Ferroelectric AI Hardware: Overcoming Conventional Paradigms & Scalability Limits

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Our Group | Re-Designing Integrated Circuit Building Blocks via Ferroelectronics

Transistor

from high-k to negative-k dielectrics

via mixed ferroelectric-antiferroelectric order

for ultra-low power logic transistors

Cheema Nature 2022
Lincoln Laboratory IEDM 2022
Samsung Nature Electronics 2023

Capacitor

from electrochemical to electrostatic energy storage

via antiferroelectric-to-ferroelectric phase transitions

for ultrahigh-power ultrahigh-density capacitors

Cheema Nature 2024
Cheema Nature 2025

Memristor

from defective to collective switching

via ultrathin-enhanced ferroelectricity

for atomic-scale resistive switching

Cheema et al Nature 2020
Cheema et al Science 2022

Diode

from p-n junctions to ferroelectric diodes

via hybrid ferroelectric-ionic order

for unlimited scalability crossbar arrays

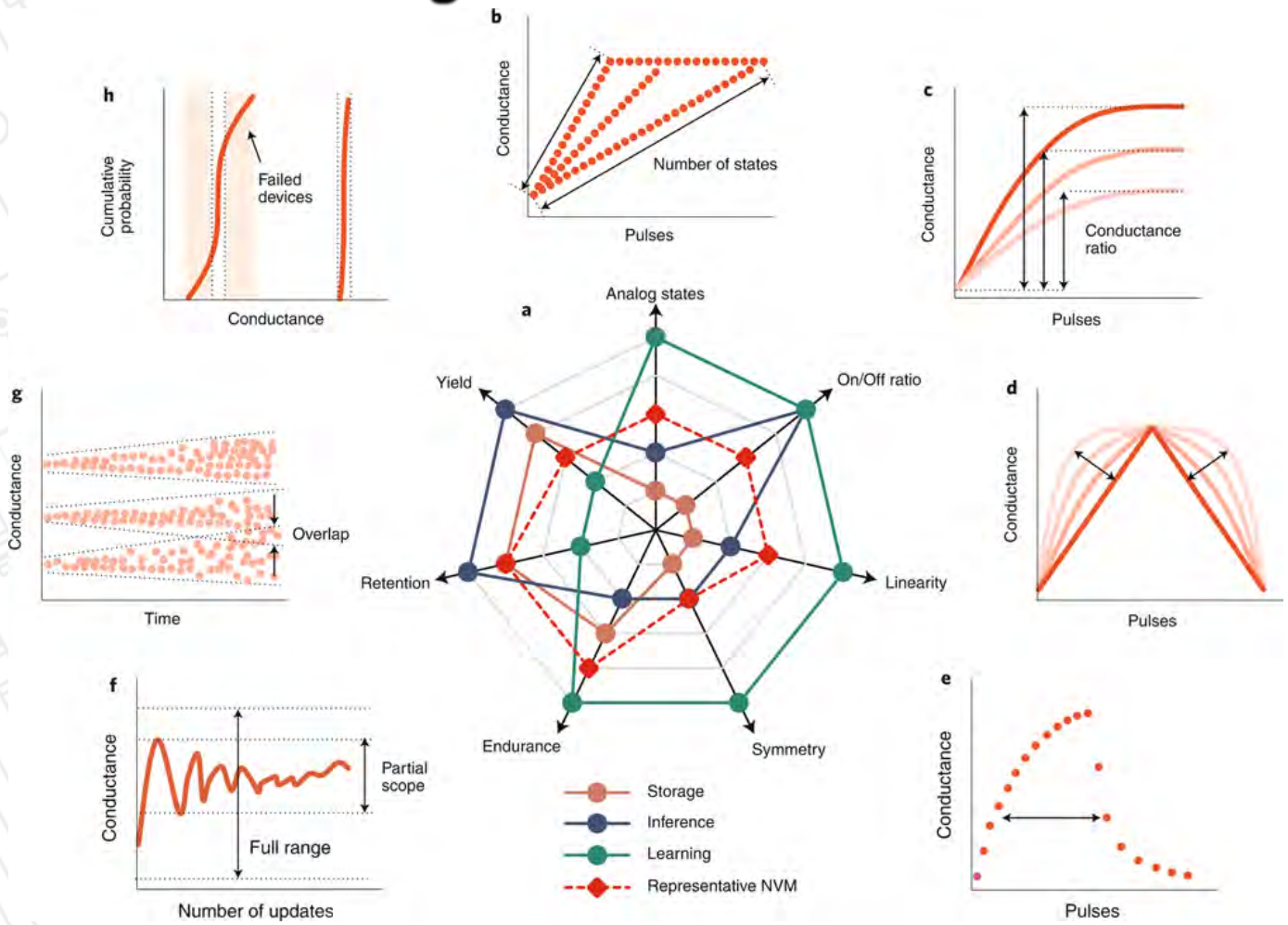
THIS WORK

MIT AI Hardware Program

MIT School of Engineering | MIT Schwarzman College of Computing

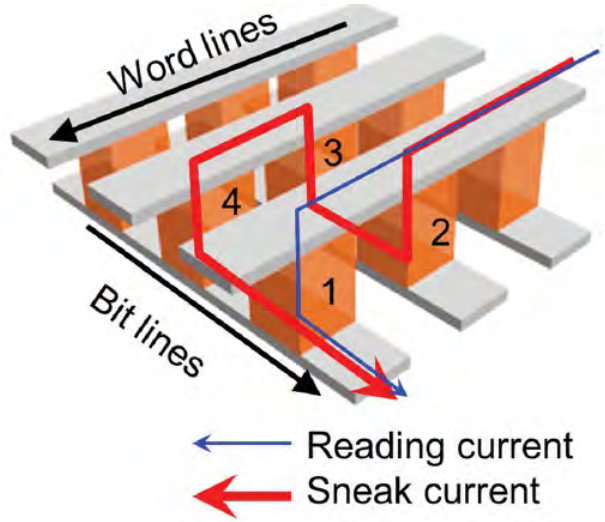
AI Hardware Considerations

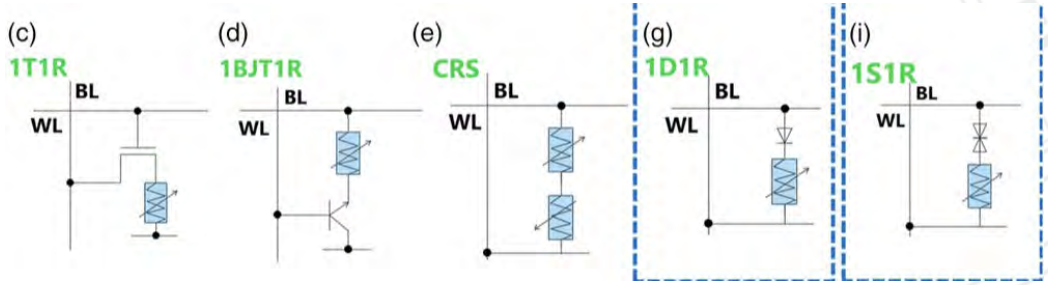
High-Performance



W. Zhang, *Nat. Electron.*, 2020.

High-Scalability





Analogue neural network based on two-terminal memristor crossbar array

→ **Sneak paths limit crossbar scalability**

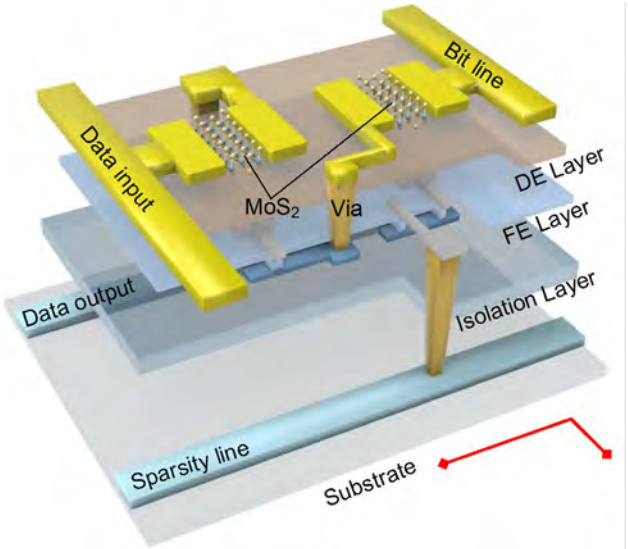
J. Seok, Adv. Func. Mater. 2014

Ferroelectric AI HW| Overcoming Conventional Bottlenecks (Dr. Hongkai Ning)

