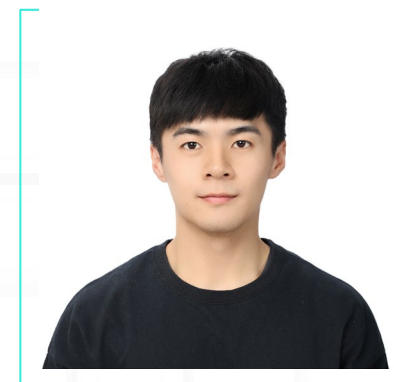


Energy-efficient Brain-inspired Computing with Electrochemical Ionic Synapse (EIS) Devices

From Knowledge to Competitiveness

Portugal-US Partnerships 2026 Summit

MIT Portugal Program

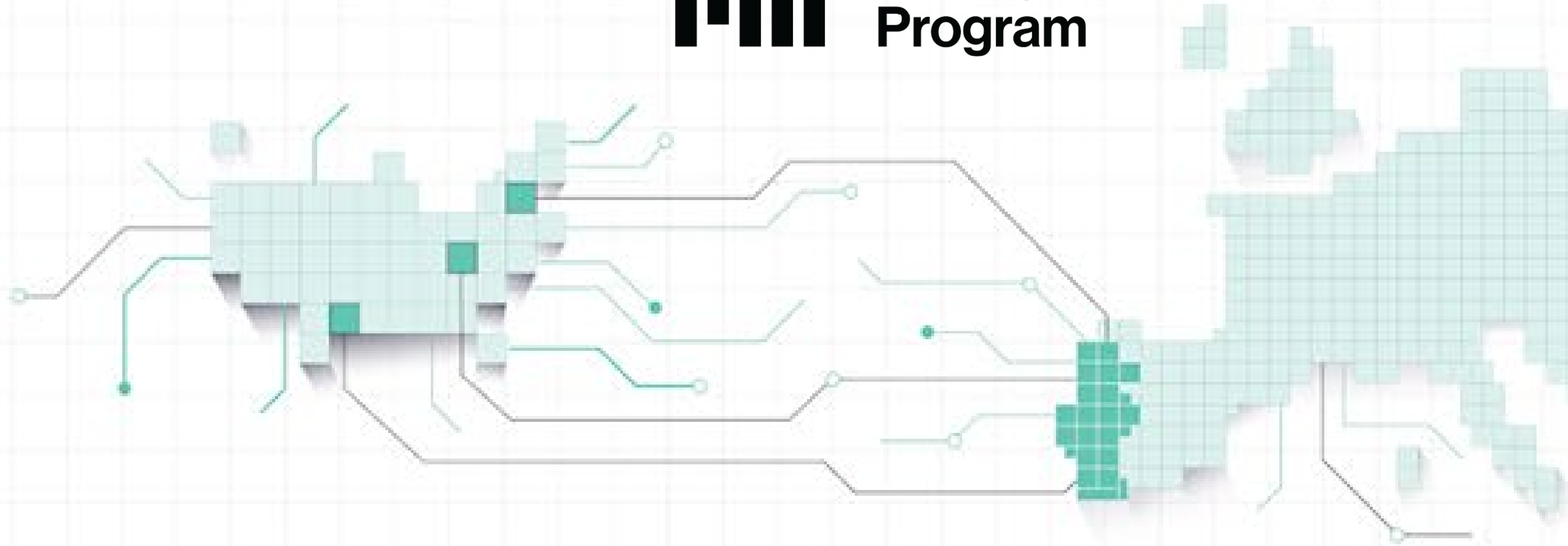


TSUNG-KAI (SAMMY) SU¹

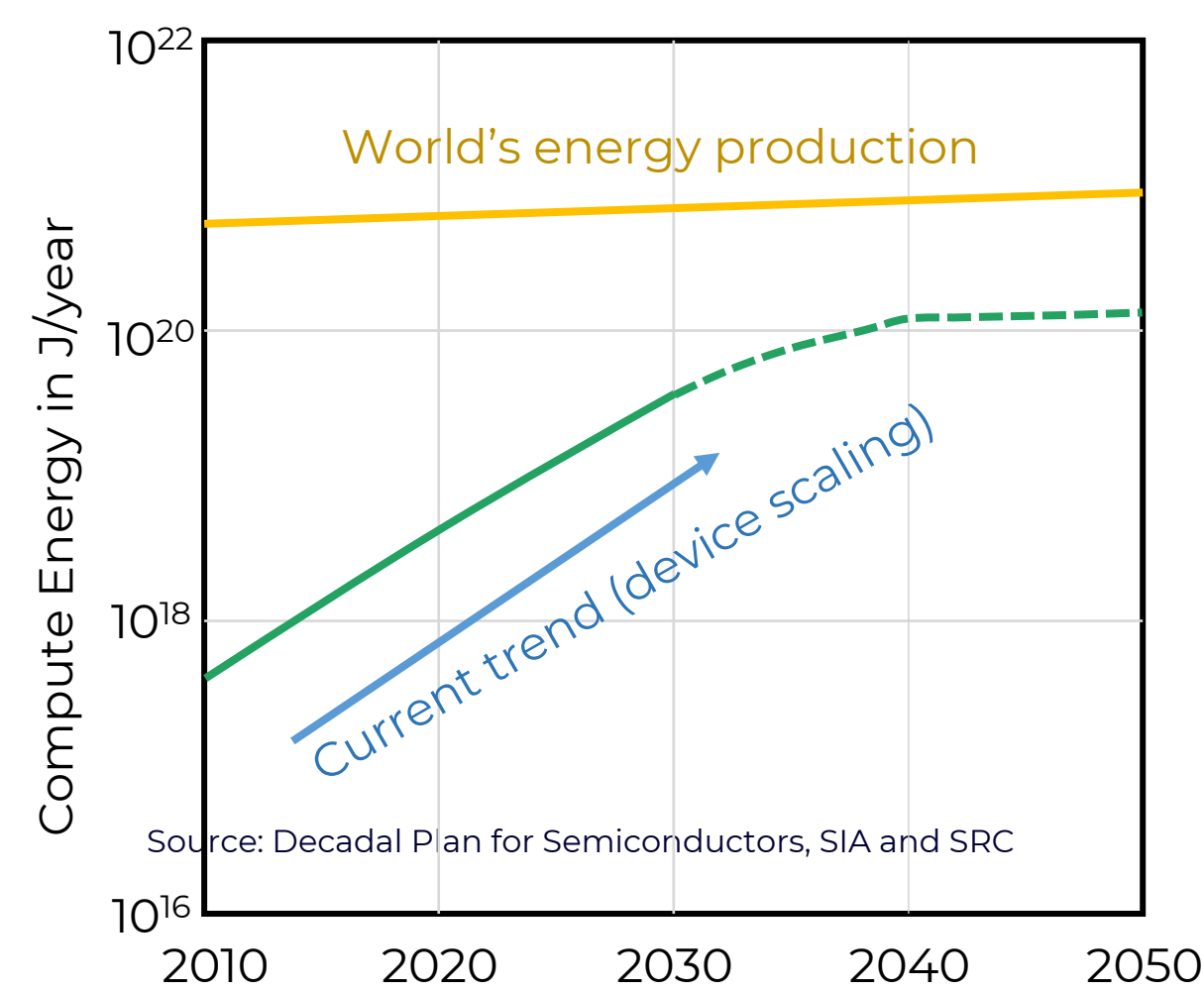
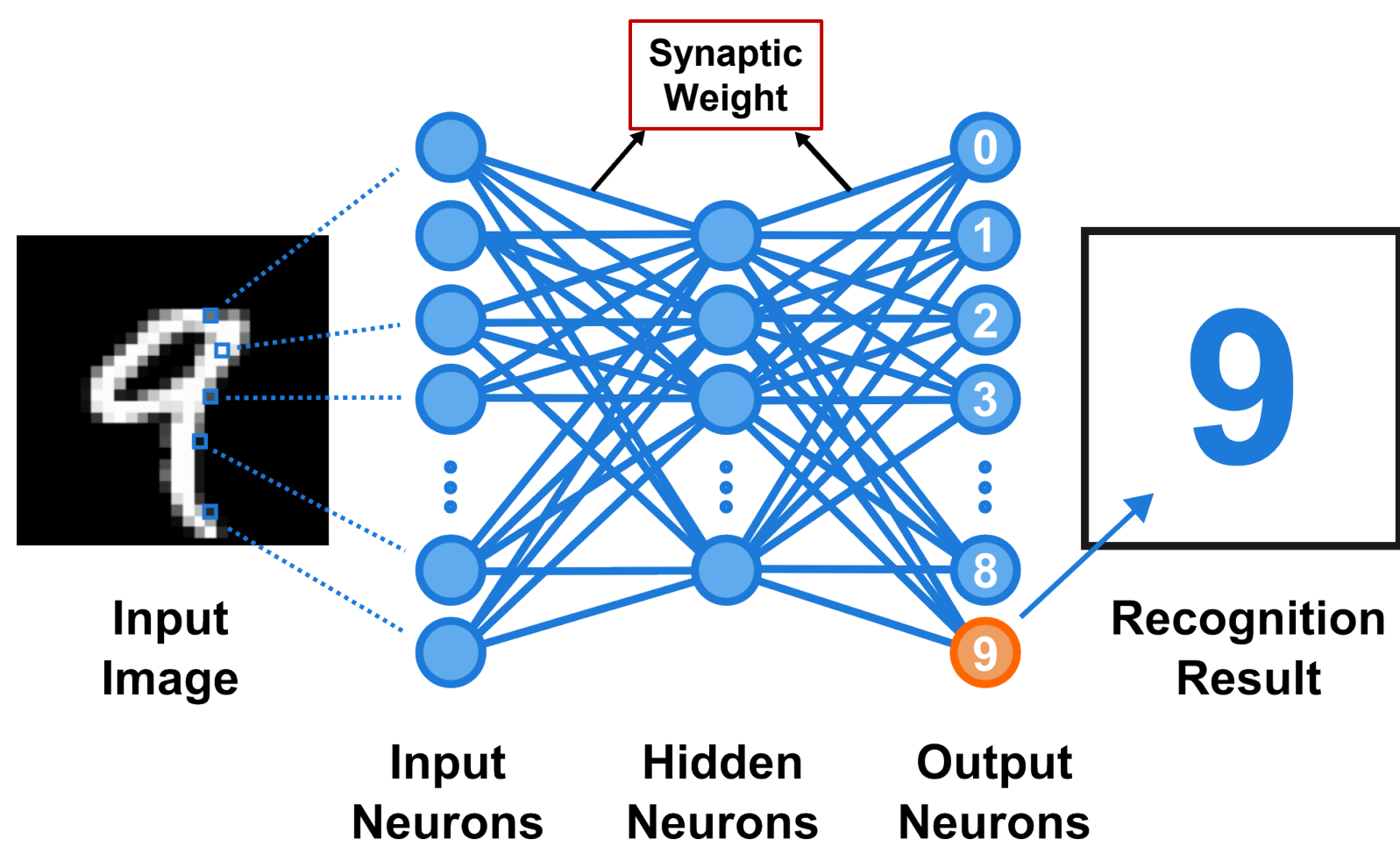
sammysu@mit.edu

