
# International Workshop on Embedded Artificial Intelligence Devices, Systems, and Industrial Applications (EAI)

MILAN
19-22 SEPTEMBER 2022
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Milan, Italy 19 September 2022

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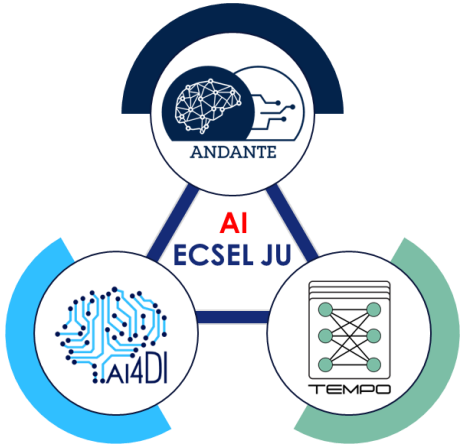


# Low-Power Vertically Stacked One Time Programmable Multi-bit IGZO-Based BEOL Compatible Ferroelectric TFT Memory Devices with Lifelong Retention for Monolithic 3D-Inference Engine Applications


Sourav De

19 September 2022 Milan, Italy

# Presentation Outline

- Introduction
- Process flow
- Capacitor Characterization
- Transistor Characterization
- Implications to Neural Network
- Benchmarking

