Noise-Induced Performance Enhancement of Variability-Aware Memristor Networks

Vasileios Ntinas, Iosif-Angelos Fyrigos, Georgios Ch. Sirakoulis, Antonio Rubio, Javier Martín-Martínez, Rosana Rodríguez, Montserrat Nafría

This work is part of a project that has received funding from the European Union's H2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 691178.

IEEE International Conference on Electronics Circuits and Systems

2019 ICECS GENOVA

November 29th 2019, Genova, Italy

Democritus University of Thrace
Department of Electrical & Computer Engineering

Universitat Politécnica de Catalunya (UPC)
Department of Electronic Engineering

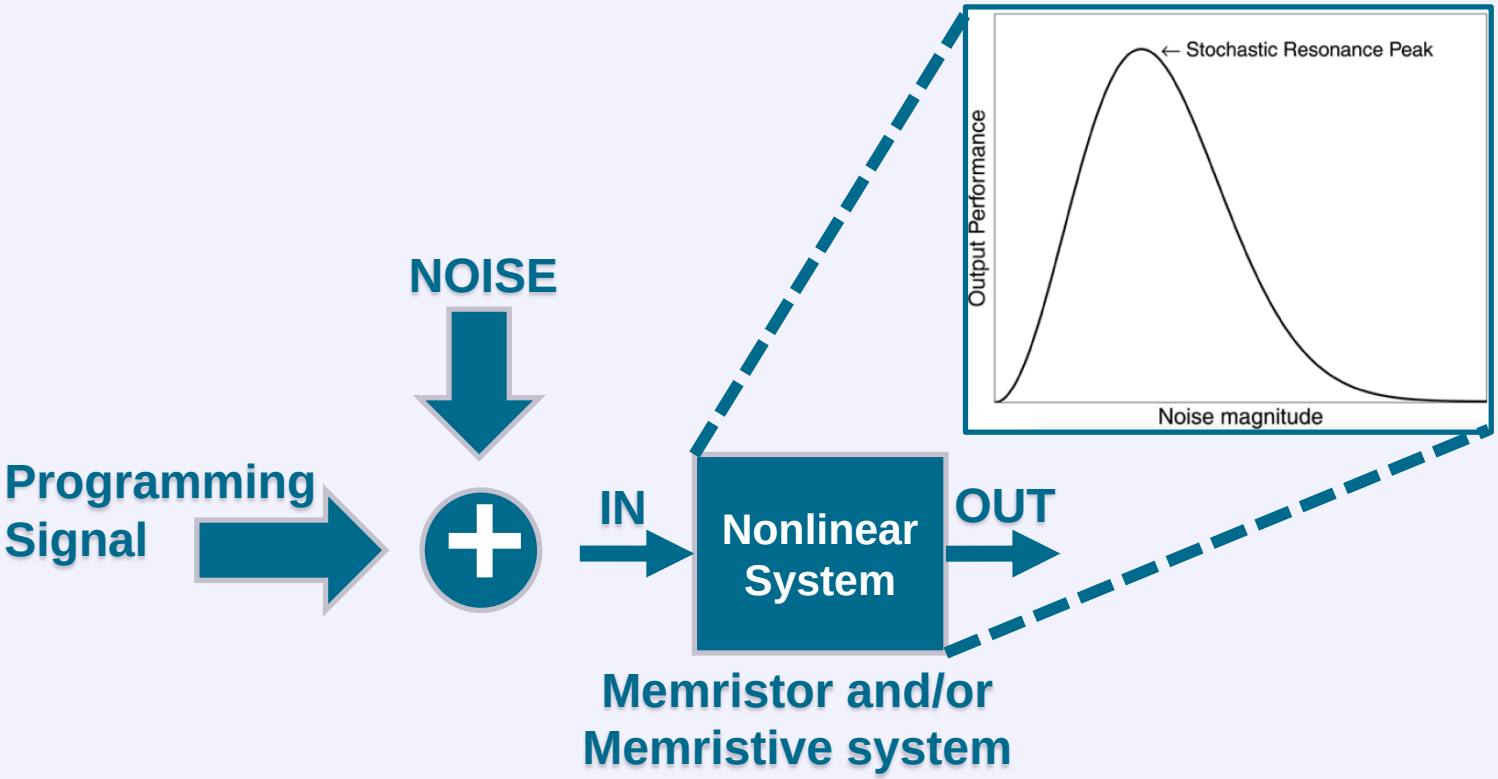
Universitat Autónoma de Barcelona
Department d' Enginyera Electrónica

