Thermal Engineering of Volatile Switching in $PrMnO_3$ RRAM: Non-Linearity in DC IV Characteristics and Transient Switching Speed

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Outline

Motivation

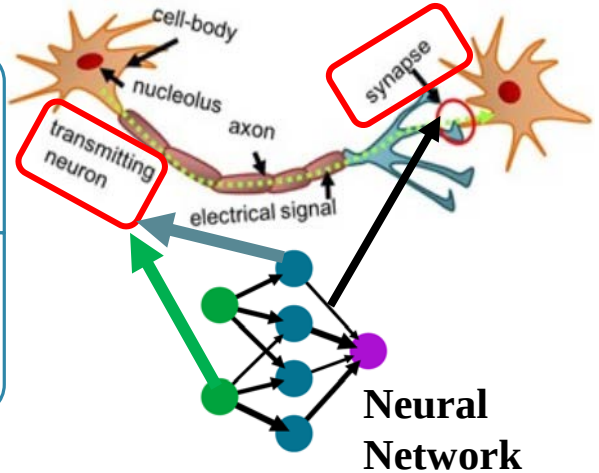
Data Driven Applications

- Computing (Volatile Memory)
- Data Storage (Non-Volatile Memory/ Volatile Memory)

Parallel Computing | **Low Energy**

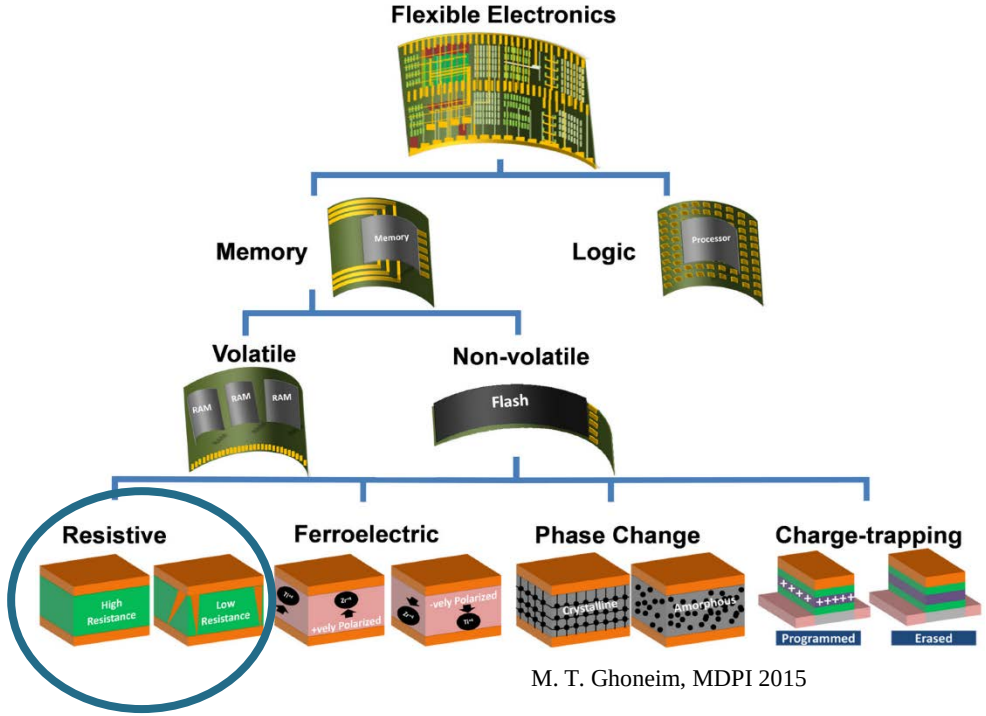
Brain Inspired Neural Networks

High Performance | **High Density**



Neural Network

Emerging Technologies

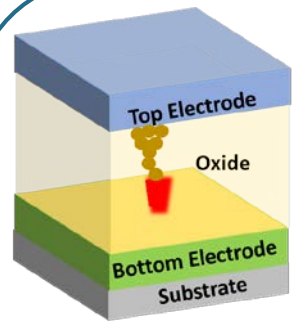


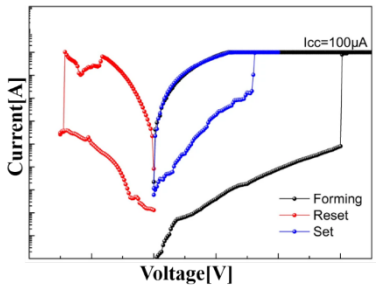
M. T. Ghoneim, MDPI 2015

Resistive Random Access Memory (RRAM)