Supervisor(s): Bilge Yildiz^{1,2}, José P. B. Silva³

1. Department of Materials Science and Engineering, MIT, MA, USA
2. Department of Nuclear Science and Engineering, MIT, MA, USA
3. Centre of Physics, University of Minho, Braga, Portugal



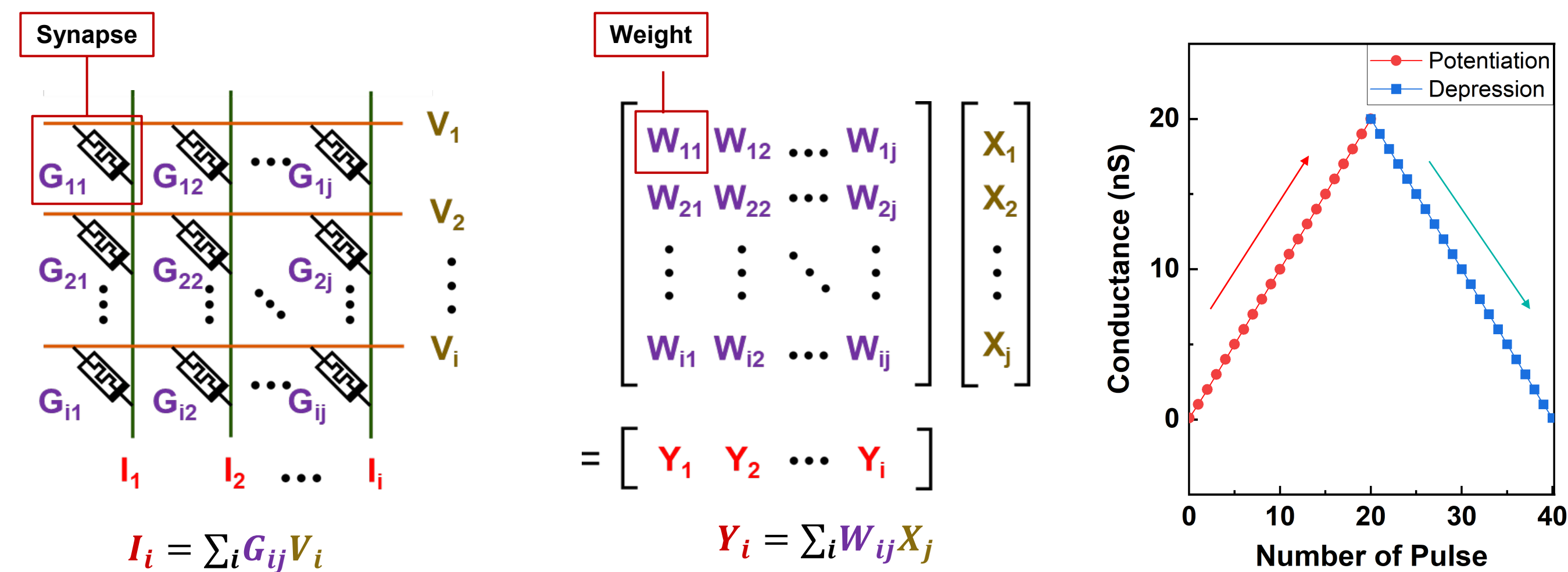
Motivation



- Problem: **Energy consumption for computation** is increasing rapidly and approaching global energy production rate.
- Bio-inspired computing paradigms**, such as artificial neural network (ANN), provide a pathway to higher energy efficiency by combining memory units and computing units.
- However, software-based ANN still have high energy consumption due to **hardware incompatibility**, motivating the needs for dedicated **neuromorphic hardware**.