AI HW Platform

2D-Channel Ferroelectric FETs

High-Performance @BEOL

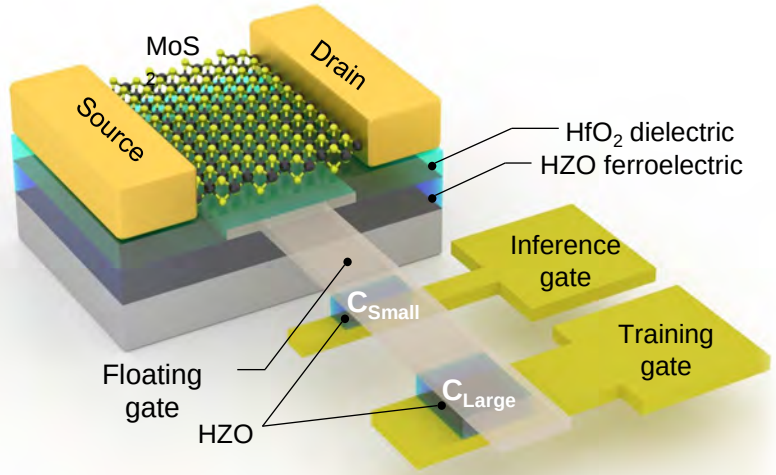


Dr. Hongkai Ning

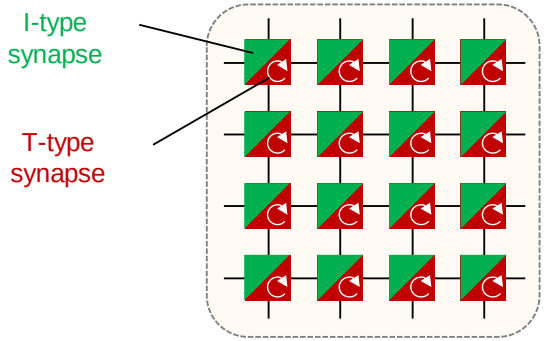
Bottleneck 1: In-Situ Learning

Training-Inference-In-One

Endurance-Retention Dilemma



Training-inference-in-one (TIIO) cell for in-situ learning

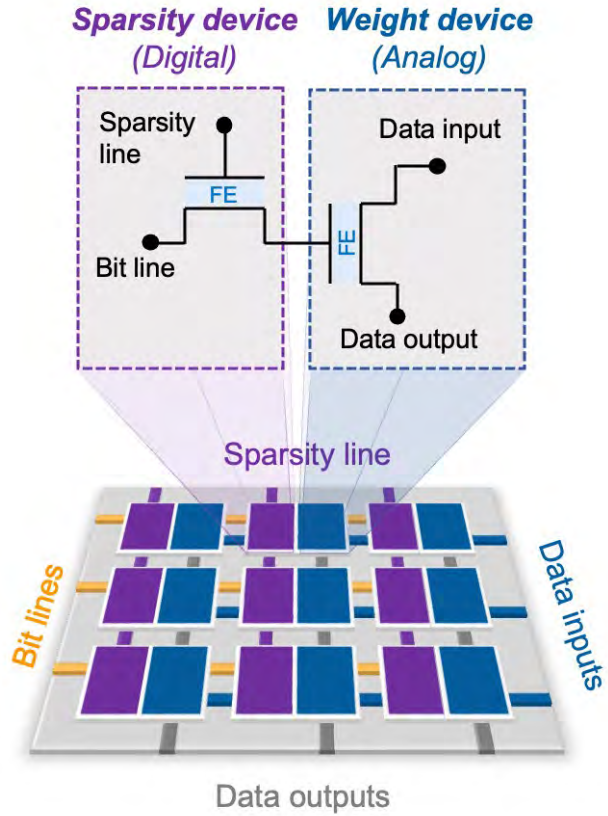


H Ning *et al.* An in-memory computing architecture based on a duplex two-dimensional material structure for in situ machine learning. ***Nat. Nanotechnol.*** 18, 493–500 (2023).