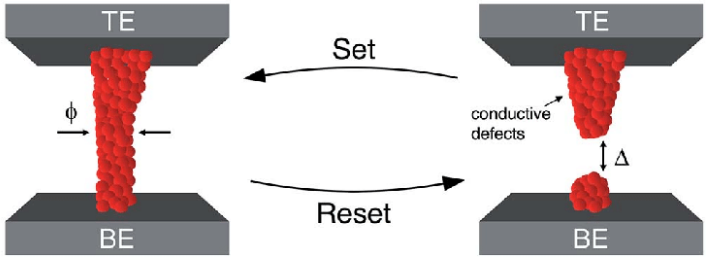
Key Features	Filamentary RRAM	Non-Filamentary RRAM	Physics

- ❑ Simple Structure
- ❑ High Density
- ❑ Low Voltage
- ❑ Fast Switching

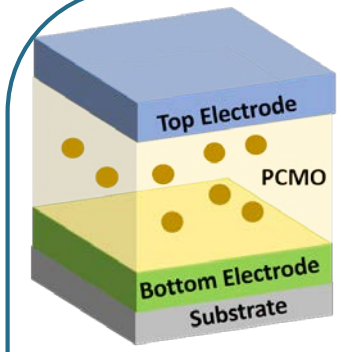


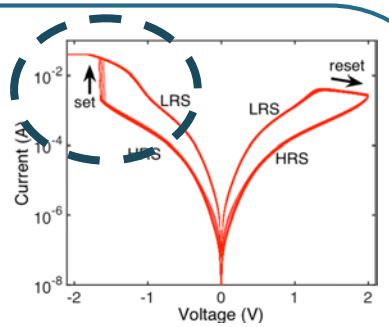


(a) (b)

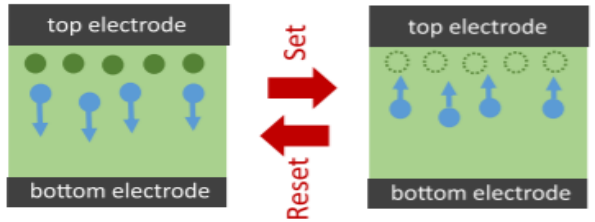


E. Ambrosi ,Faraday Discuss 2019





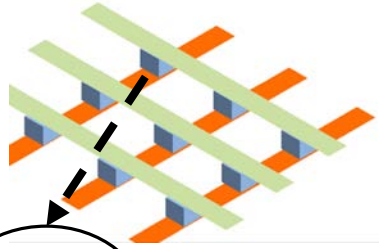
N.Panwar, TED 2017
S.Chouhan, DRC 2017
P. Kumbhare, TED 2018



