



HAL
open science

Relaxor ferroelectrics for neuromorphic computing

Haoyuan Ma, Long Cheng, Omar Ibder, Charles Paillard, Brahim Dkhil

► **To cite this version:**

Haoyuan Ma, Long Cheng, Omar Ibder, Charles Paillard, Brahim Dkhil. Relaxor ferroelectrics for neuromorphic computing. International School of Oxide Electronics (ISOE), Aug 2023, Cargese (Corse), France. hal-04431676

HAL Id: hal-04431676

<https://centralesupelec.hal.science/hal-04431676v1>

Submitted on 2 Feb 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

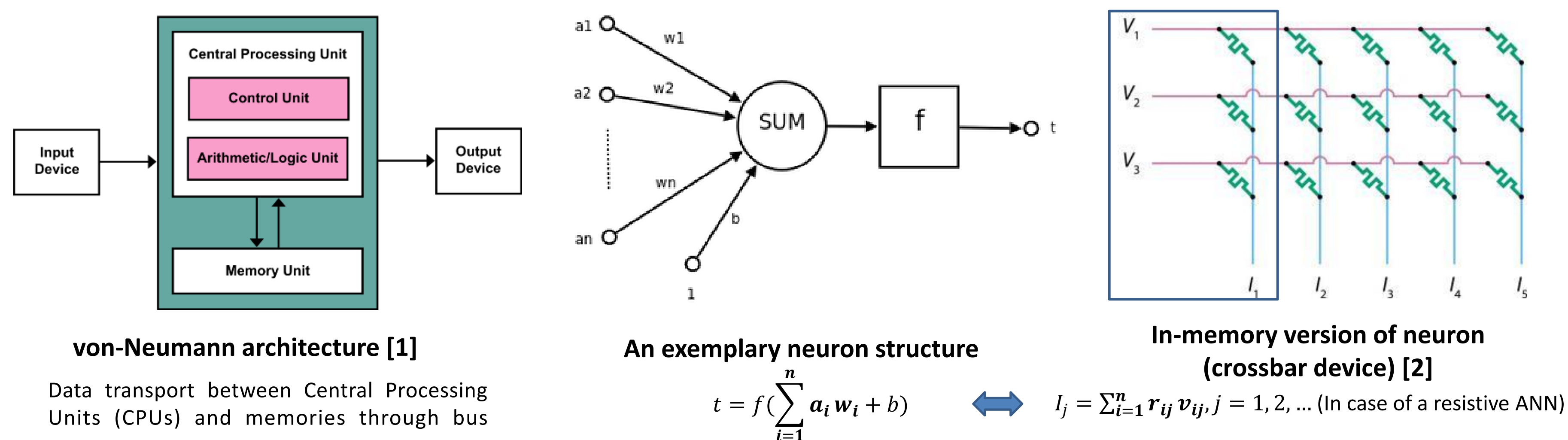
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Context

Neuromorphic computing: Recreating brain functions using Artificial Neural Networks (ANN) and its hardware implementations. Essential units: neurons and synapses

Conventional ANN: von-Neumann architecture, computing outside of memory, high energy consumption due to data transportation (“von-Neumann bottleneck”)