Bottleneck 2: Sparse Training

In-Memory Sparsity

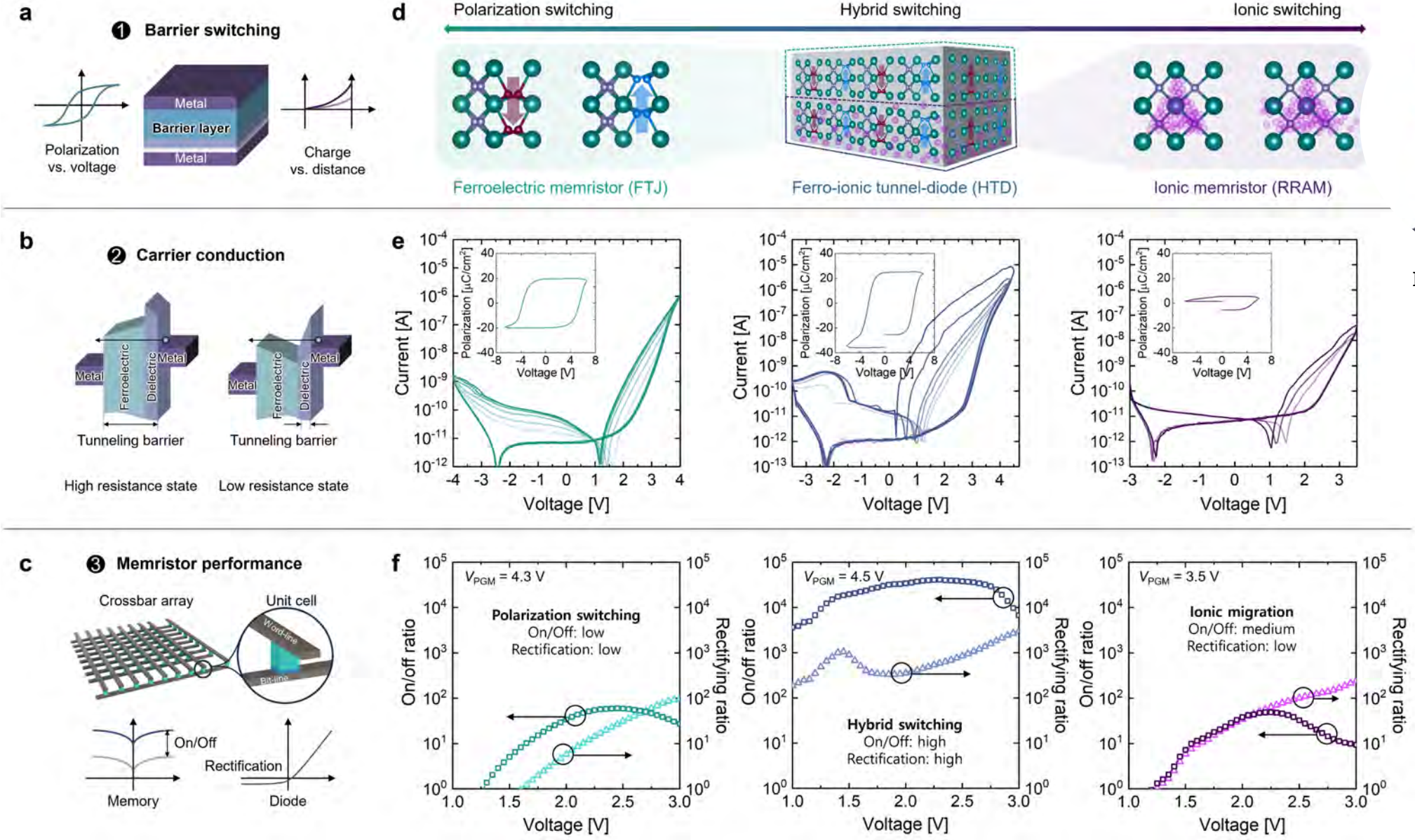
Accuracy-Efficiency Dilemma



H Ning *et al.* An index-free sparse neural network using two-dimensional semiconductor ferroelectric field-effect transistors. ***Nat. Electron.*** 8, 222–234 (2025).

Ferroelectric AI HW | Towards Unlimited Array Scalability (Dr. Wonjun Shin)