NANOxCOMP - Marie Skłodowska-Curie grant agreement No 691178

Performance Enhancement

"Based on Stochastic Resonance"

Towards the implementation of more robust resistive switching systems

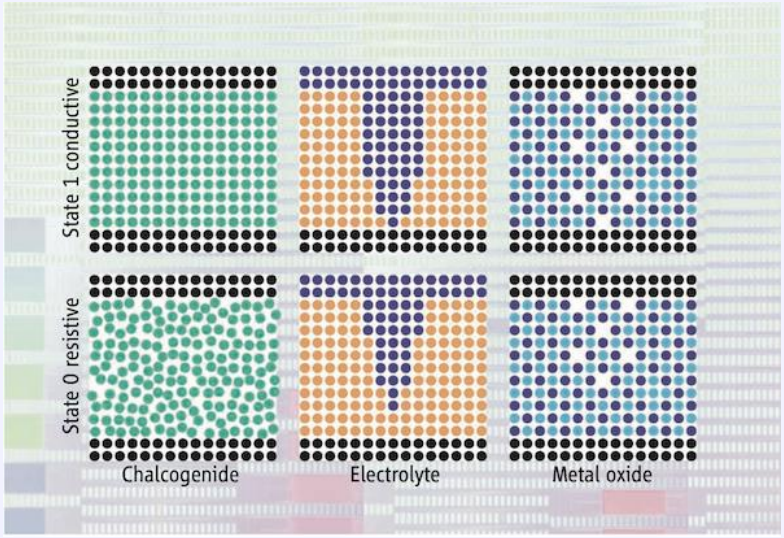


Presentation Outline

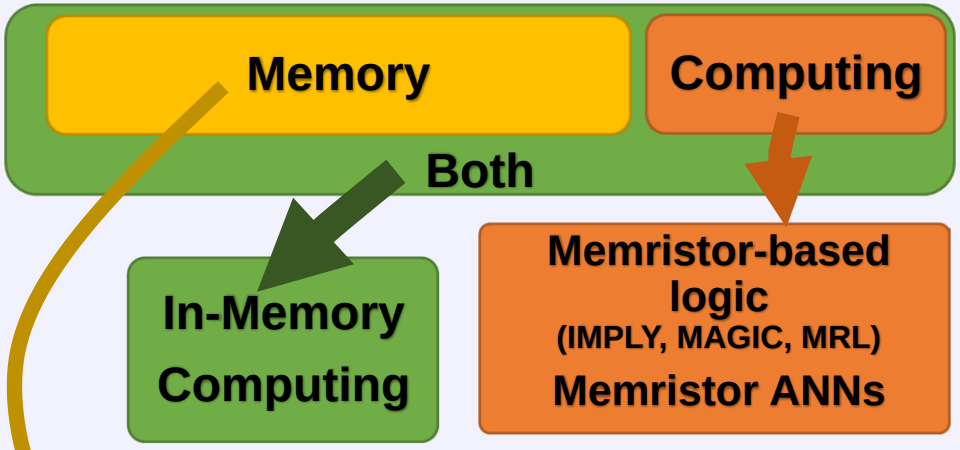
- ☞ **Memristor Devices and Applications**
- ☞ **Memristor-based Cell and Memristor Crossbar**
- ☞ **Variability in Memristor Crossbar**
- ☞ **Stochastic Resonance on Memristance Enhcancement**
- ☞ **Noise-induced Bit-Error-Rate Reduction**
- ☞ **Conclusions**

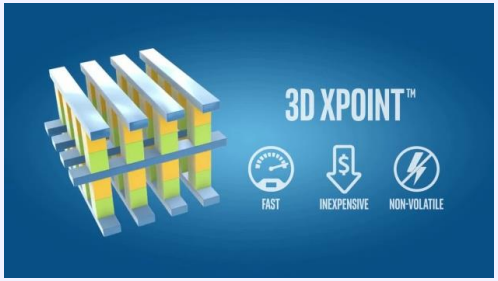
Memristor Devices and Applications

Wide range of devices



Wider range of Applications





[Meijer, G.I., Science 319(5870) (mar 2008) 1625–1626]
[Intel Corporation: Revolutionizing Memory and Storage]
[Kvatinsky, S., Belousov, D., Liman, S., Satat, G., Wald, N., Friedman, E.G., Kolodny, A., Weiser, U.C., IEEE TCAS:II (2014)]
[E. Lehtonen, J. H. Poikonen, and M. Laiho, IEEE ISCAS, Seoul, South Korea, May 2012]
[Kvatinsky, S., Wald, N., Satat, G., Kolodny, A., Weiser, U.C., Friedman, E.G., CNNA 2012]