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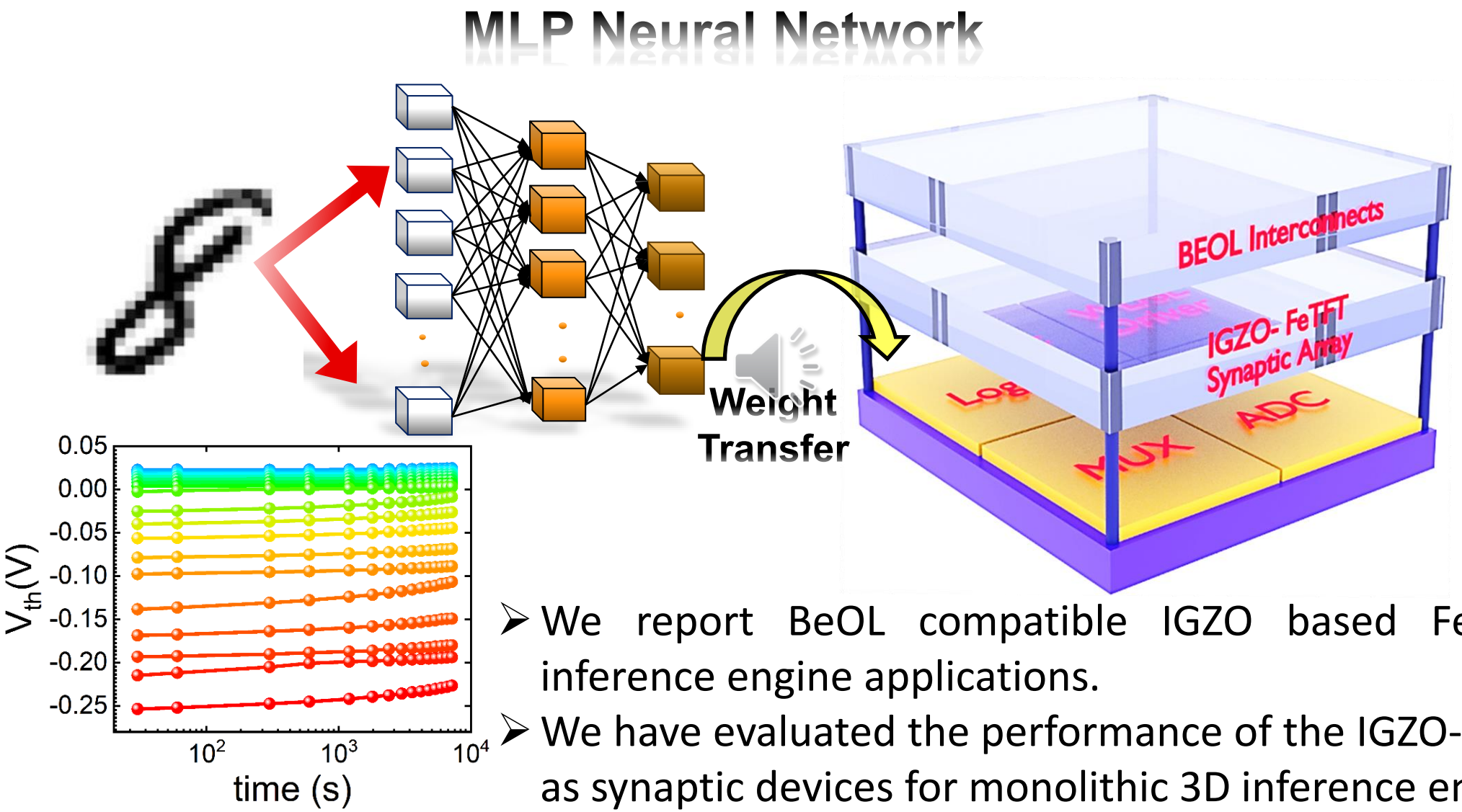