Dr. Wonjun Shin

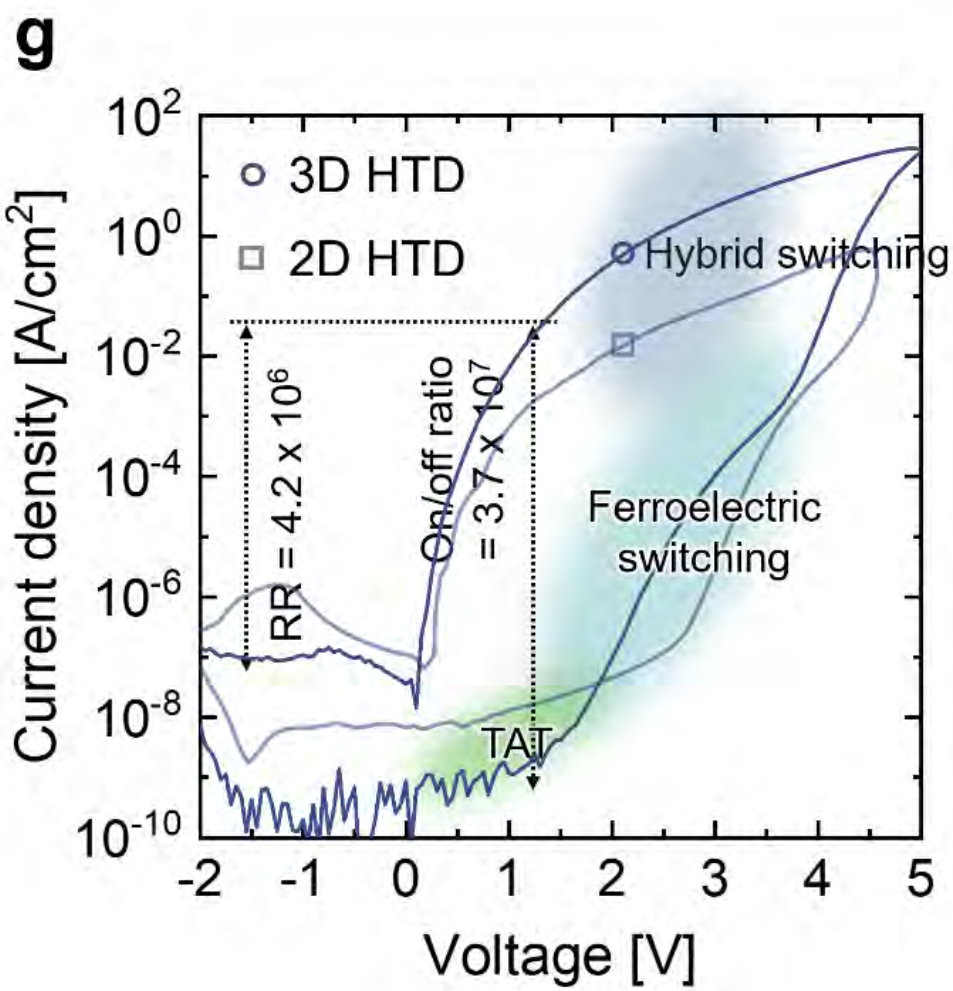


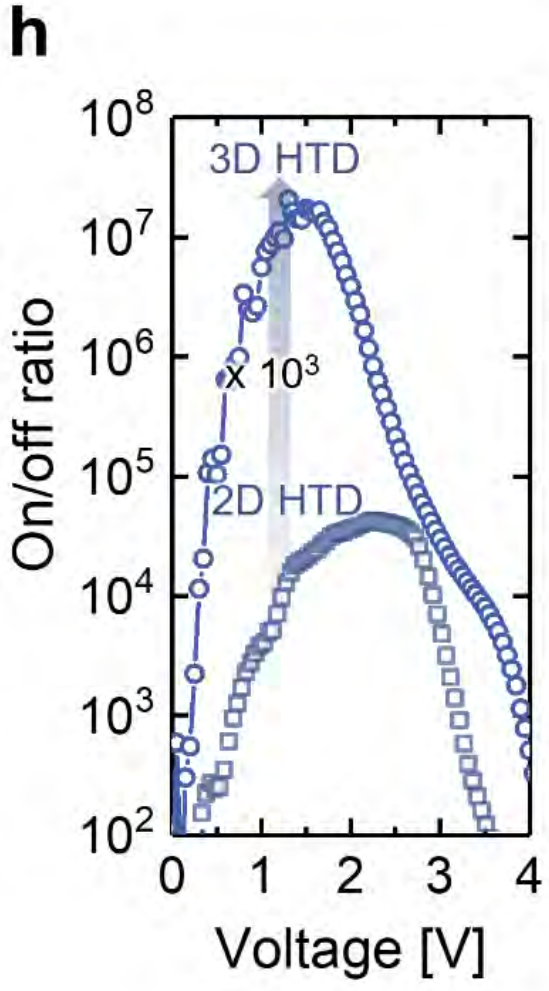
W Shin *et al.* Giant switching, rectification, and scalability via ferroelectric-ionic in-memory computing platform. ***In Prep***

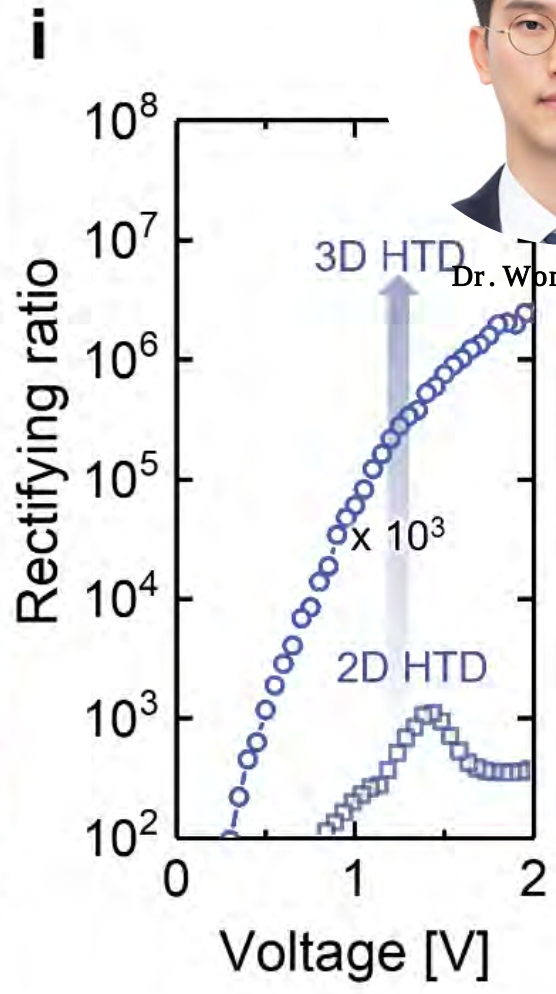
Ferroelectric AI HW | Towards Unlimited Array Scalability (Dr. Wonjun Shin)