Objective

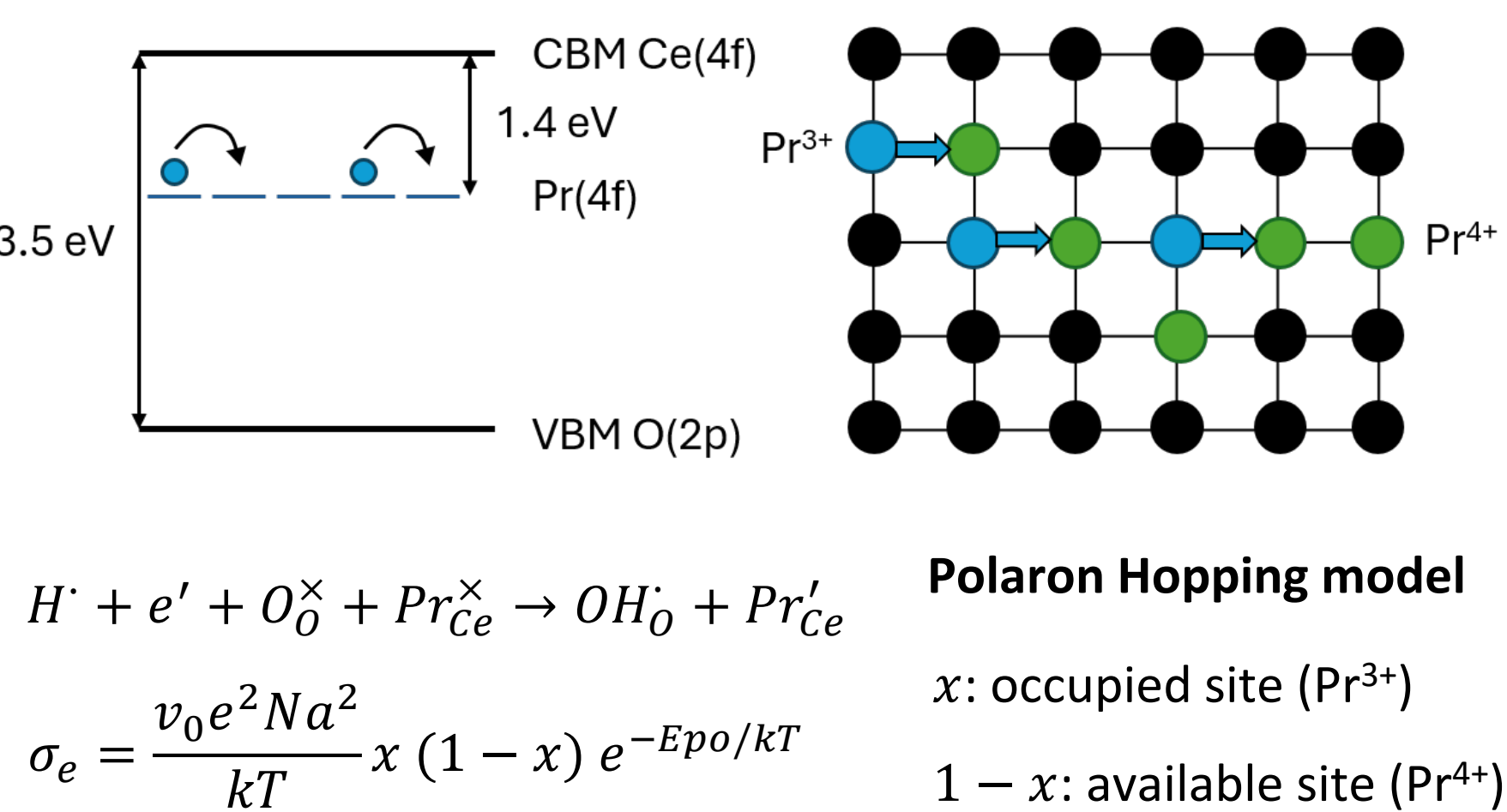
MPP research area



- The goal is to improve the **energy efficiency** of computing by more than **10⁶x**.
- Energy-efficient devices supporting neural-network operation are keys to the problem.
- Artificial synapses** are devices whose conductance can be modulated linearly, which can be used to represent weights in ANNs, enabling hardware-based matrix-vector multiplication by Kirchhoff's law.