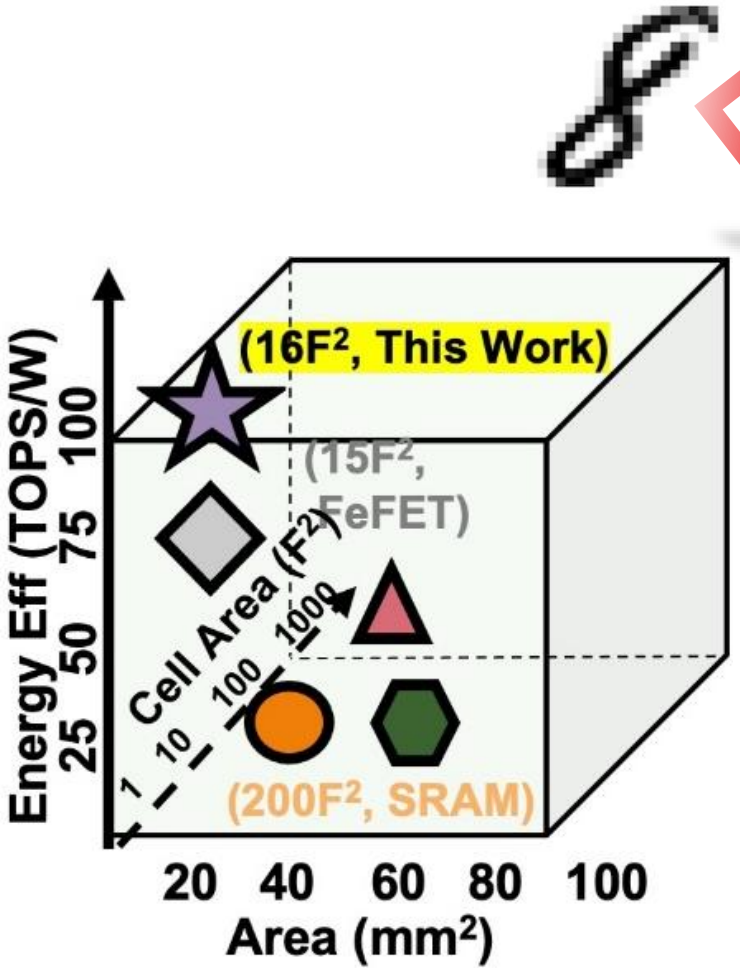
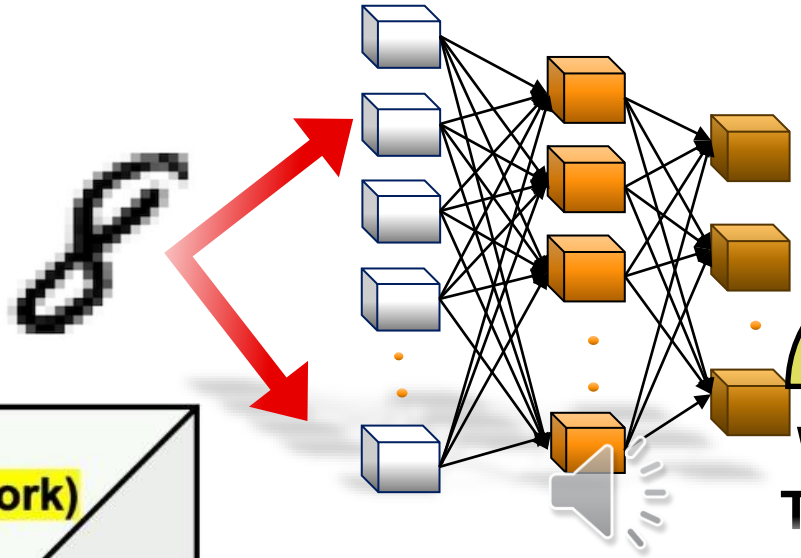
# Introduction



