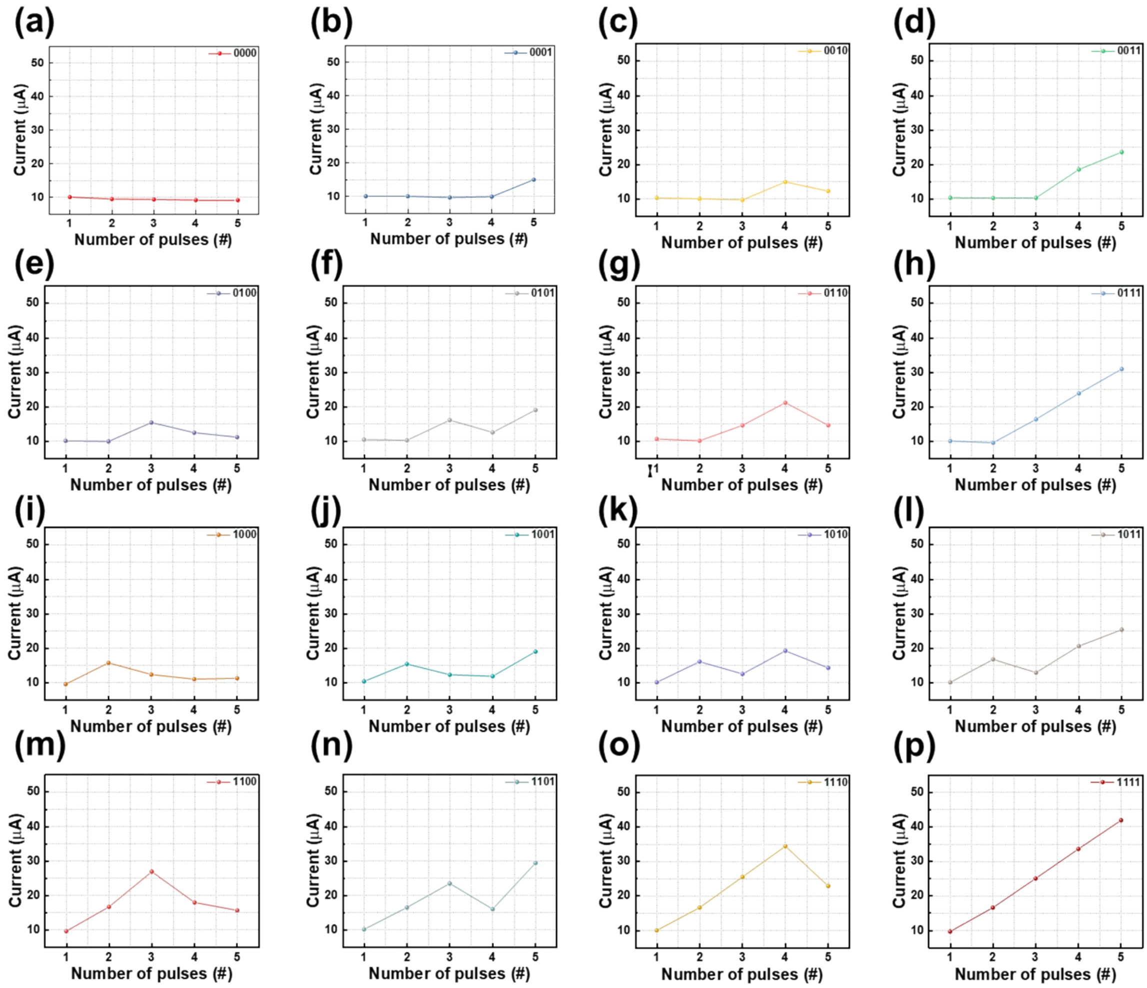

Figure S7. The 16 different states of the 4-bit RC system. (a) 0000, (b) 0001, (c) 0010, (d) 0011, (e) 0100, (f) 0101, (g) 0110, (h) 0111, (i) 1000, (j) 1001, (k) 1010, (l) 1011, (m) 1100, (n) 1101, (o) 1110, (p) 1111.

Table S1.

Device stack	Annealing condition	$2P_r$ ($\mu C/cm^2$) / PUND Voltage	Endurance	TER	Accuracy	Reference
TiN/HAO/n^+ Si (MFS)	700 °C, 20 s	17.92 / 5.5 V	$< 10^6$	146.35	-	[1]
TiN/SiO_2/n^+ Si (MIFS)	700 °C, 20 s	15.59 / 5.5 V	$< 10^6$	911.06	~89 % (MNIST, CNN)	[1]
TiN/HAO/n^+ Si (MFS)	700 °C, 20 s	14.09 / 7 V	$<10^7$	241.3	~90.06 % (MNIST, CNN)	[2]
TiN/HSO/n^+ Si (MFS)	750 °C, 20 s	16 / 7 V	$<10^6$	2104	~97.68 % (MNIST, CNN)	[3]
TiN/HZO/HfO_x TiN (MFIM)	500 °C, 30 s	23.3 / 4 V	1.5×10^{11}	-	-	[4]
TiN/HZO/TiN (MFM)	500 °C, 60 s	60 / 3.5 V	$<10^9$	-	~90 % (EMNIST,SNN)	[5]
W/HAO/ZrO_2/n^+ /Si (MFIS)	500 °C, 60 s	13.92 / 6 V	$<10^6$	511	~98.51 (MNIST, CNN)	**This work**

Comparison of key device performance by device stack

References

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