Compute-in-memory (CIM): emerging solution of the von-Neumann bottleneck

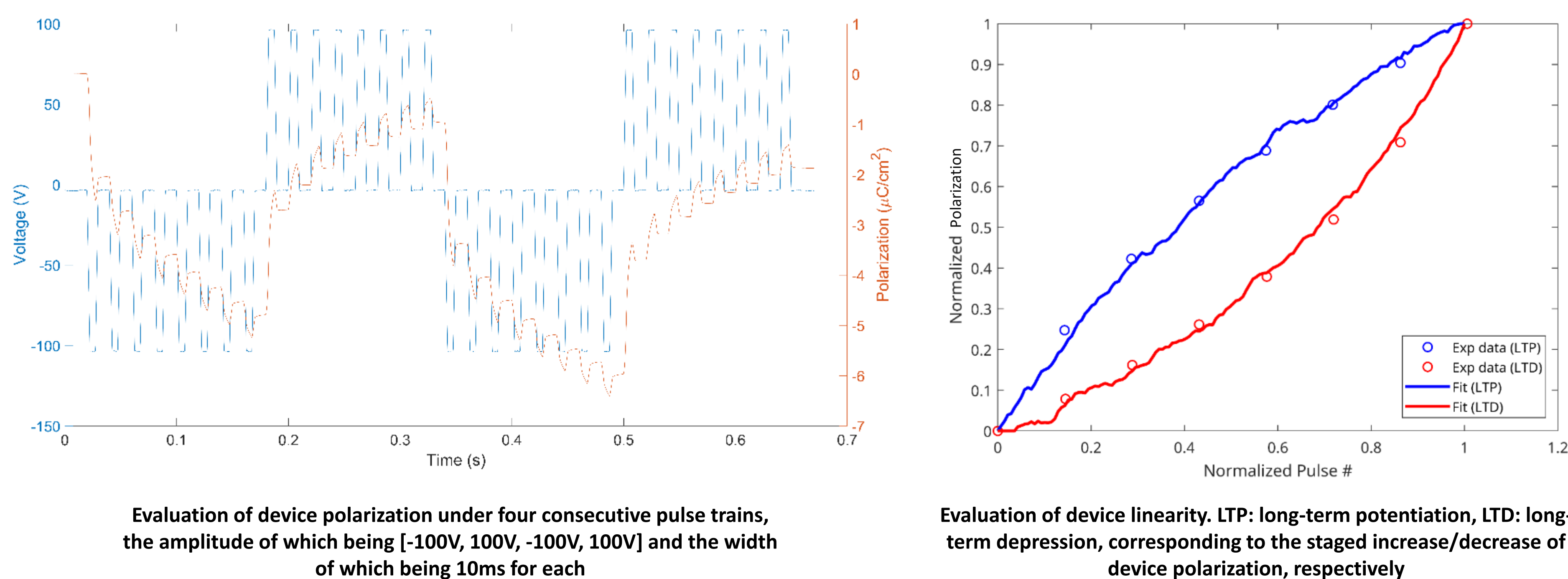


Requirements for analog states in crossbar device: nonvolatile, readily programmable, high ON/OFF ratio, long retention time, good endurance

Devices used in crossbar ANNs: resistive devices, ferroelectric diodes, **capacitive devices** (most promising due to its near-zero static power)

State Establishment of Relaxor Ferroelectrics

The evaluation of the state establishment ability of PZN-4.5PT was performed. Four consecutive pulse trains with the amplitude of [-100V, 100V, -100V, 100V] and the width of 10ms were applied to the material.



Observations:

- (1) PZN-4.5PT demonstrates distinct long-term potentiation (LTP) and long-term depression (LTD) behavior, showing the ability of manageably updating device state and mimicking the biological synapses of human brain;
- (2) PZN-4.5PT shows the ability to access multiple polarization states by simply changing the profile of applied electric pulse;
- (3) The linearity factor A of PZN-4.5PT is derived from [3,4]