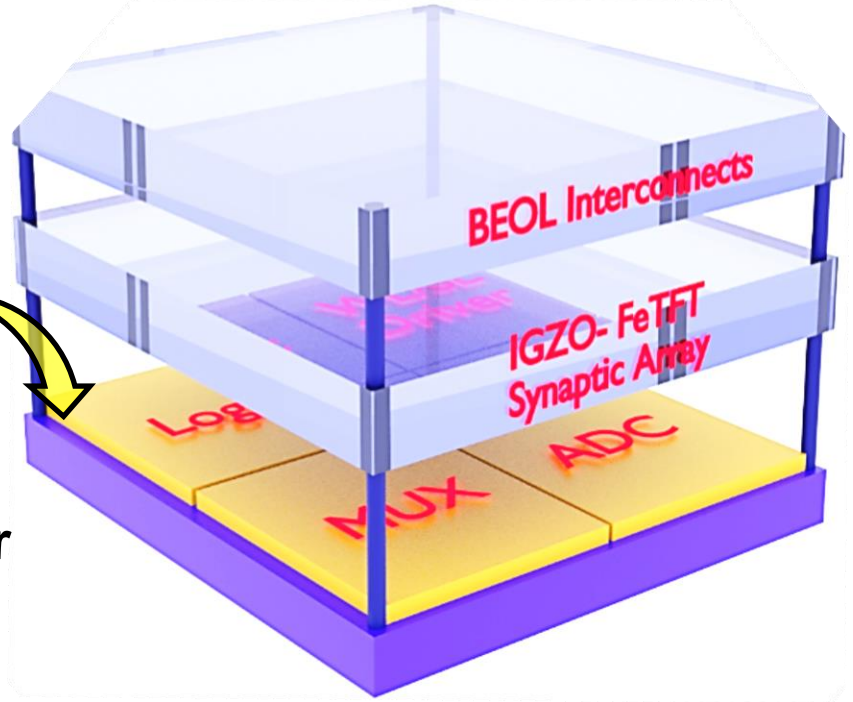

- We report BeOL compatible IGZO based FeTFT device inference engine applications.
- We have evaluated the performance of the IGZO-based FeTFT as synaptic devices for monolithic 3D inference engine.

# Introduction



Weight Transfer




- The inference engine maintains ~95% inference accuracy over ten years (extrapolated).
- The inference engine maintains and energy efficiency of 95.33 TOPS/W and $16F^2$ feature size.

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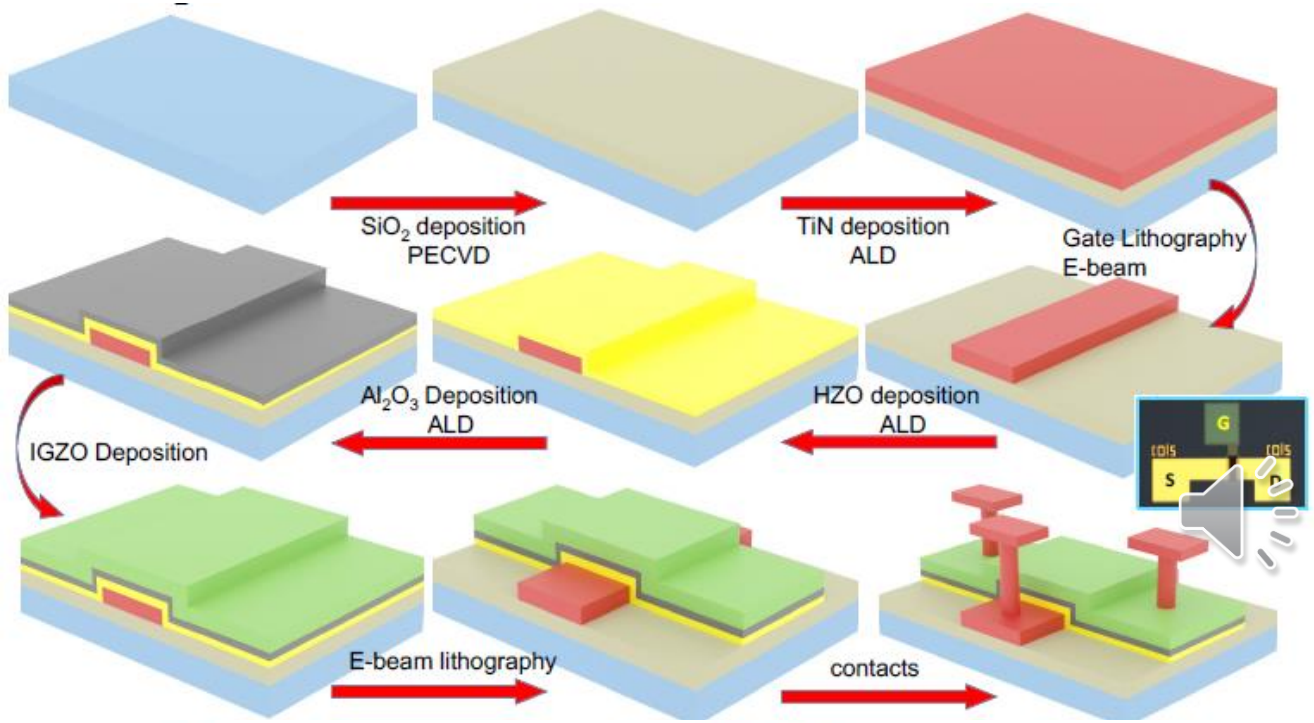
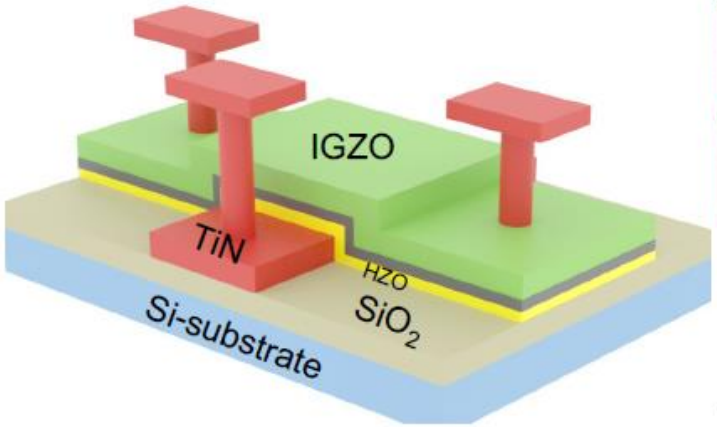
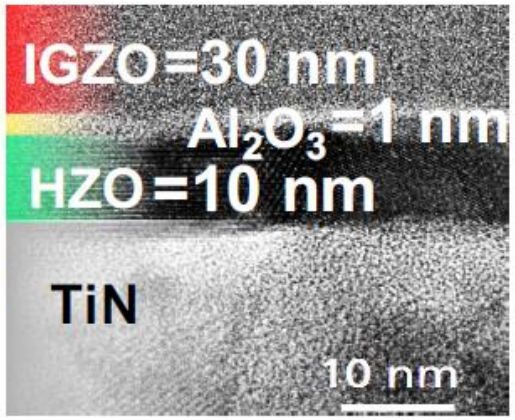
# Process flow