- In this project, we aim to develop a new **electrochemical ionic synapse (EIS)** through mechanism-driven materials design. In addition to improving performance toward the desired regime, we will explore the fundamental electrochemistry and ion transport mechanisms in **cerium oxide (CeO₂)**-based materials.

Methodology

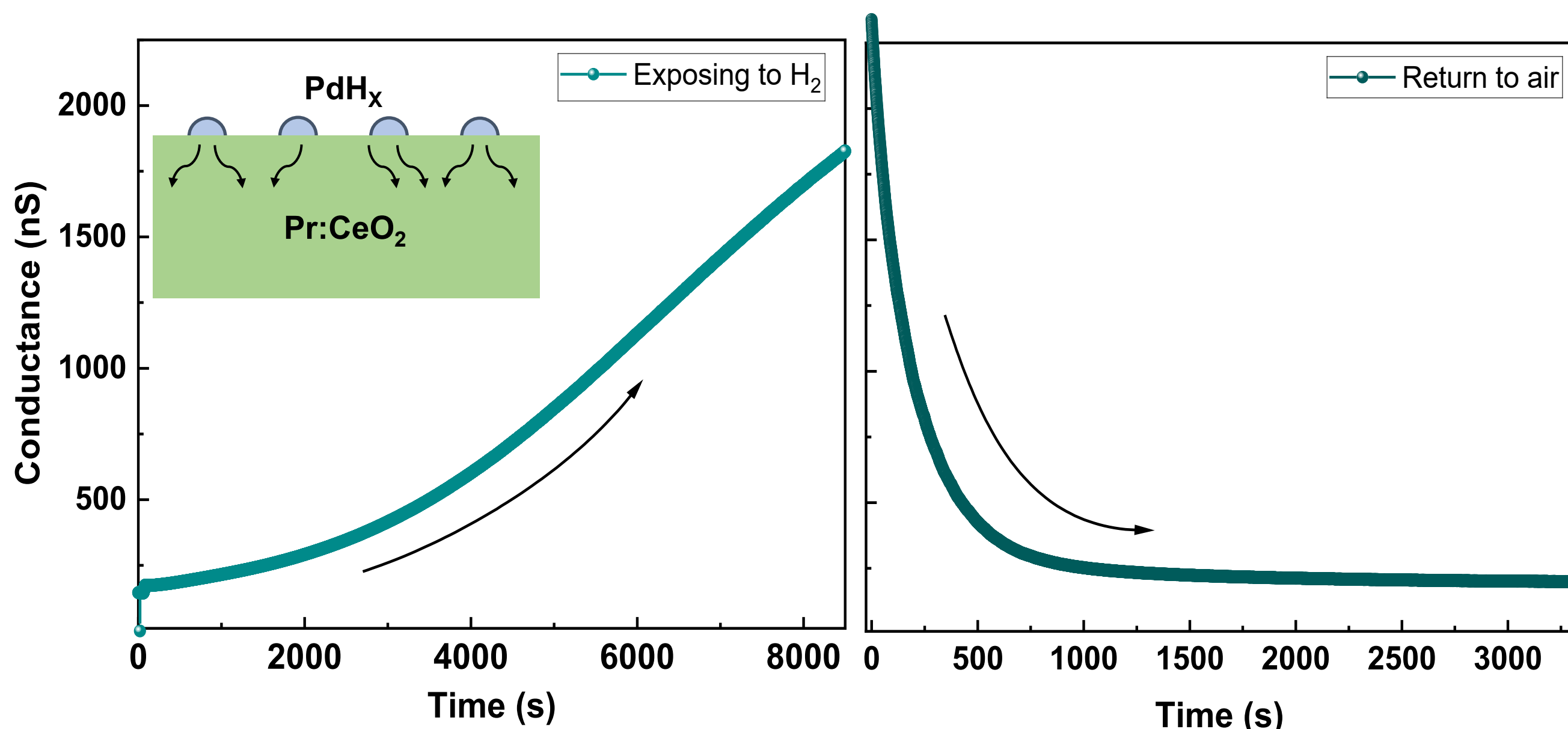
Channel Materials Selection: Pr-doped CeO₂ (Pr:CeO₂)