Dr. Wonjun Shin

❸ Enhanced Performance







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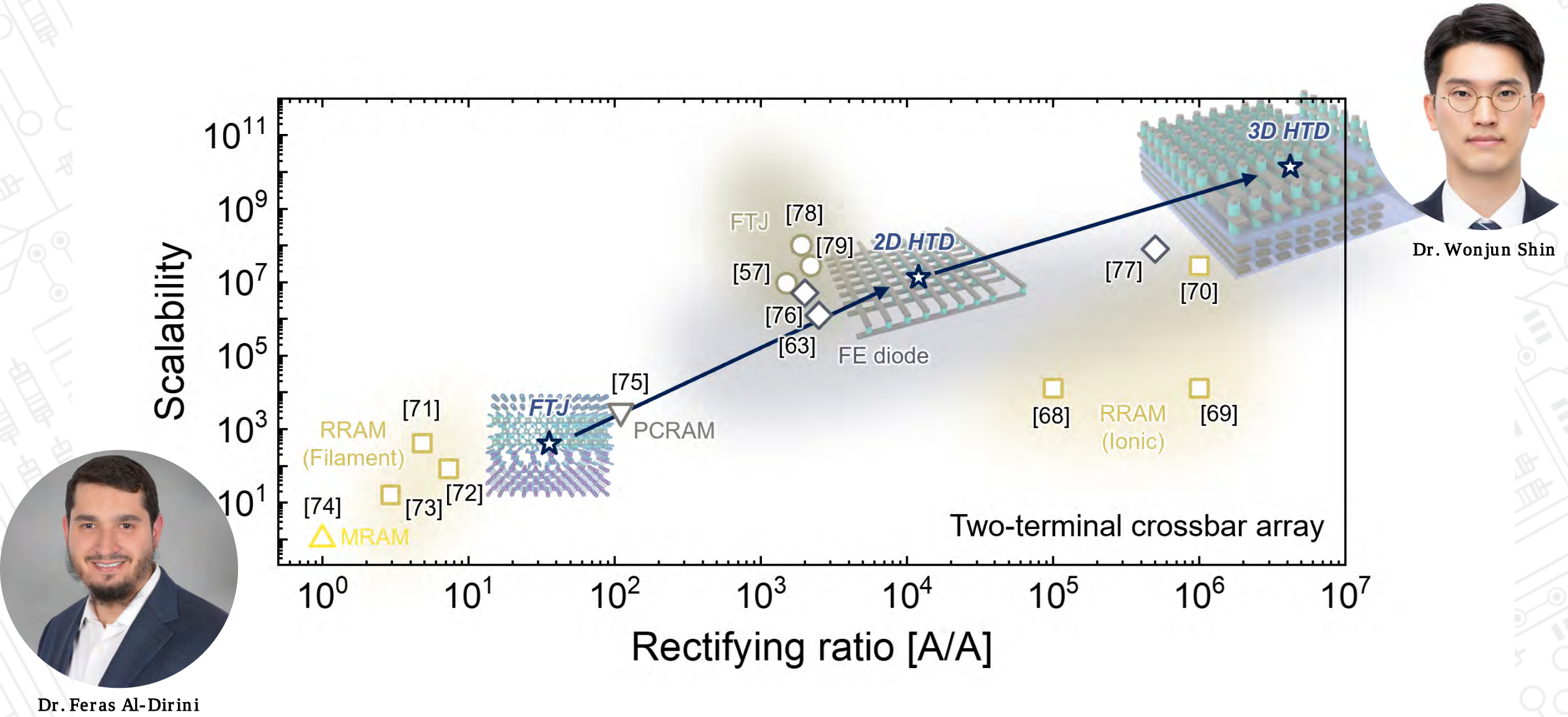