- Standard cleaning of Si wafer
- Deposition of $SiO_2$ by PECVD
- Deposition of TiN by ALD
- Gate lithography by E-beam
- Deposition of HZO by ALD
- Deposition of $Al_2O_3$ by ALD
- Deposition of IGZO
- E-beam lithography
- Contact pad deposition.

Maximum process temperature is 350°C

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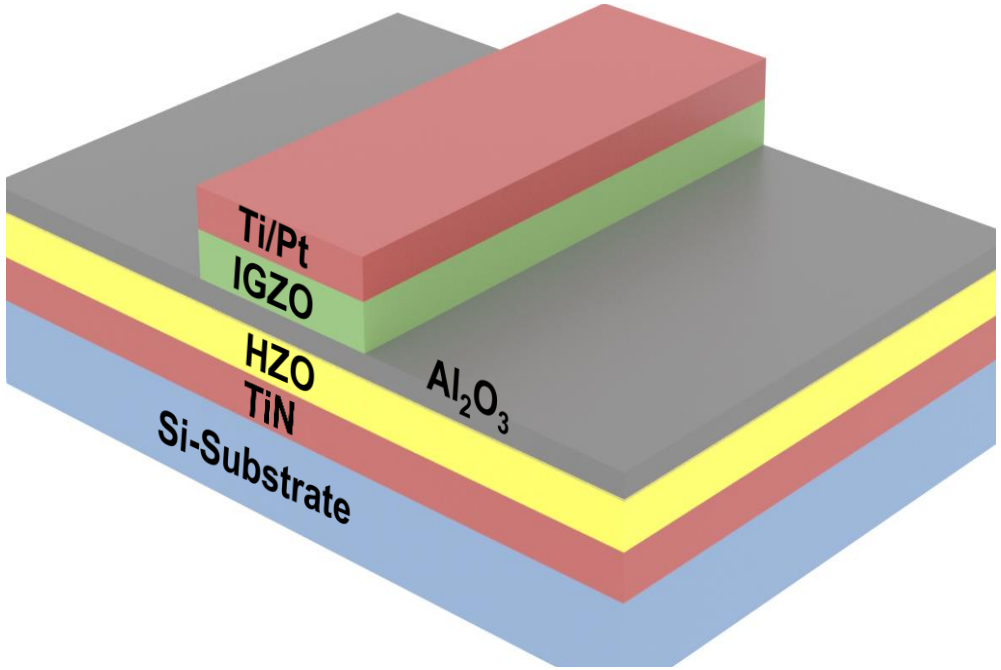
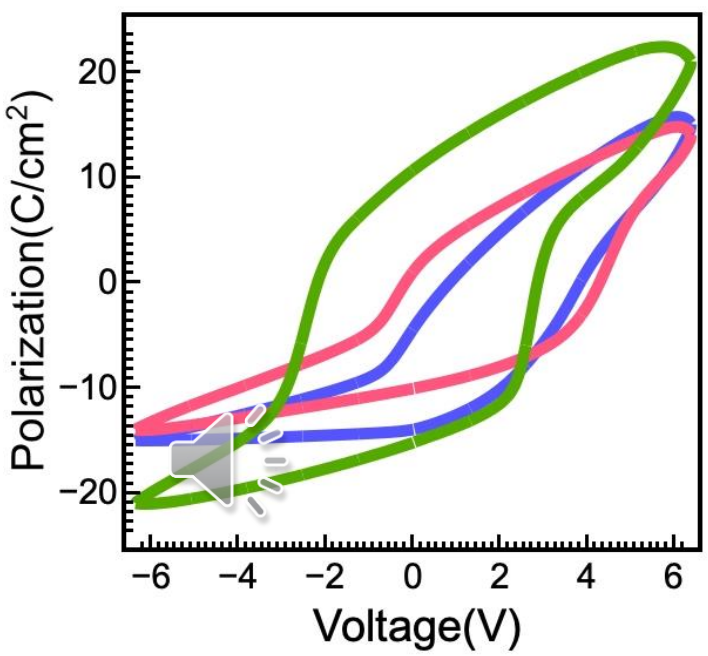
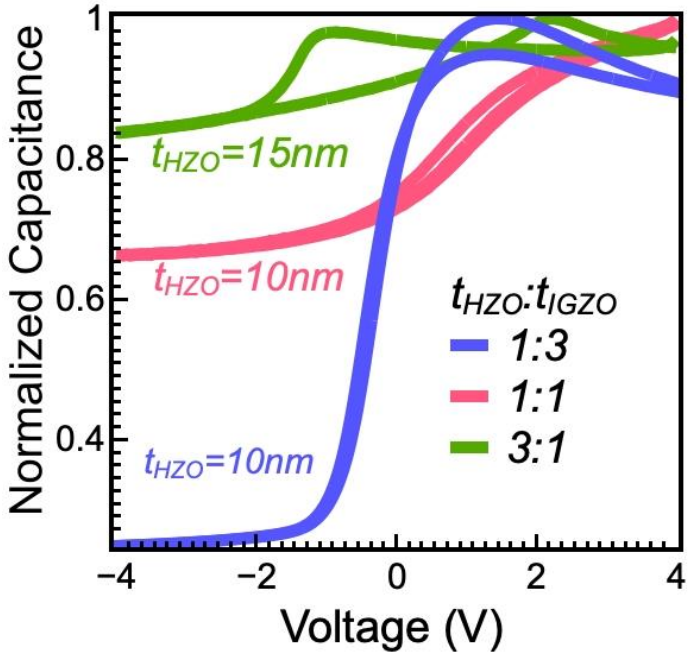
# Capacitor Characterization




- Schematic of the gate-stack with IGZO as semiconductor and HZO as a ferroelectric layer.
- Polarization versus voltage (P–V) response of metal-semiconductor-FE-metal (MSFM) gate stacks with various thicknesses of the HZO and IGZO.
- Capacitance versus voltage (C–V) response of metal-semiconductor-FE-metal (MSFM) gate stacks with various thicknesses of the HZO and IGZO.