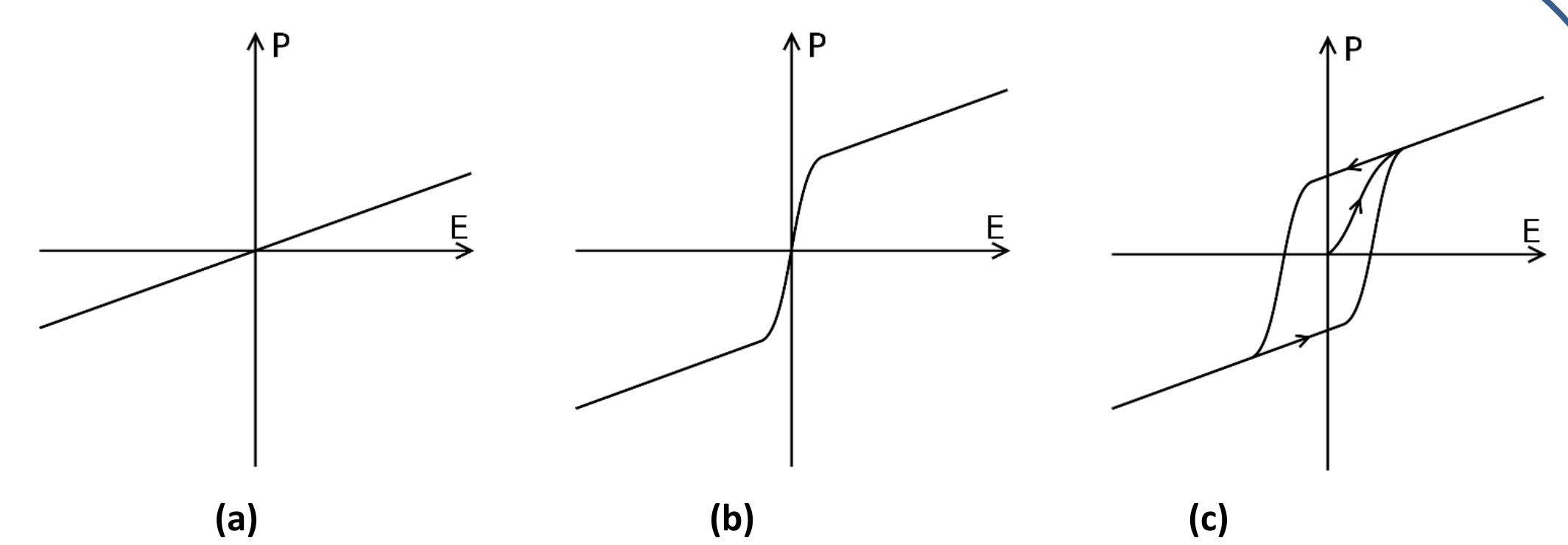
$$\begin{cases} P_{LTP} = B \left(1 - \exp\left(-\frac{N}{A}\right) \right) + P_{min} \\ P_{LTD} = -B \left(1 - \exp\left(-\frac{N - N_{max}}{A}\right) \right) + P_{max} \\ B = \frac{P_{max} - P_{min}}{1 - \exp\left(-\frac{N_{max}}{A}\right)} \end{cases}$$

where P stands for device polarization, N stands for number of pulses, and P_{min} , P_{max} and N_{max} were extracted from the experimental data.

The calculated A equals to **1.28** for long-term potentiation (LTP) and **-2** for long-term depression, ensuring relatively low accuracy degradation during the learning works [4].

From the observation above, we can conclude that PZN-4.5PT is a potential candidate for neuromorphic computing.