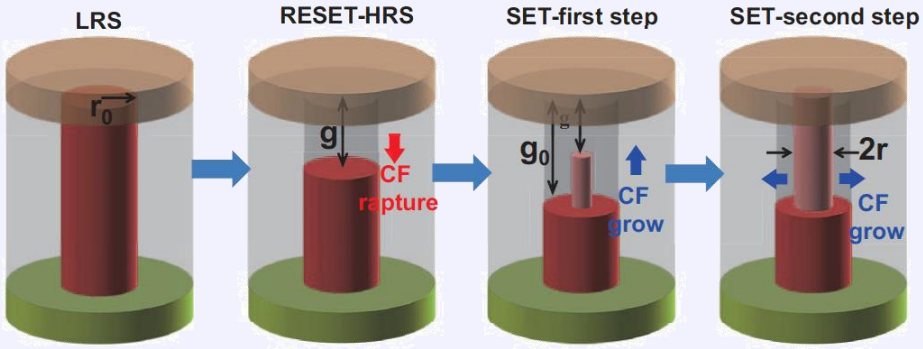
Metal Oxide: Bipolar Filament

Metric	Value	Quality
Scalability	F_{min} < 10nm	✓✓
MLC	Possible	✓
3D integration	Feasible	✓✓
Fabrication cost	Low	✓✓
Retention	Long (>10yrs)	✓✓
Latency	Medium (0.3-10us)	✓
Power	Medium	✓
Demonstrated Write Endurance	Medium (≤1E10 cycles)	✓
Variability	Problematic	✗

[Table BC2.7 in the International Roadmap for Devices and Systems. "Beyond CMOS," 2018.]

Stanford-PKU Metal-Oxide Memristor Model

Conductive Filament Evolution



Conductive Filament Dynamics

Conductive Filament Construction

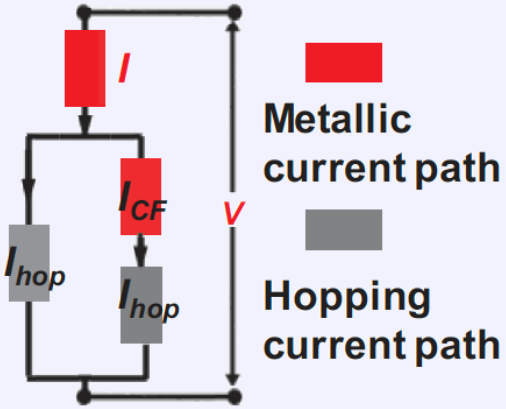
$$dg/dt = af\exp\left(-(E_a - \alpha_a ZeE)/k_B T\right)$$

$$dr/dt = \left(\Delta r + \Delta r^2/2r\right) f\exp\left(-(E_a - \alpha_a ZeE)/k_B T\right)$$

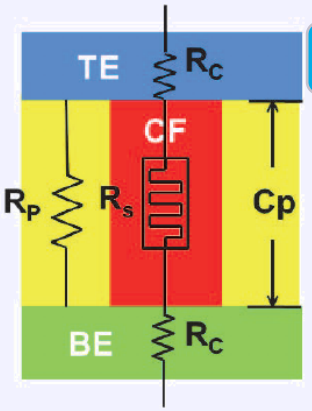
Conductive Filament Disruption

$$min\begin{cases} dg/dt = af\exp\left(-\left(E_i - \gamma ZeV\right)/k_B T\right) \\ dg/dt = af\exp\left(-E_h/k_B T\right)\sinh\left(\alpha_h ZeE/k_B T\right) \end{cases}$$