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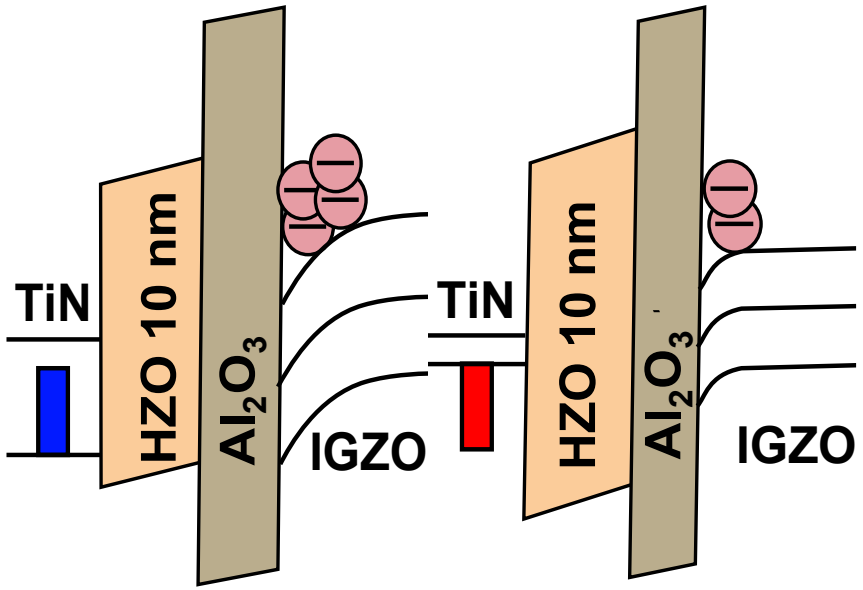
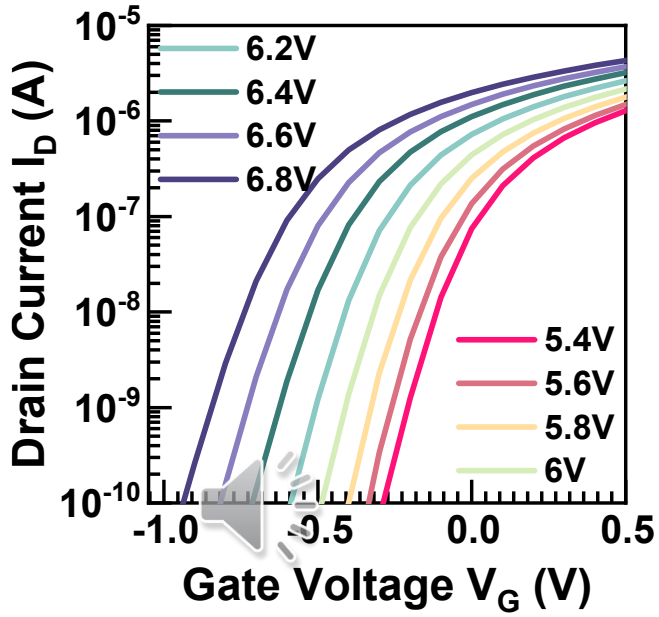
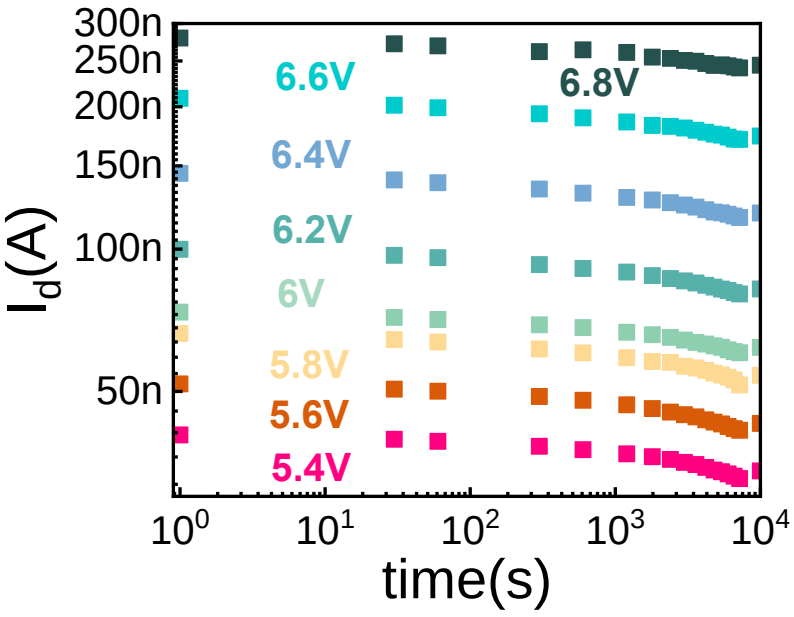
# Transistor Characterization




- The band diagram of the IGZO-MOS capacitor during the program and erase operation. Although the high value of $\mu_n$ facilitates fast programming, the low value of $\mu_p$ inhibits the erase operation by preventing the supply of holes during erase operation.
- 3 bits/ cell WRITE operation in IGZO-based FeTFTs with 200 ns wide pulses of minimum amplitude 5.2 V and maximum amplitude of 6.8 V.
- The measured retention characteristics show stable retention of 8-states for $10^4$ seconds and for ten years for 2bits/cell operation with negligible degradation.