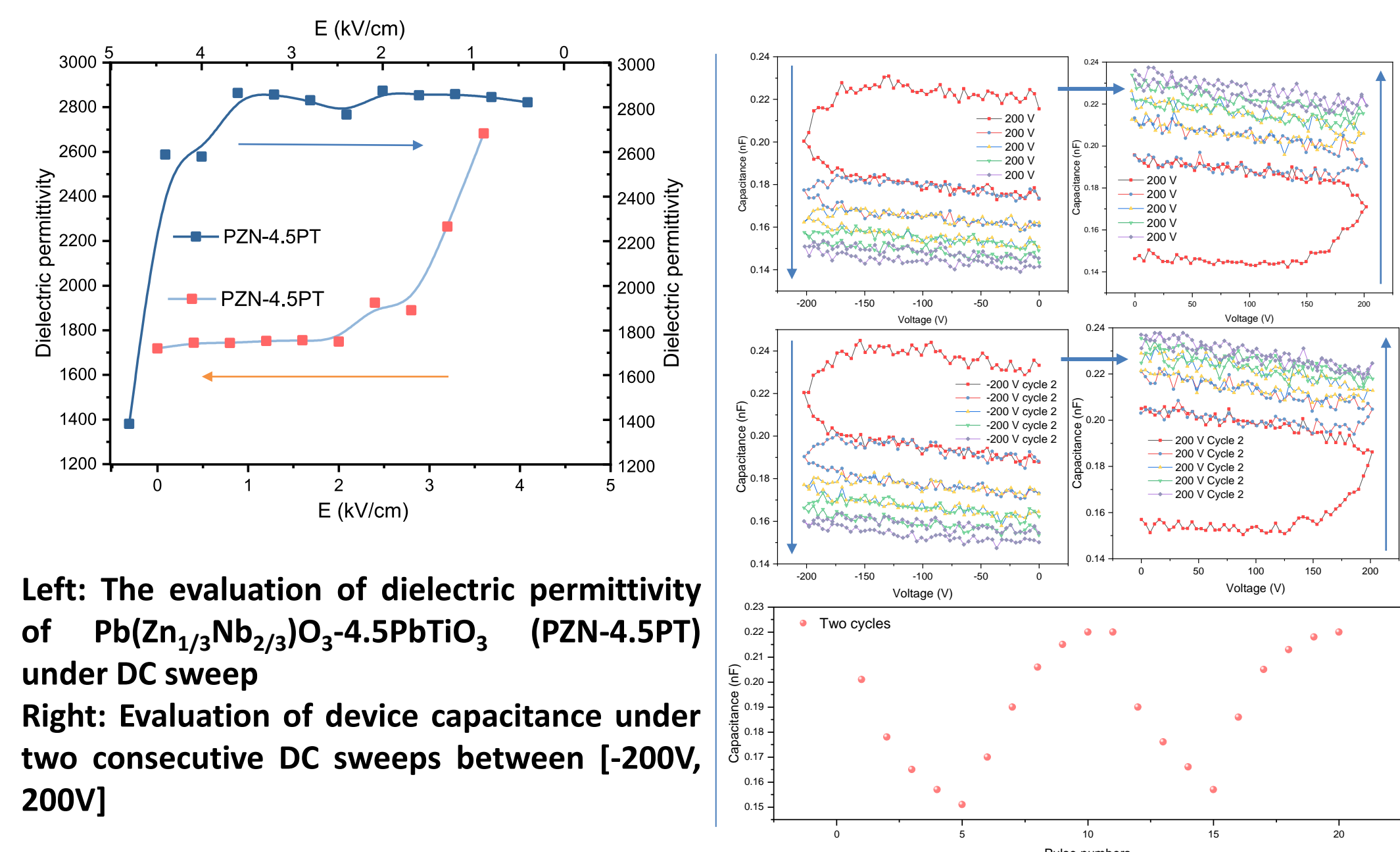
Relaxor Ferroelectrics



Polarization - Electric field (P-E) relationship of (a) linear dielectric, (b) paraelectric, and (c) ferroelectric materials