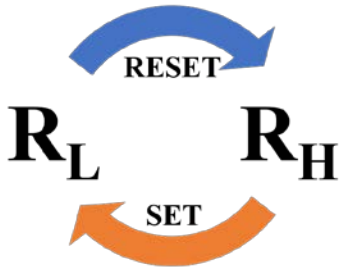
S.Slesazeck ,Nanotechnology 2019

- ❑ Ionic Transport
- ❑ Joule Heating

RRAM Crossbar Array



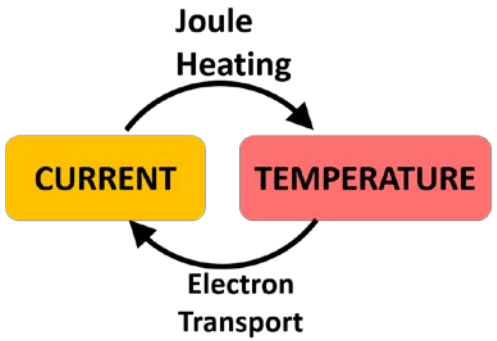
Area
Power
Speed



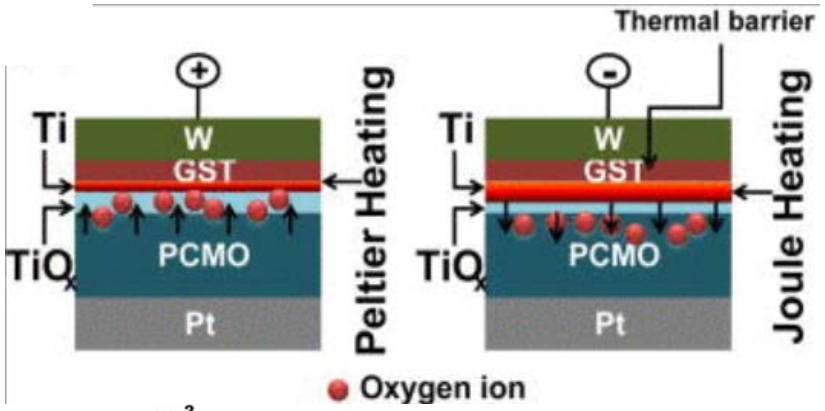
Selector-less RRAM with enhanced ***Non-Linearity*** is attractive