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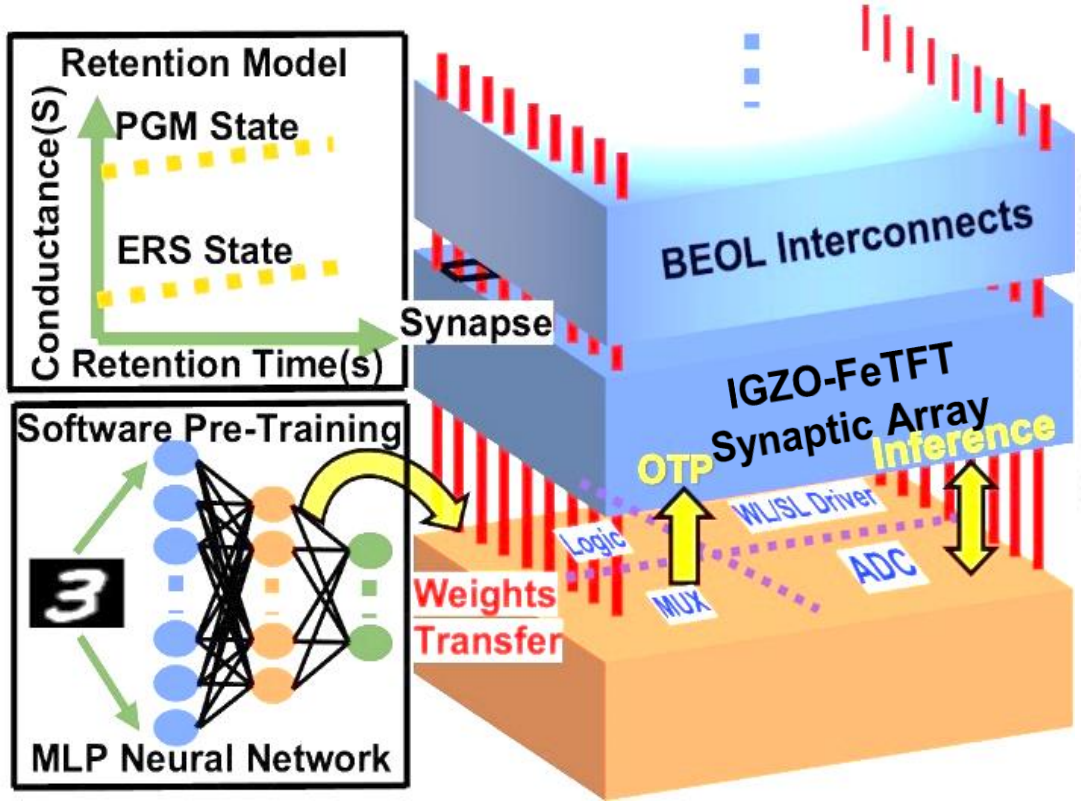
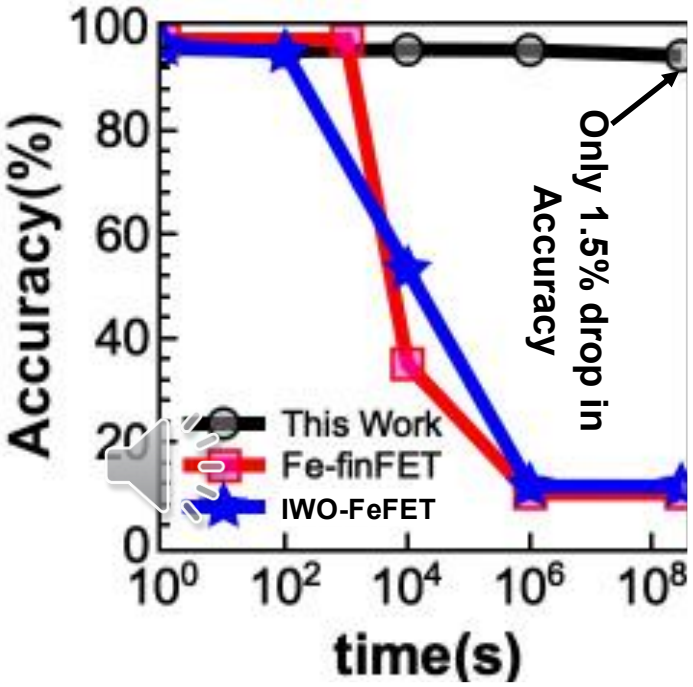
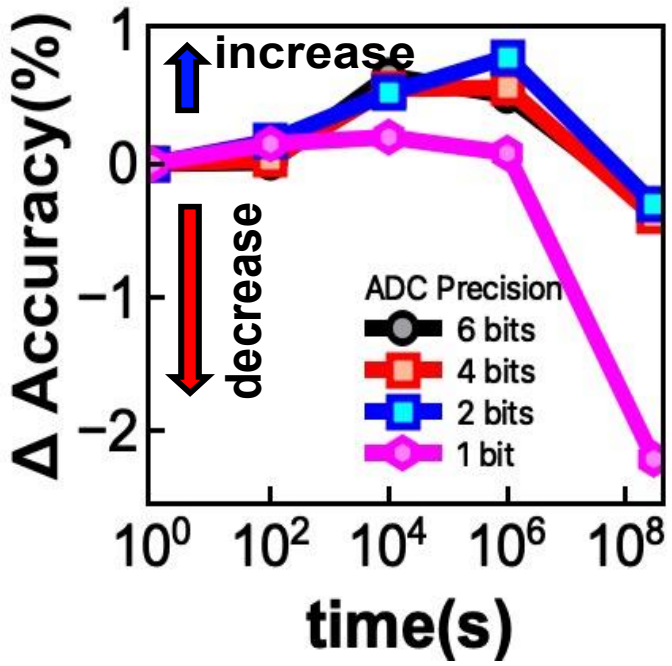
# Implications to Neural Network