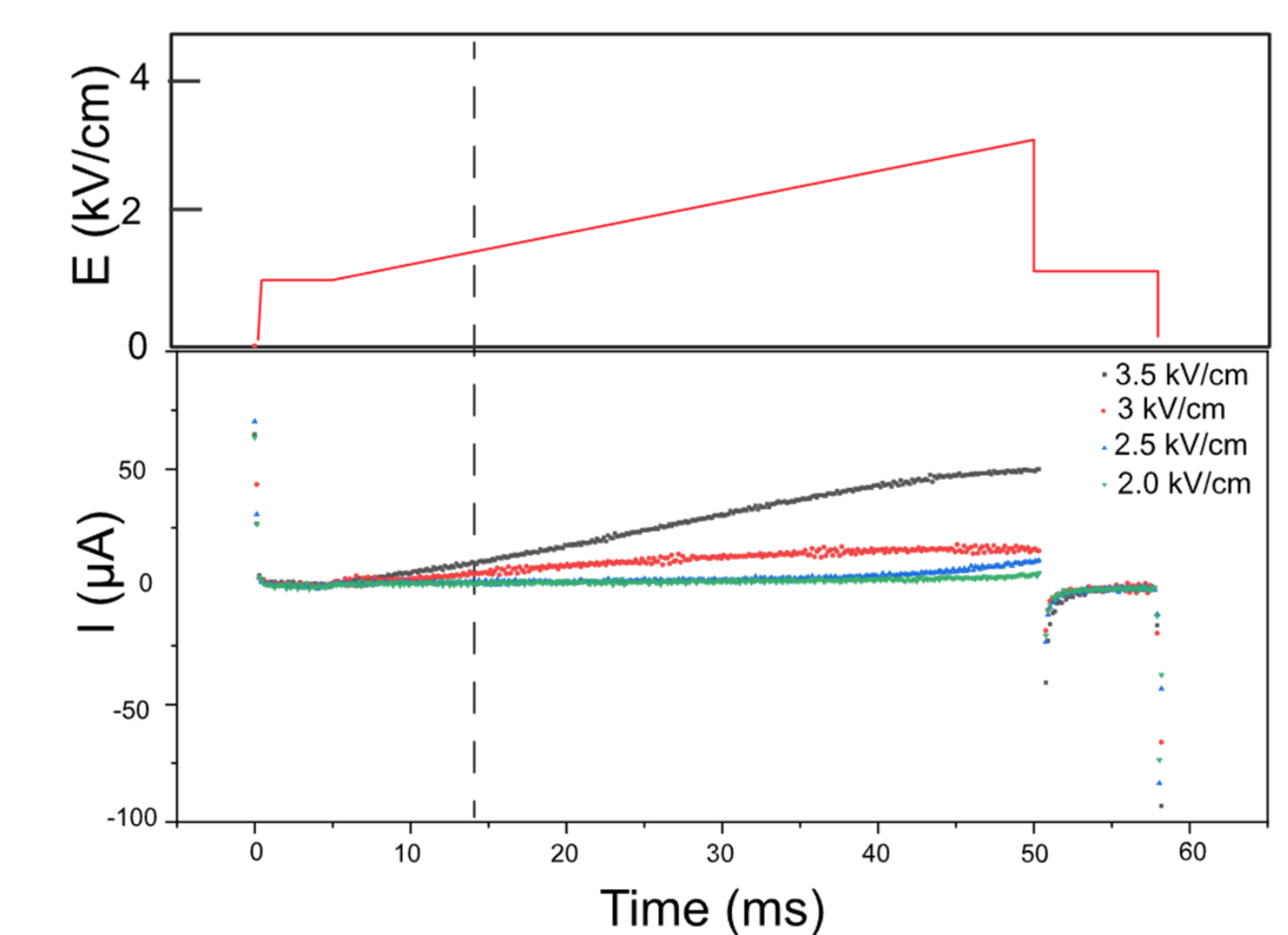
Relaxor ferroelectrics: a category of ferroelectric materials with with strong electric field instabilities, permitting readily state programming

Representative RFEs: PMN, PZN, PMN-xPT, PZN-xPT, PLZT...