Dr. Feras Al-Dirini

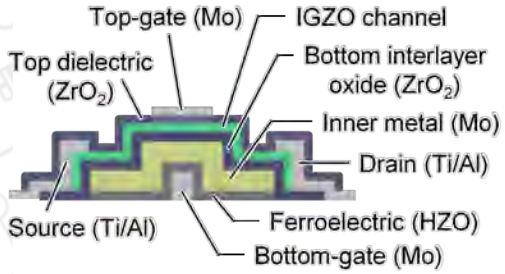
Dr. Wonjun Shin

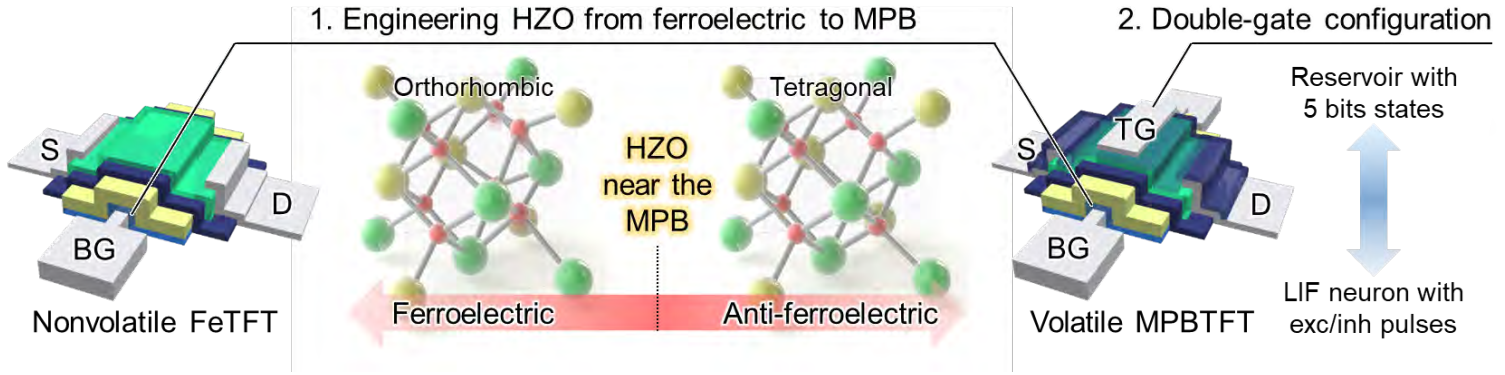
W Shin *et al.* Giant switching, rectification, and scalability via ferroelectric-ionic in-memory computing platform. ***In Prep***

Ferroelectric AI HW| Synapse-Neuron Co-Integration (Dr. Jangsaeng Kim)