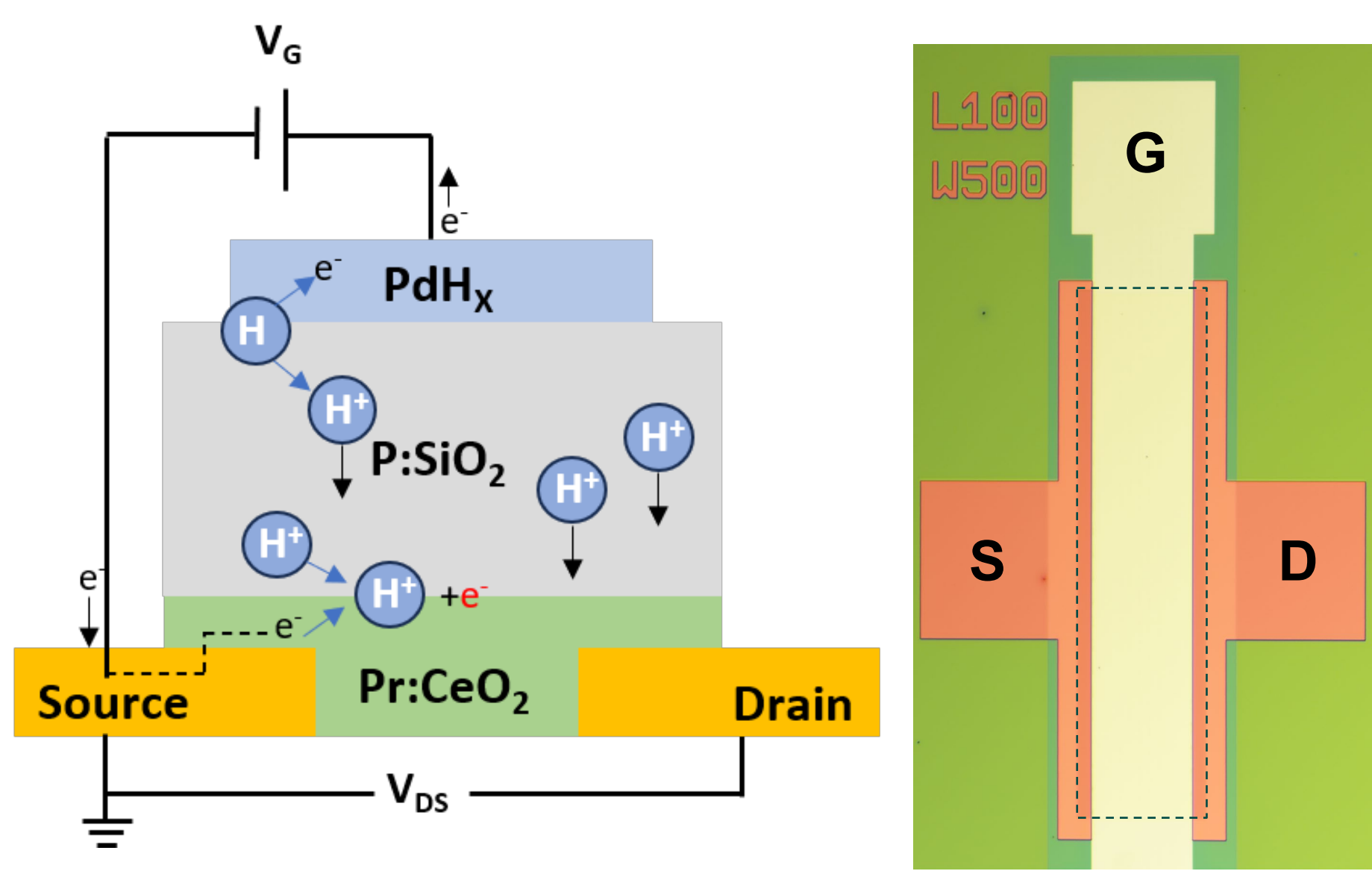
Pr:CeO₂ is known for its electrochemical activity, commonly used in solid oxide fuel cells.