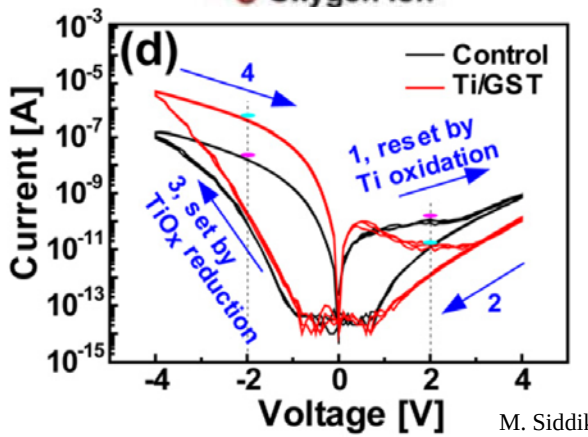
Enhancing Non-Linearity in RRAM

Positive Thermal Feedback



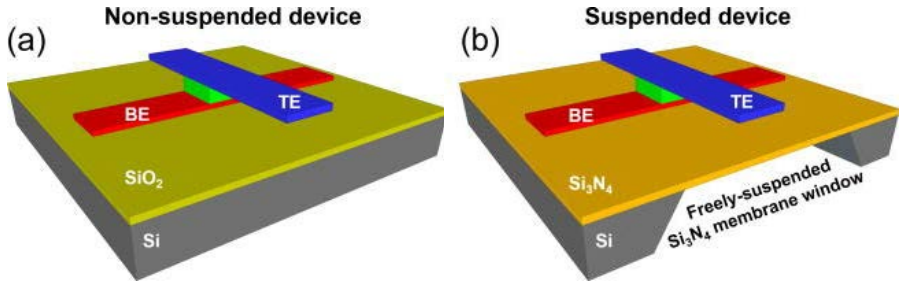
Incorporated Thermally Insulated Layer

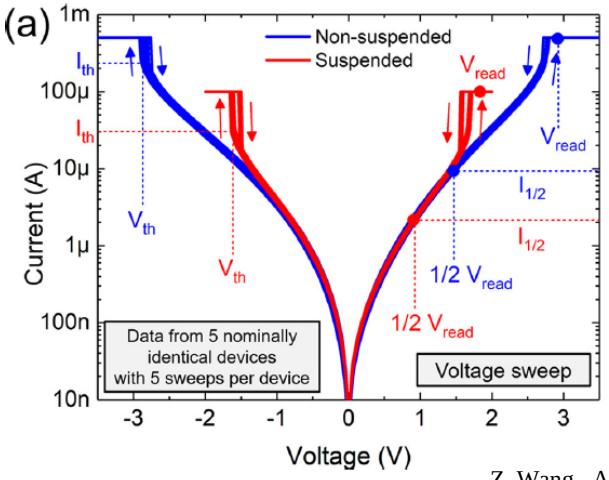




M. Siddik, APL,2011

Substrate Modification

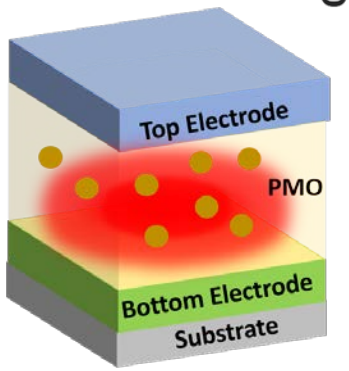