Currents through the Device



Device Parasitics



Do not forget the Temperature

$$T = T_0 + IVR_{th}$$

Conductive Filament Variability

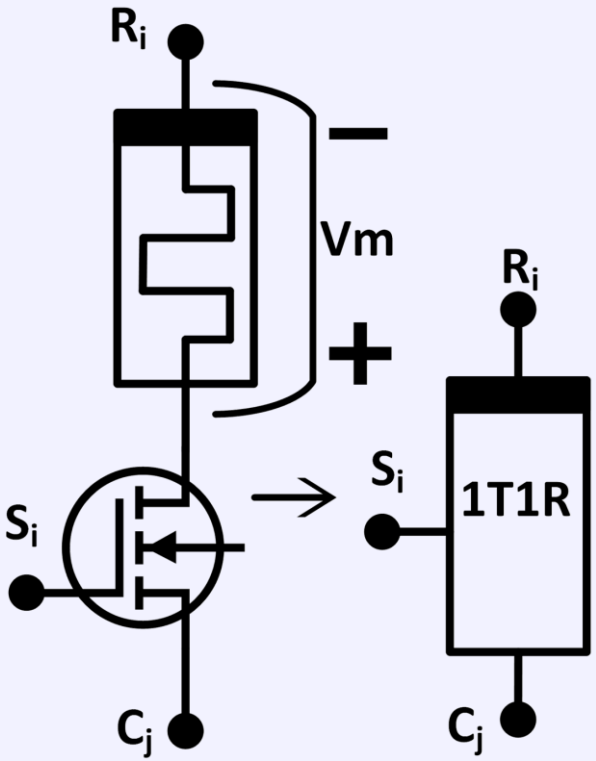
$$I_{hop} = I_0 \exp\left(-\frac{dg}{\tau_0} + \frac{\delta g}{\tau_0}\right)\sinh\left(\frac{V_{gap}}{V_T}\right)$$

$$r = r_0 + \int\left(\frac{dr}{dt} + \delta r\right)dt$$

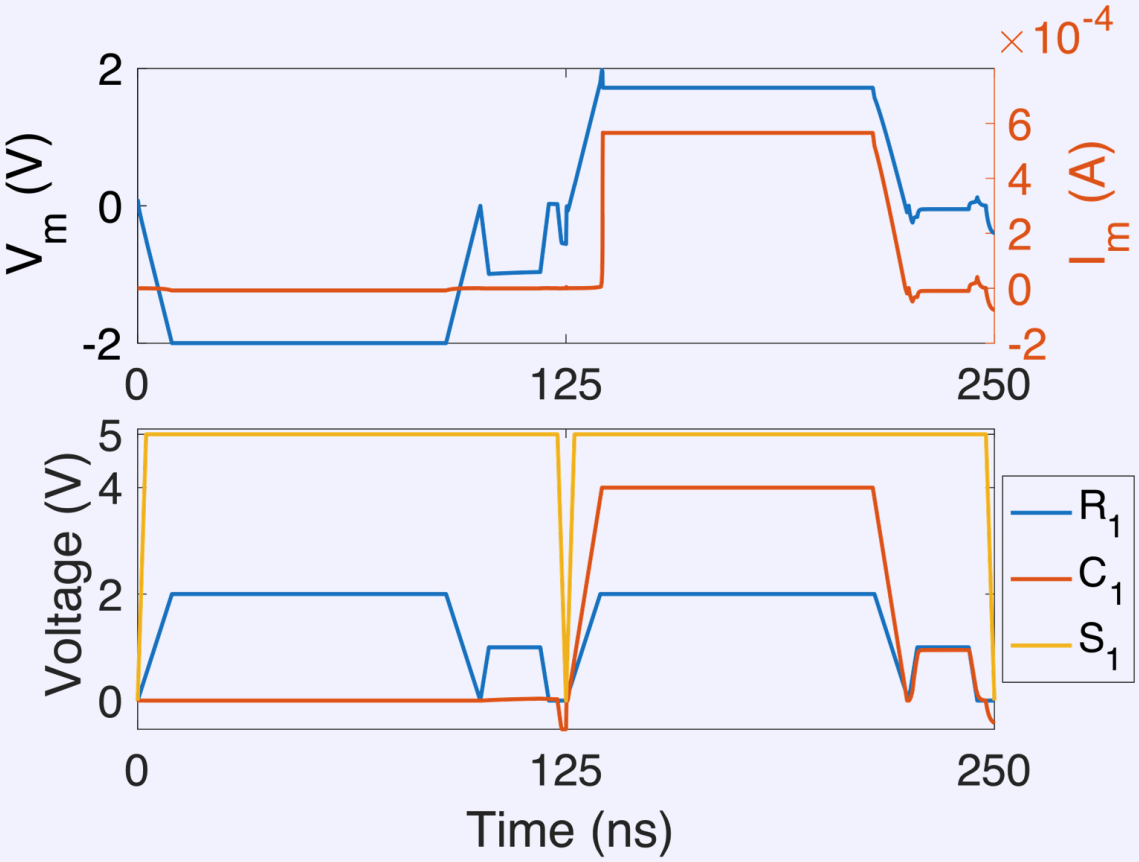
[Li, H., Jiang, Z., Huang, P., Wu, Y., Chen, H. Y., Gao, B., Liu, X. Y., Kang, J. F. & Wong, H. S., DATE 2015]