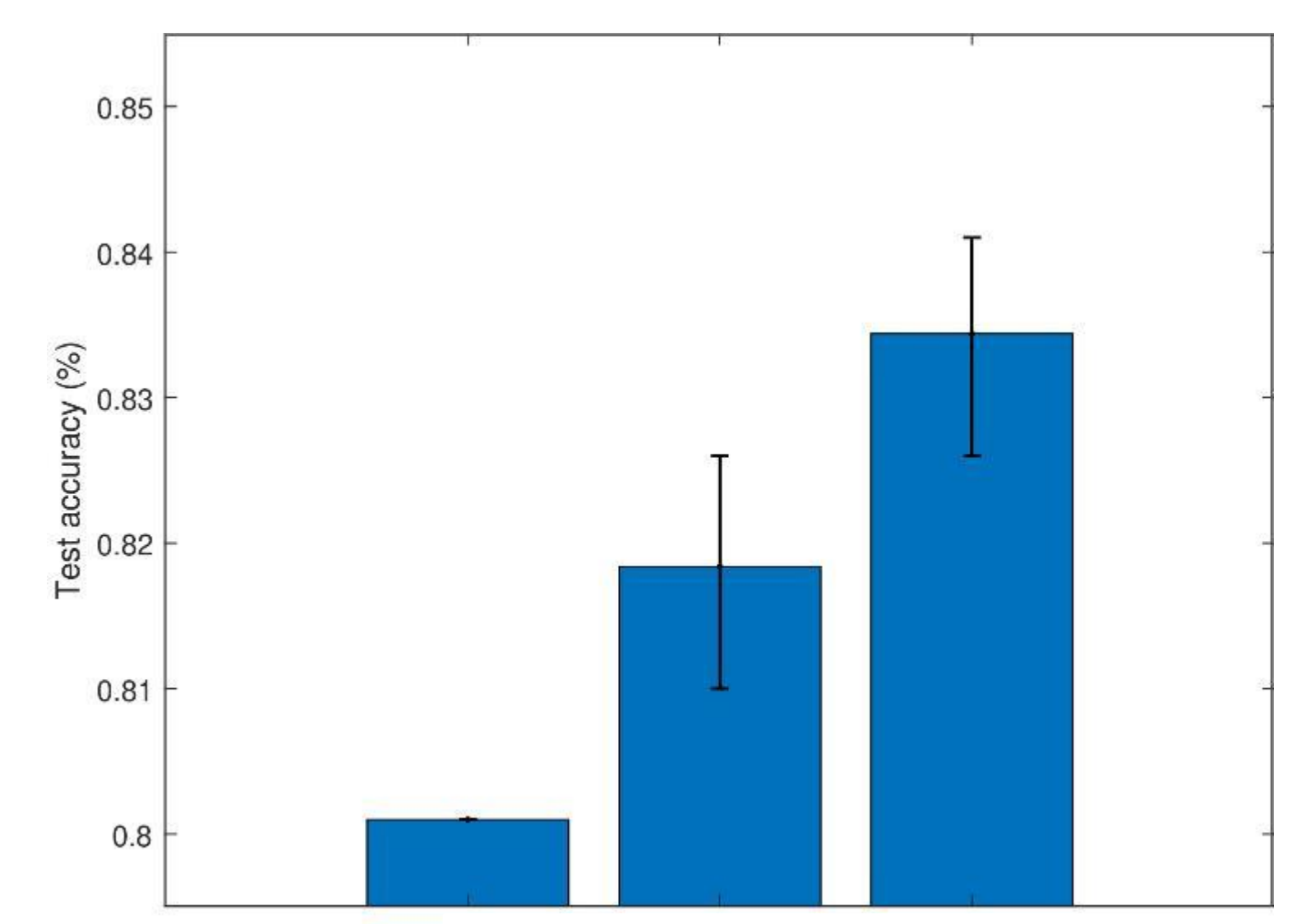


Observation: RFEs like PZN-PT can exhibit multiple nonvolatile and readily programmable capacitive states, giving it great potential to be used in neuromorphic computing

Relaxor Ferroelectrics in Neural Networks



Integration of signals for PZN-4.5PT under different electric fields, resembles the dendrite in the human brain



Comparison of the recognition accuracies for the simplified SVHN dataset in a neural network [5] with three different dendrites. w/o: test accuracy of the network without dendrite [5]

Reservoir node	Test error	a_1	a_2	a_3	a_4
[6]	0.7944	0.96	1.0	0.9867	1.0
PZN-4.5PT	0.7343	1.0	1.0	0.9933	1.0

Comparison of the performance of a reservoir system [6] on dynamic gesture recognition (DGR) with different reservoir node. a_i : The recognition accuracy of the i -th gesture.