AI HW Platform

Oxide-Channel Ferroelectric TFTs

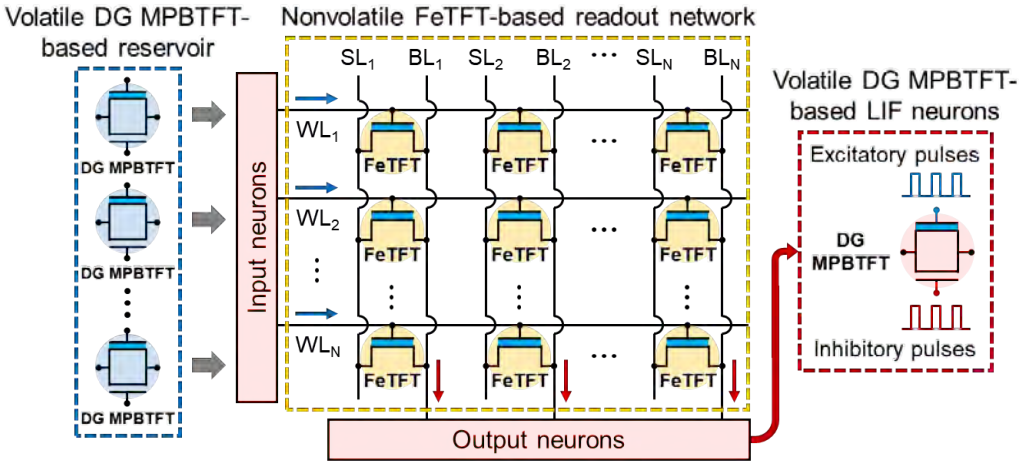


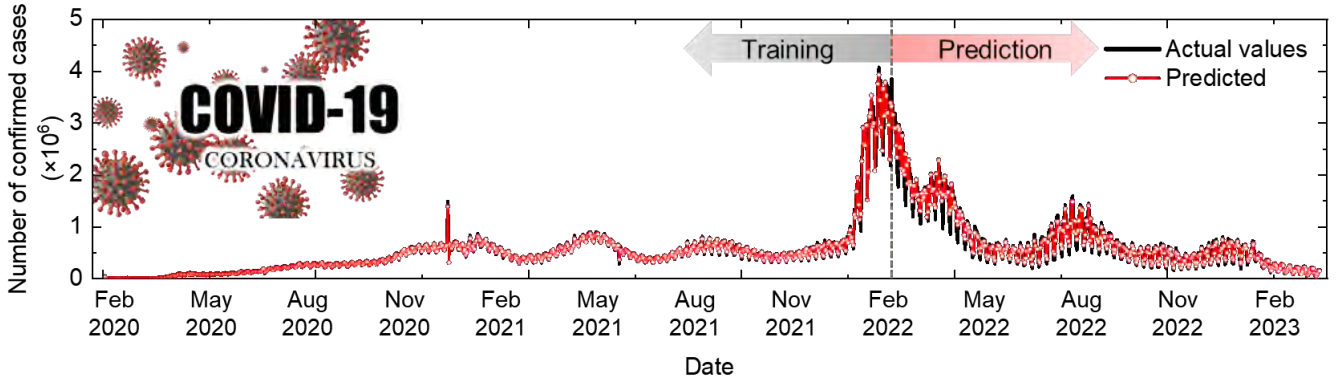


Dr. Jangsaeng Kim

Seamless Physical Reservoir System

Volatile Reservoir, Nonvolatile Synapse, & Volatile Neuron in same FeTFT platform





J Kim *et al.* Analog reservoir computing via ferroelectric mixed phase boundary transistors. ***Nat. Commun.*** 15, 9147 (2024).

Ferroelectric AI HW| Synapse-Neuron Co-Integration

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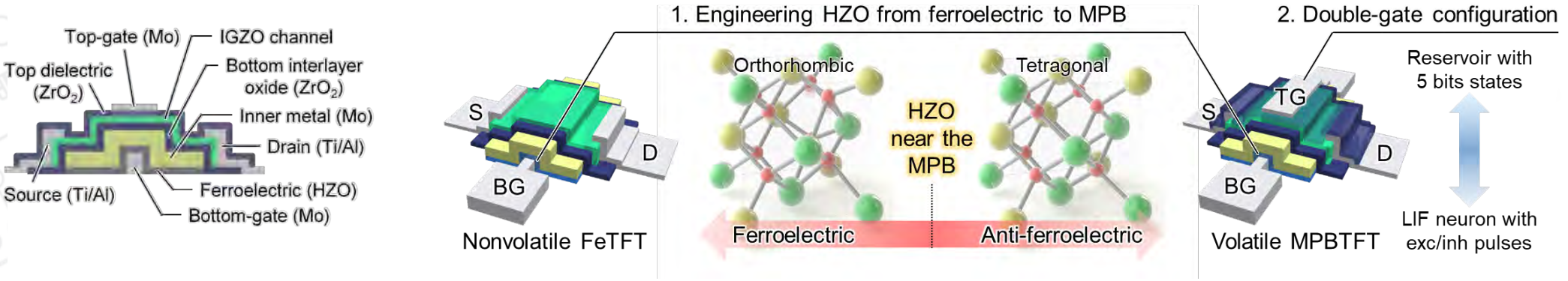


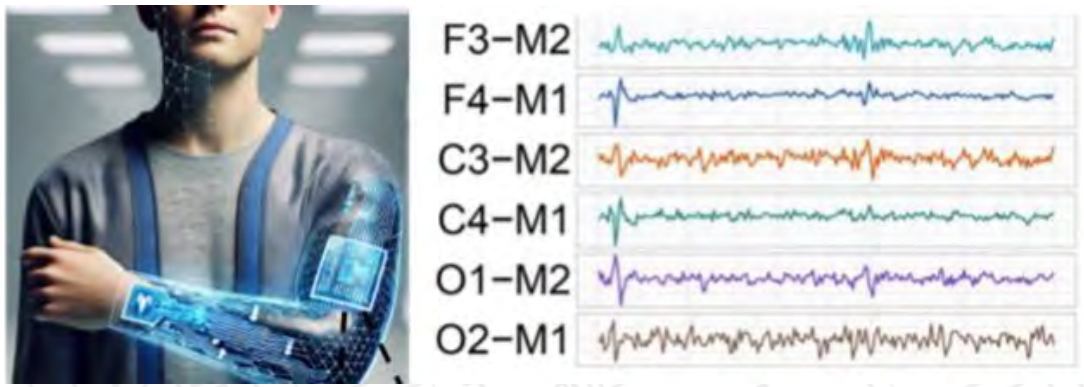
Dr. Jangsaeng Kim

FUTURE: Wearable Medical AI Devices for Continuous Healthcare Monitoring

Health monitoring: heart rate, ex/ inhale, sleep patterns, etc.

→ Small size CNN/ DNN/ RC is sufficient

Integrate FeTFTs on flexible platform co-integrated with electrical (ECG, EMG, EOG) sensors



Dr. Atharva Sahasrabudhe