1T1R Configuration for Memristor Crossbar

1T1R ReRAM-based Memory Cell



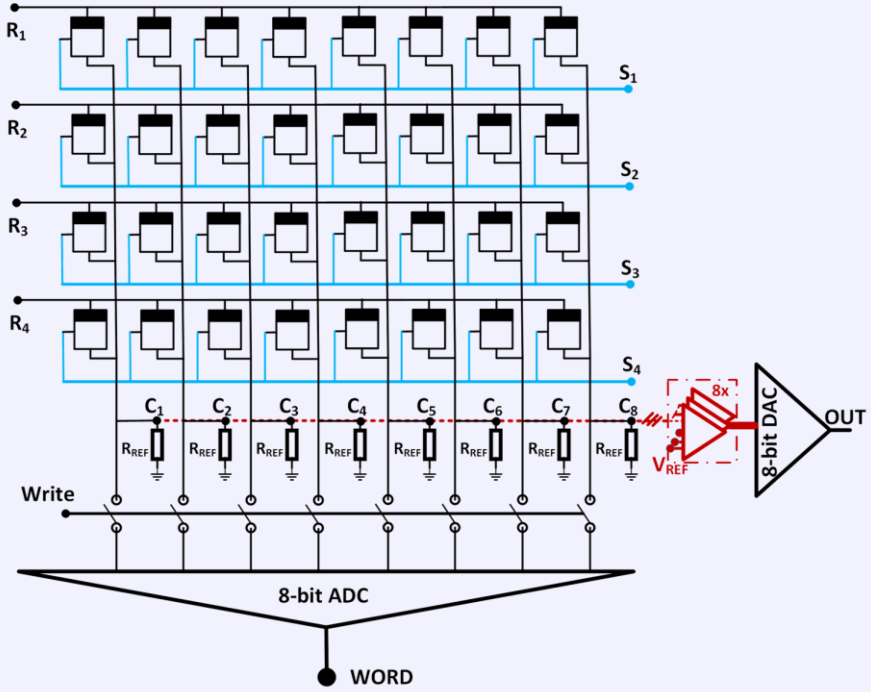
SET and RESET Processes of the ReRAM Cell

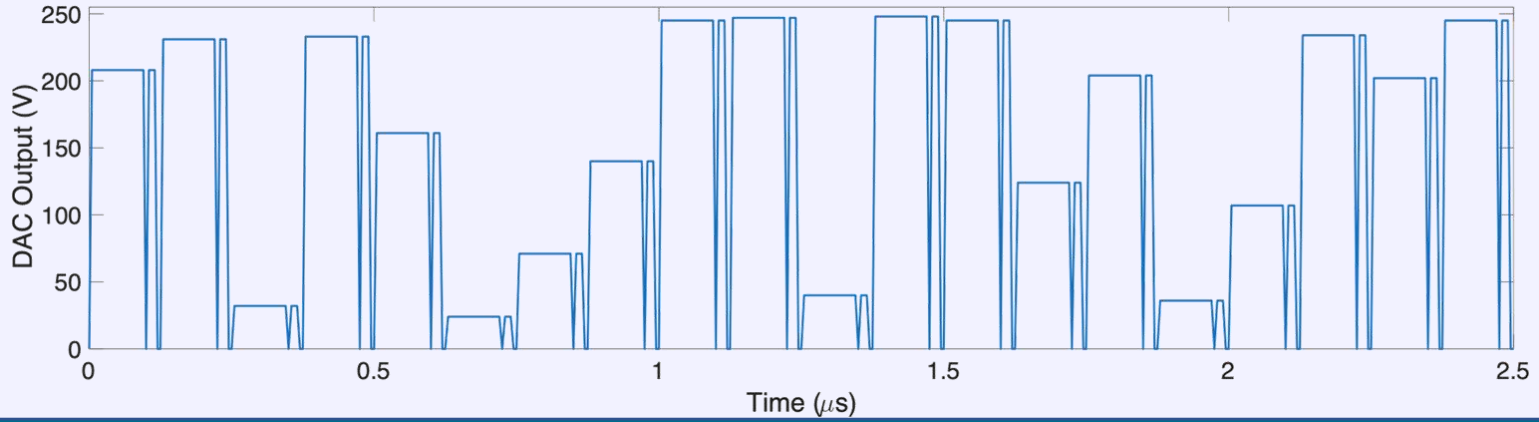


ReRAM Crossbar Configuration

ReRAM crossbar array with the read/write peripheral circuitry.