Multivalent nature of Pr (**Pr³⁺** and **Pr⁴⁺**) enables **polaron hopping** mechanism for conductance modulation with proton insertion/extraction.

Hydrogen spillover test shows reversible and analog conductance change of Pr:CeO₂: increases in hydrogen gas and decreases in the air, with an on/off ratio over 10.

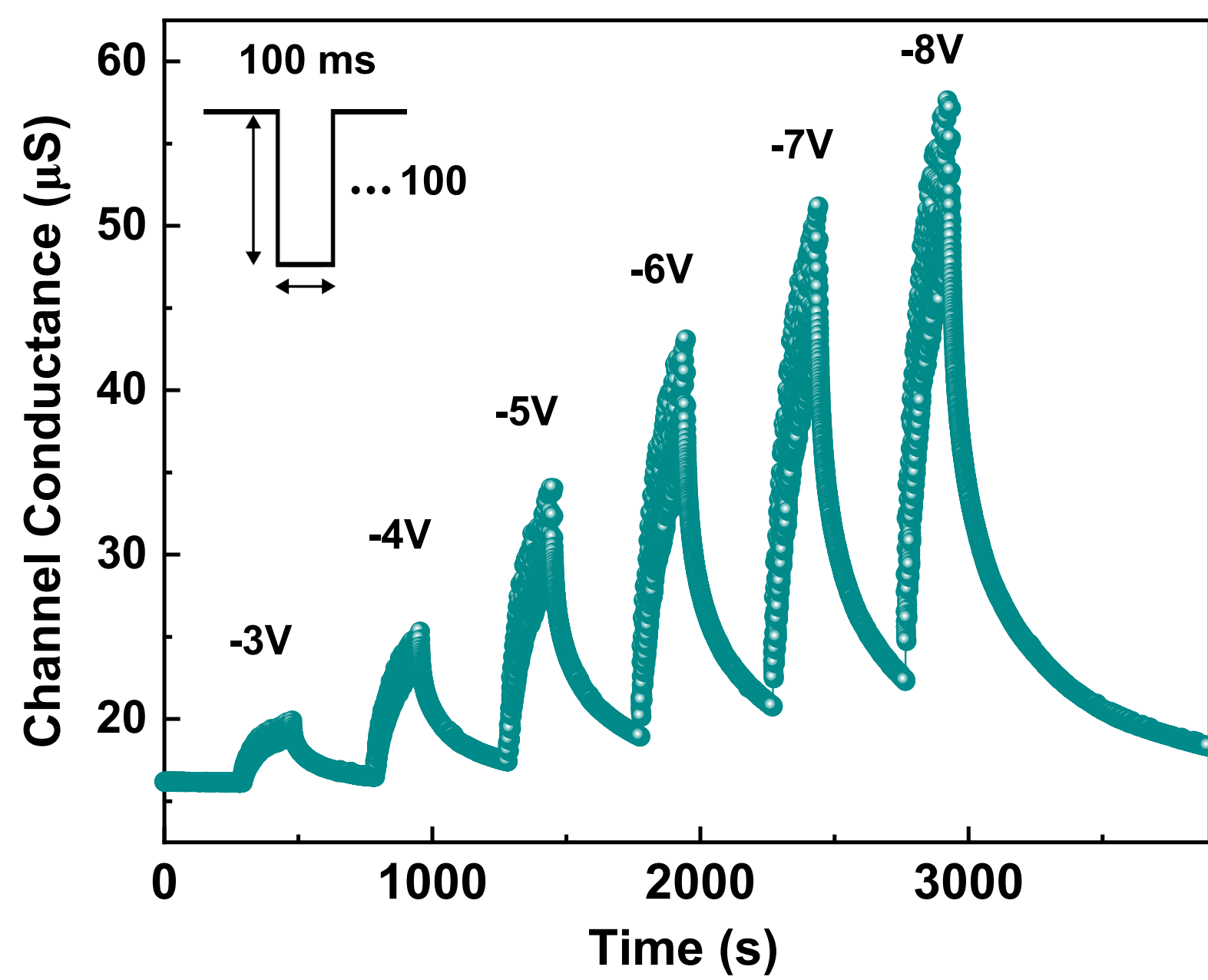


Results and Discussion



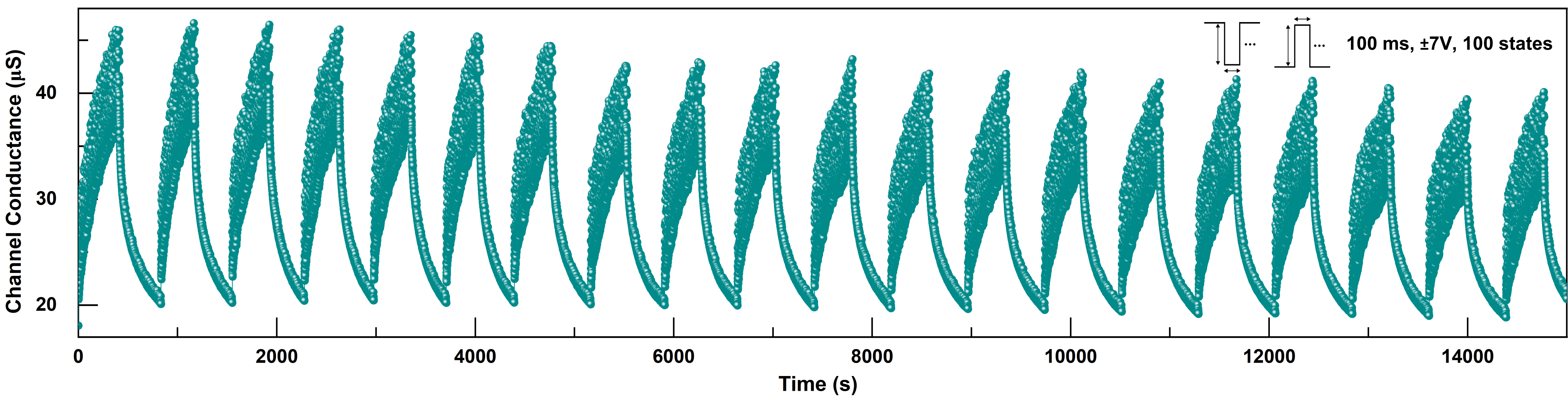
Fabrication Flow

- Pulse Laser Deposition Pr:CeO₂, followed by etching and patterning
- E-beam evaporation Ti/Au as S/D contact, followed by lift-off
- PECVD Phosphate Silicate Glass as electrolyte
- E-beam Evaporation Pd, followed by lift-off
- Exposing to 3% forming gas to form PdH_x



- Pr:CeO₂ devices show stable conductance modulation with voltage pulses.
- Larger voltage amplitudes lead to greater conductance changes, consistent with the field-assisted ion hopping model in solid-state electrolytes.