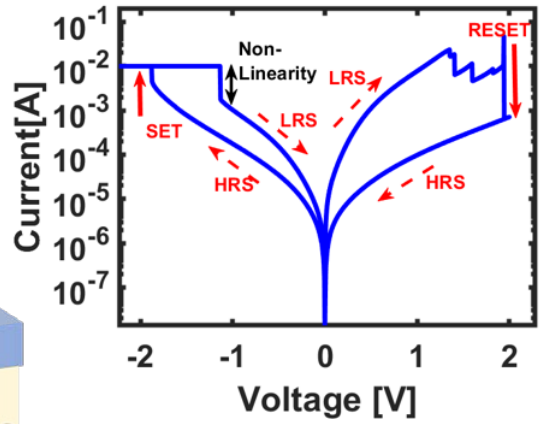
Z. Wang , APL 2018

Thermal Engineering is an effective medium to enhance Switching Characteristics

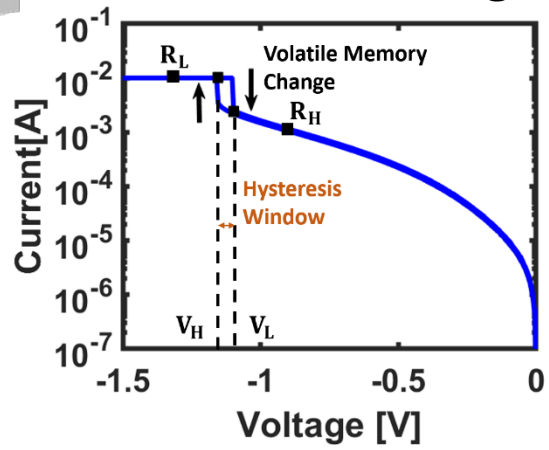
$PrMnO_3$ Based RRAM

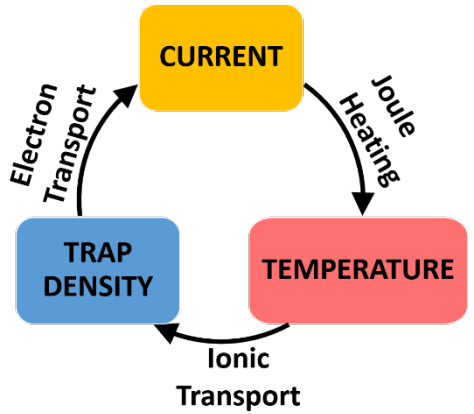


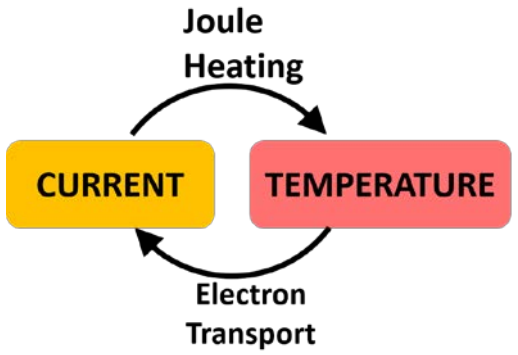
Non-Volatile Switching



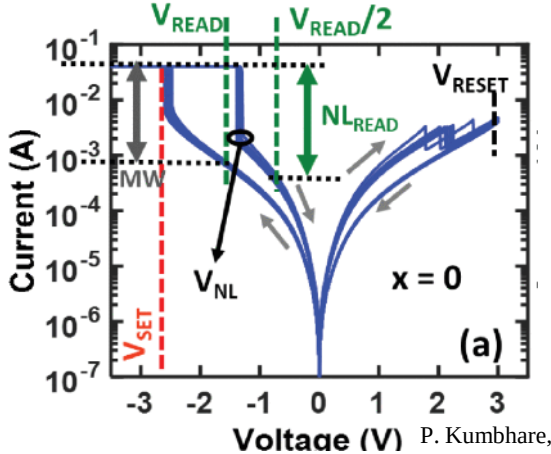