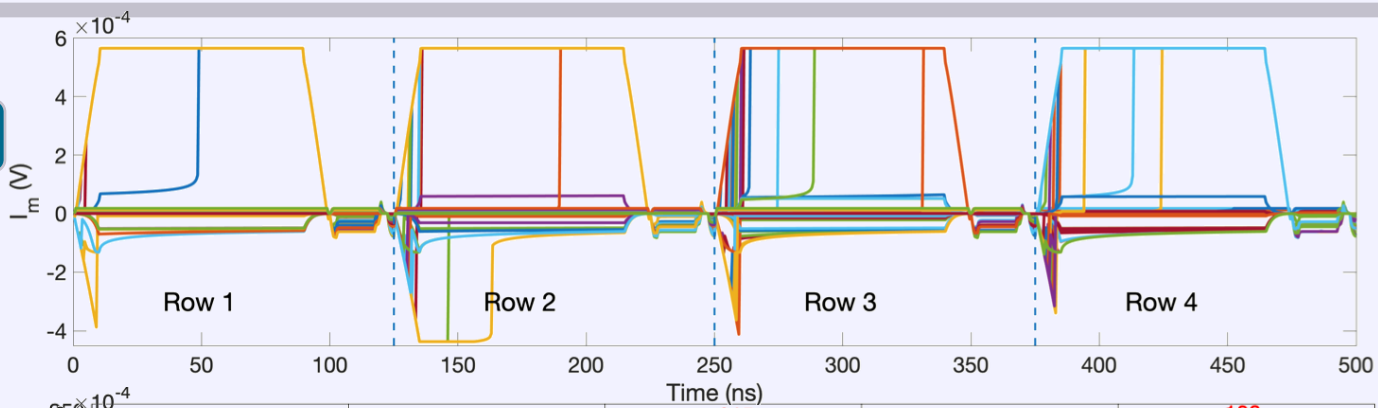
Writing (long pulses) and Reading (short pulses) of words in the crossbar array.