- Potentiation with negative voltages and depression with positive voltages are demonstrated, with retention around a few hundred seconds.
- Preliminary endurance testing demonstrates 100 conductance states over more than 20 cycles with stable modulation.

- All-solid-state** Pr:CeO₂-based EIS are fabricated with **CMOS-compatible** processes. The channel dimensions are 100μm length by 500μm width.



Conclusion and Future Works

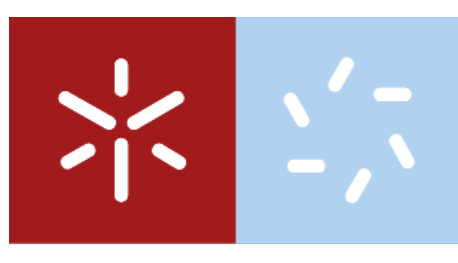
- CMOS-compatible all-solid-state Pr:CeO₂ EIS devices are demonstrated, with linear conductance modulation and endurance over 4000 pulses.
- Scale down device dimensions to improve the operating speed.
- Integrate with nanoporous CeO₂ electrolyte to build a high-quality interface, reducing the operating voltage.
- Verify the interfacial resistance contribution and the conductance-modulation mechanism through materials characterization, such as XPS and XAS.

Acknowledgement

Funded by:



Affiliation and Facilities:



MIT.nano