Volatile Switching





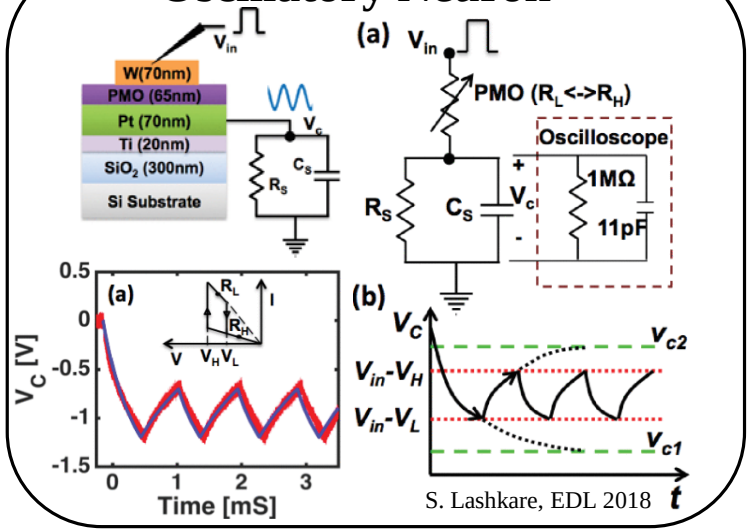


Selector-Less Memory



P. Kumbhare, TED 2018

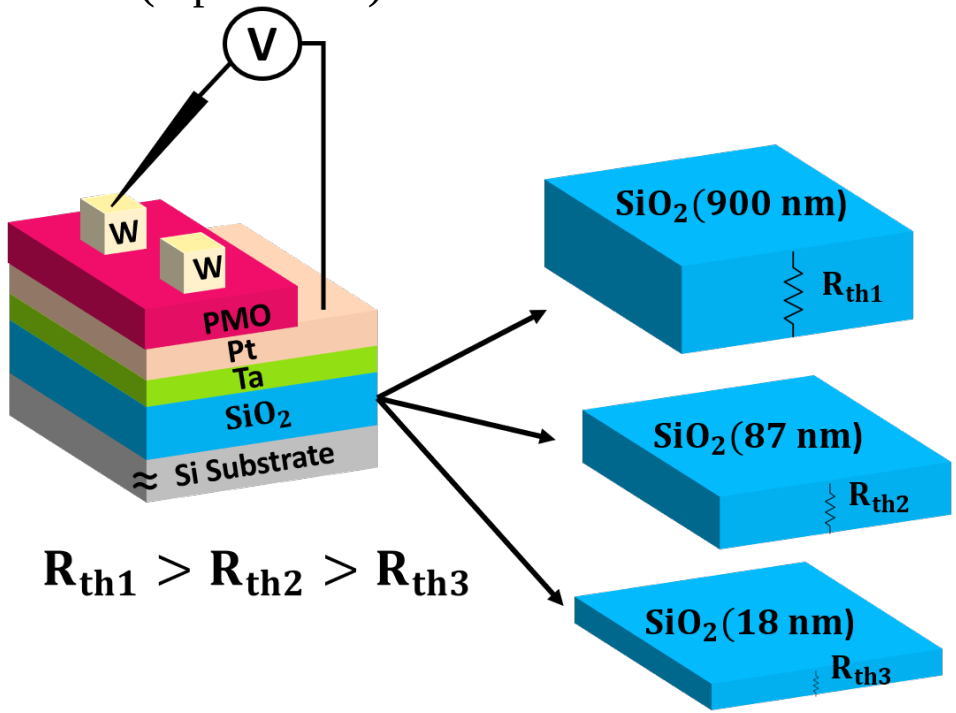
Oscillatory Neuron



S. Lashkare, EDL 2018

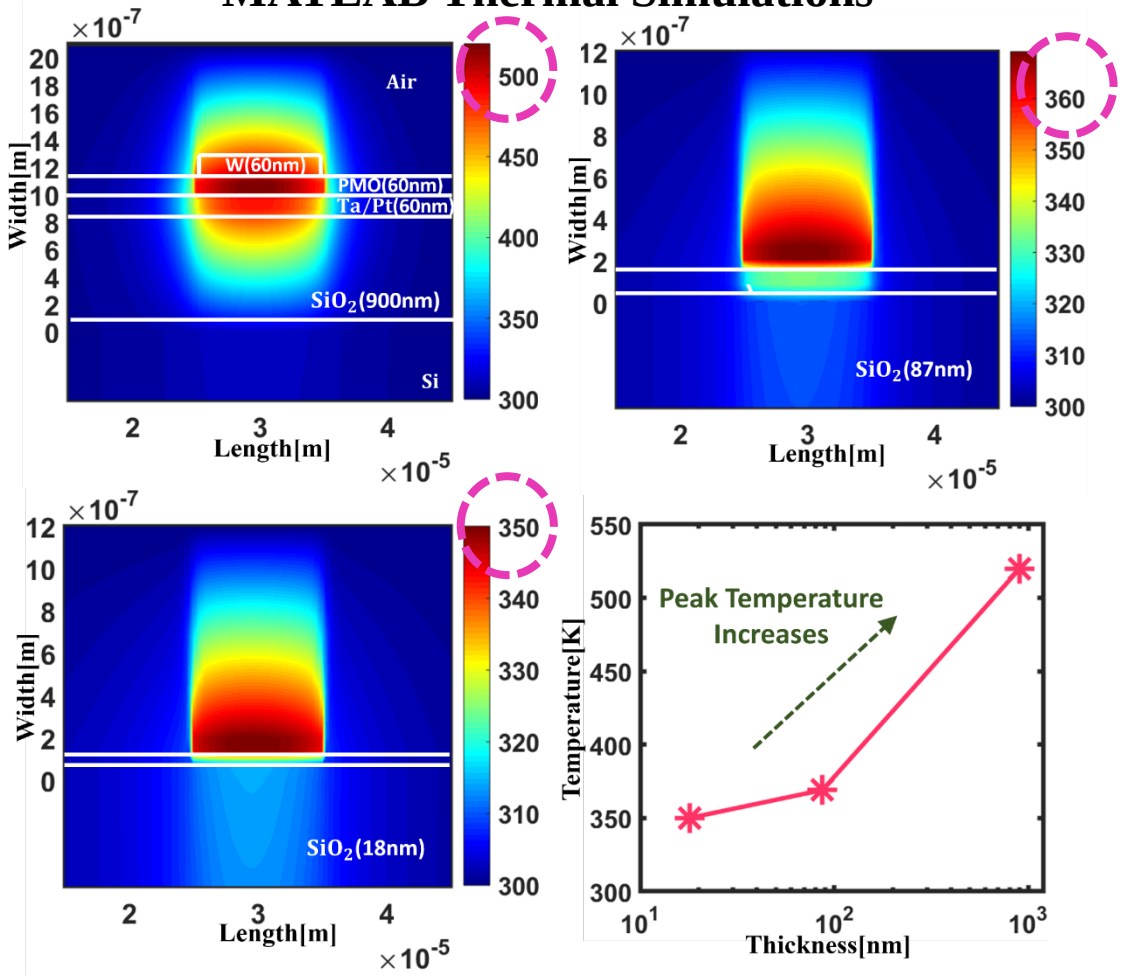
Thermal Engineering of Volatile Hysteresis

10 µm x 10 µm
W area(top contact)