- The modus operandi of monolithic 3D inference engine based on multilayer perceptron neural network.
- The reported inference engine shows life-long lossless inference operation and (c). Reducing the ADC precision to 1bit causes a mere accuracy degradation of 1.87% from FP precision.
- 1-bit ADC shows less than 2% accuracy loss over 10 years.

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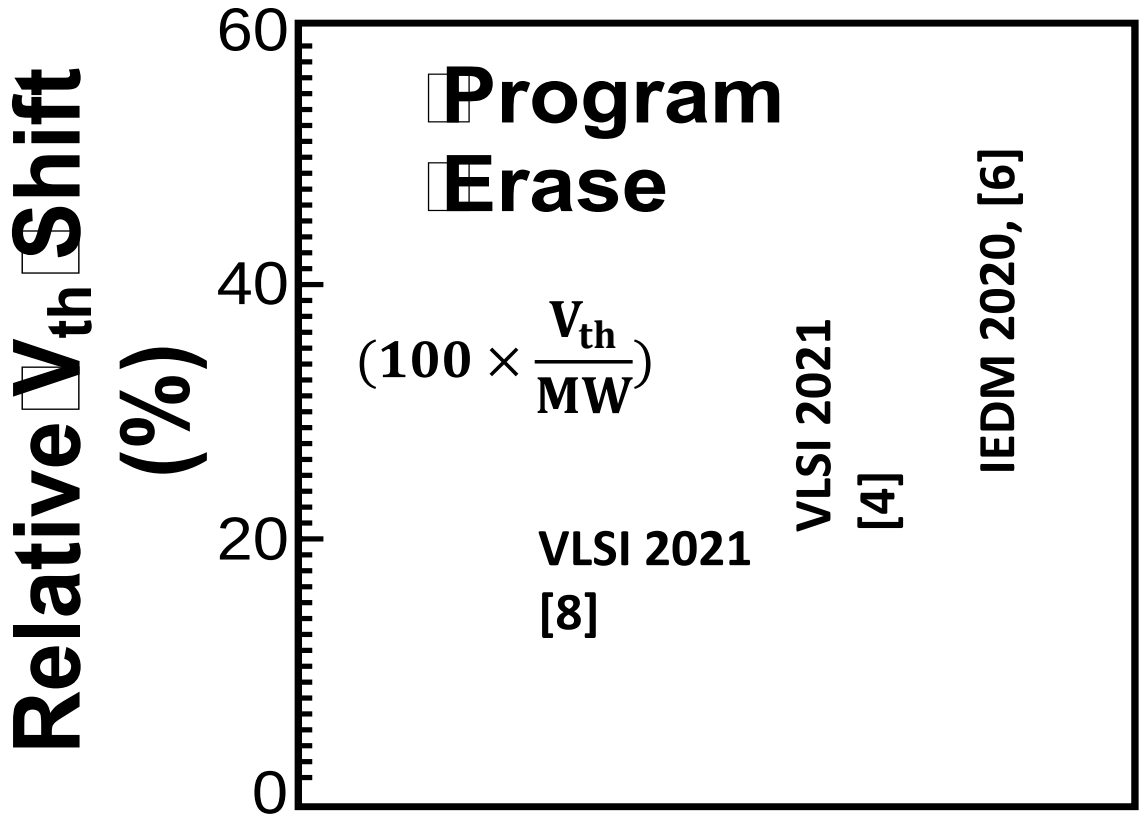


| Device Type | Fe-FinFET [9] | IWO-FeFET [14] | This Work |
|---|---|---|---|
| M3D Integrator | No | Yes | Yes |
| Cell Area ($F^2$) | $15F^2$ | $15F^2$ | $16F^2$ |
| $R_{on}$ (Ω) | 100K | 4M | 100M |
| MW @10 years | 1 | 0.2 | 1 |
| Inference Accuracy Drop @10 years | ~85% | 85% | 1.5% |
| Energy Efficiency (TOPS/W) | N/A | 71.04 | 95.33 (Binary) |

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