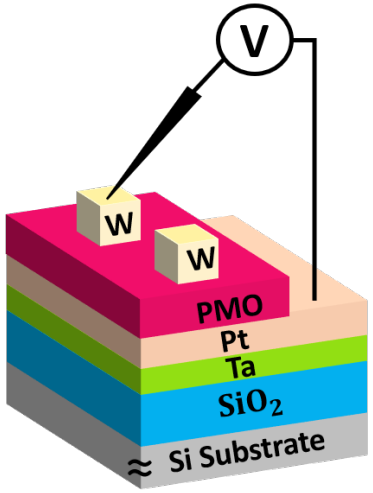
$R_{th1} > R_{th2} > R_{th3}$

MATLAB Thermal Simulations

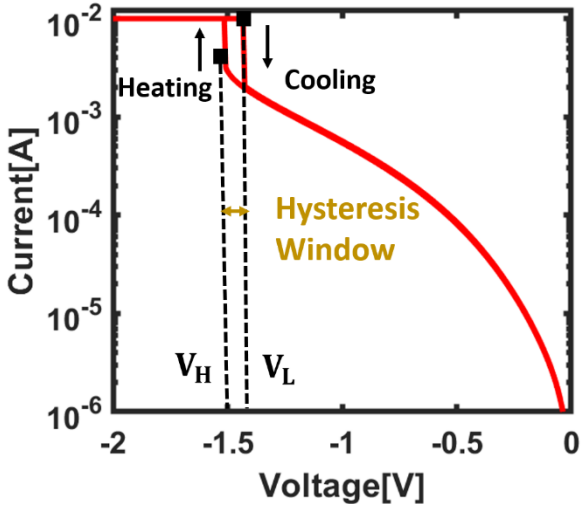


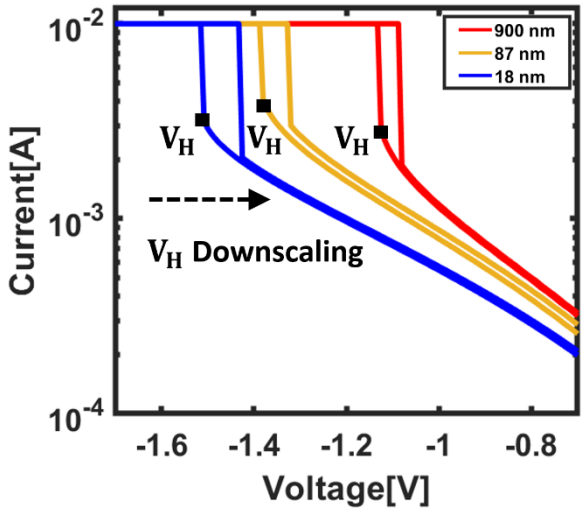
Low Thermal conductivity makes *SiO_2 Good* Thermal Insulator

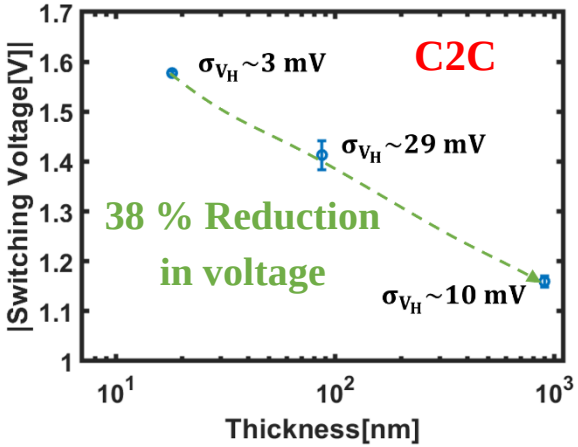
Threshold Voltage Scaling (DC-IV Measurements)

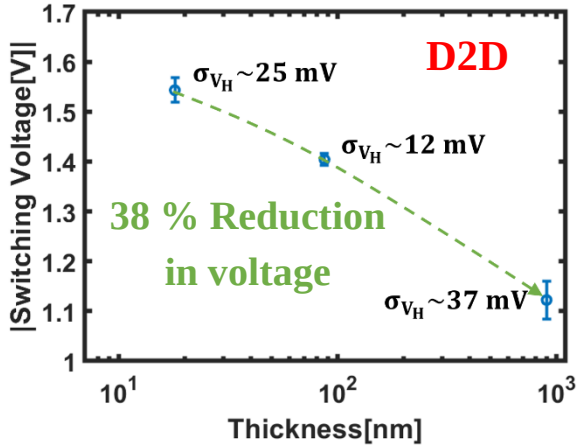


Input Voltage Double Sweep:
-2 V @ 10 mA





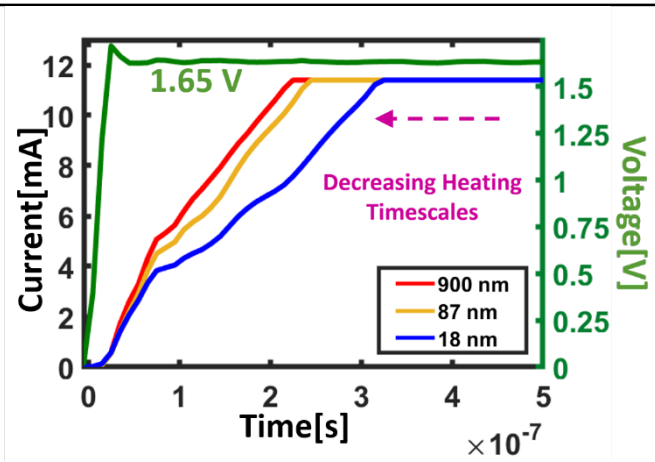


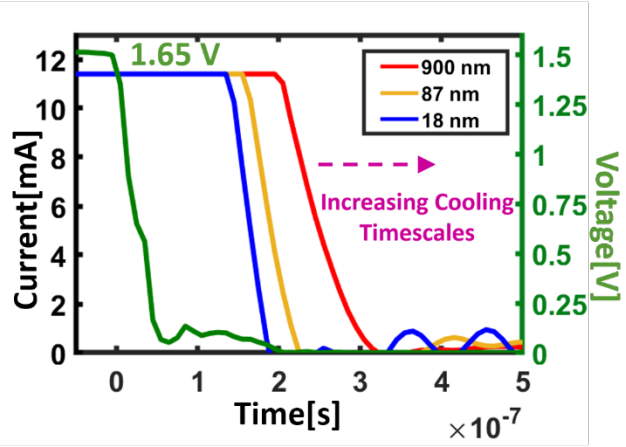


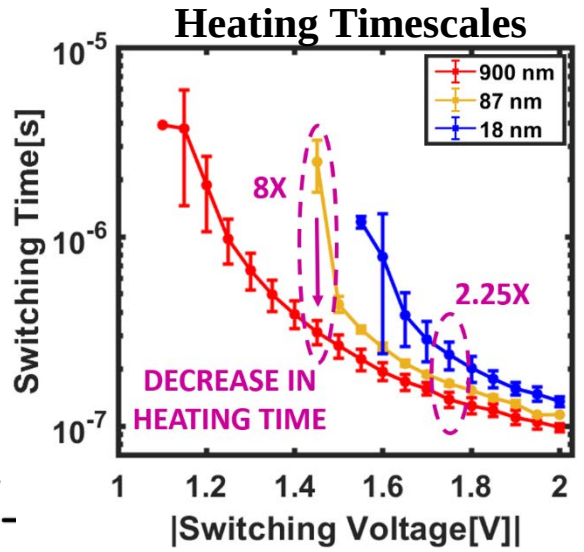
Threshold ***Voltage Scaling*** by changing device's thermal resistance

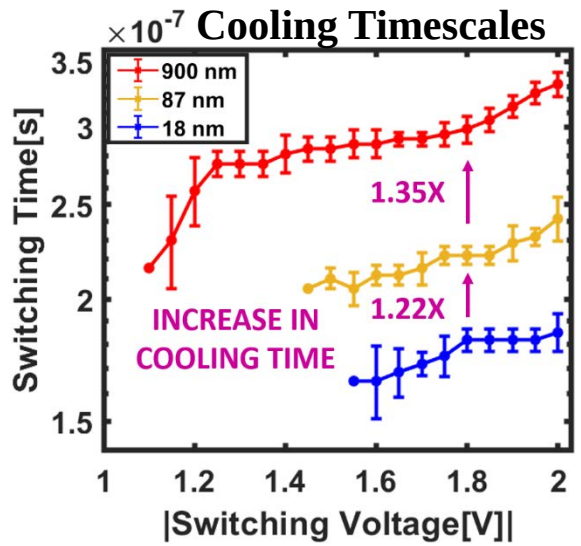
Speed Scaling (Transient Measurements)

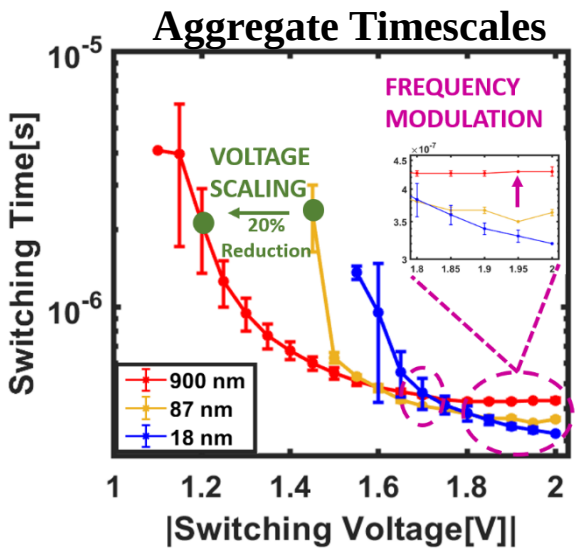
Input voltage pulse for voltage range[-1 V to -2 V] @ threshold current of 10mA











Aggregate Timescales gives ***voltage benefit*** at Lower Voltages and ***speed improvement*** at Higher Voltages

Conclusion

1. **Voltage downscaling by 38 % in DC and by 20 % in transient analysis is significant for power efficiency.**
2. **An 8X improvement in heating transients is significant for selector-less applications and oscillations.**
3. **The aggregate of Heating and Cooling timescales is important for accurate analysis.**
4. **An electro-thermal speed engineering study is critical for RRAM devices to model elements of neural networks that use NL characteristics**

THANK YOU ☺ ☺

Questions?