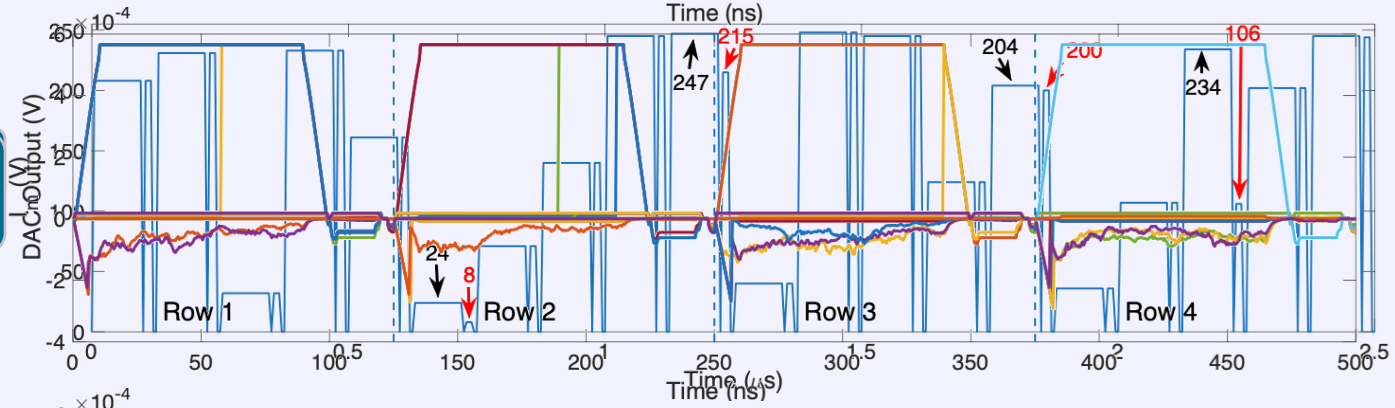


SET and RESET variations in the Crossbar Array

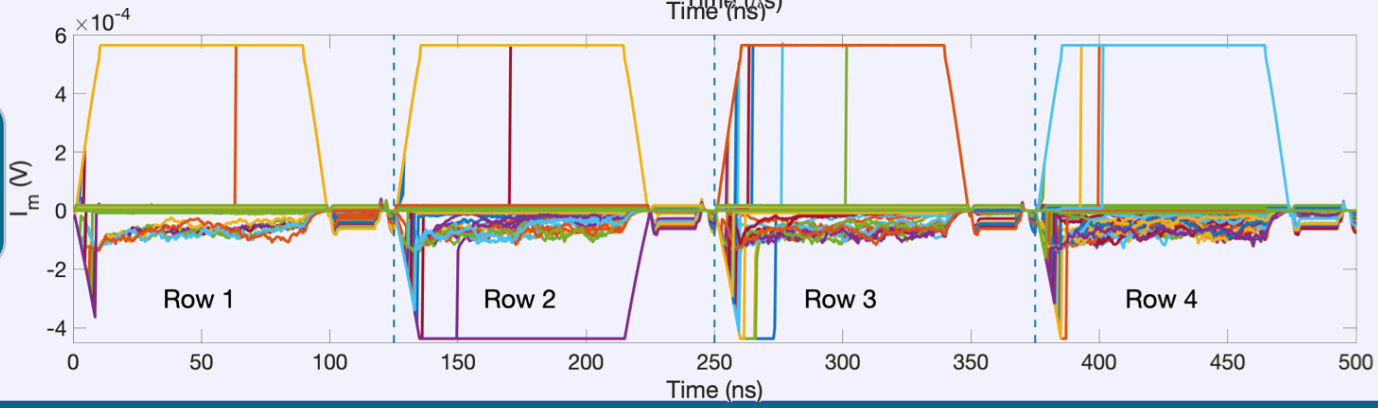
Device-to-Device



DAC Output under variations



Both Device-to-Device Cycle-toCycle



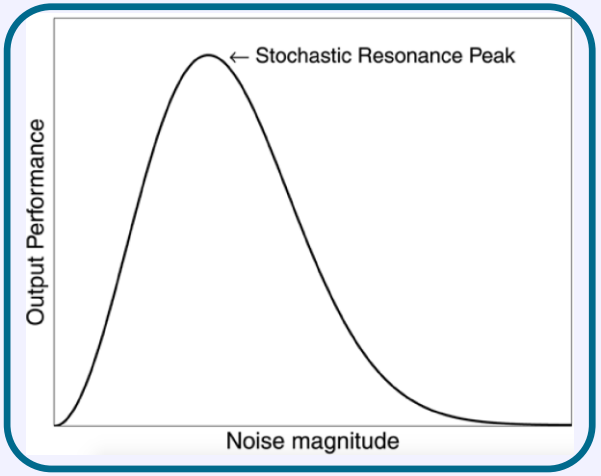
Stochastic Resonance

Can noise be a positive factor???

Stochastic Resonance
(from the perspective of Engineers):

"An ***increase*** to the input noise can result in an ***improvement*** in the output signal-to-noise ratio (SNR)"

Performance(noise+nonlinearity)>Performance(nonlinearity)



Where to find Stochastic Resonance?

- **Earth's climate changes**
- **Electronic circuits**
- **Differential equations**
- **Lasers**
- **Neural models**
- **Physiological neural populations and networks**
- **Chemical reactions**
- **Ion channels**
- **SQUIDs (superconducting quantum interference devices)**
- **Ecological models**
- **Cell biology**
- **Financial models**
- **Psychophysics**
- **Carbon nanotube transistors**
- **Nanomechanical oscillators**
- **Organic semiconductor chemistry**
- **Social systems**

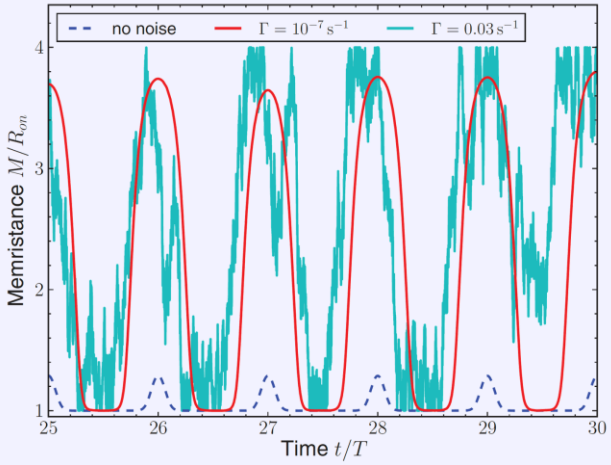
Stochastic Resonance requires:

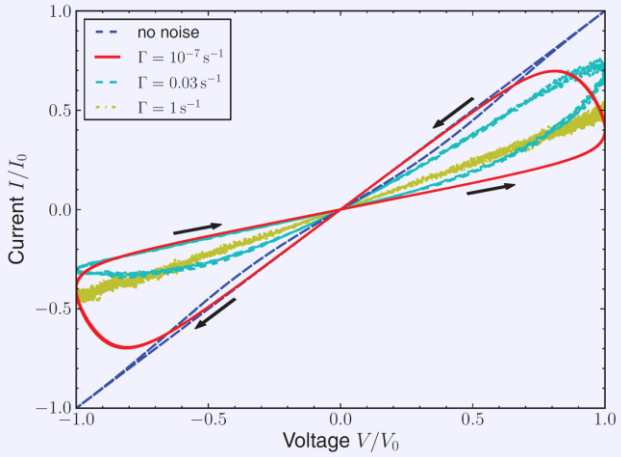
(a) A form of Threshold
(b) A driving signal
(c) A source of noise (inherent or external)

[Gammaitoni, L., Hänggi, P., Jung, P., & Marchesoni, F. (1998). Reviews of modern physics, 70(1), 223.]
[McDonnell, M. D., & Abbott, D. (2009). PLoS computational biology, 5(5)]

Stochastic Resonance on Memristance Enhancement

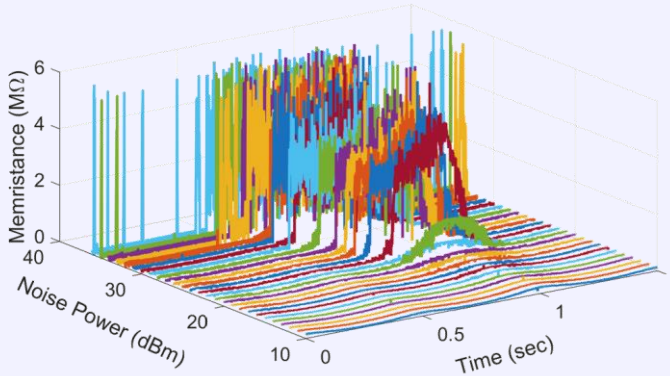
SR through intrinsic Noise

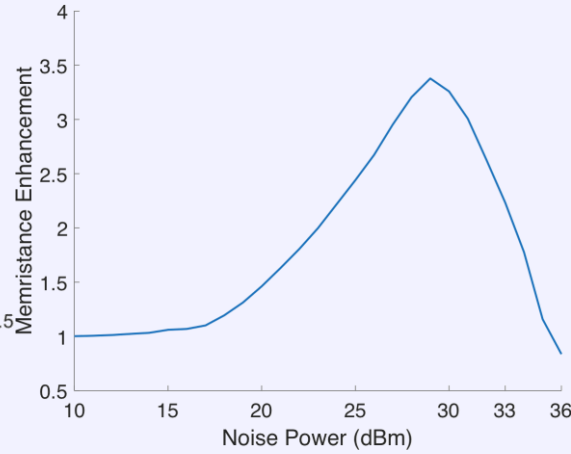




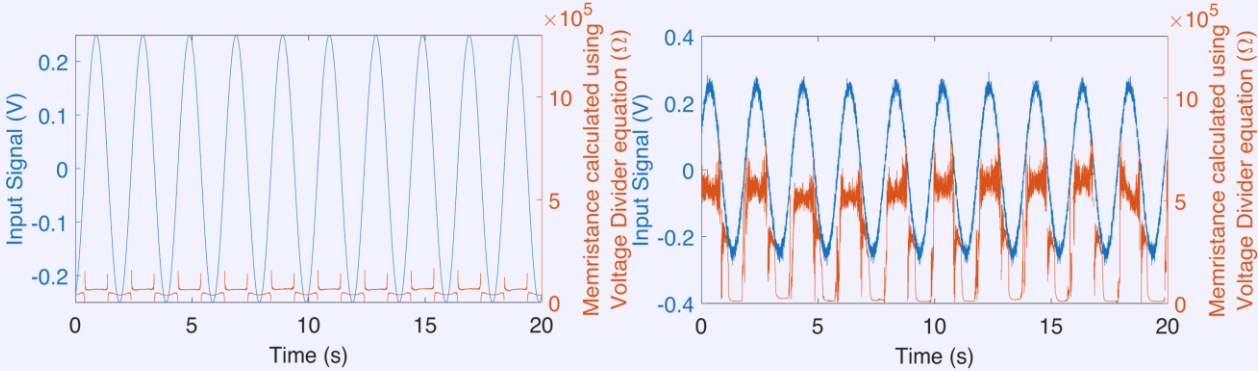
[Stotland, A., & Di Ventra, M. (2012). Physical Review E, 85(1)]

SR by external noise excitation





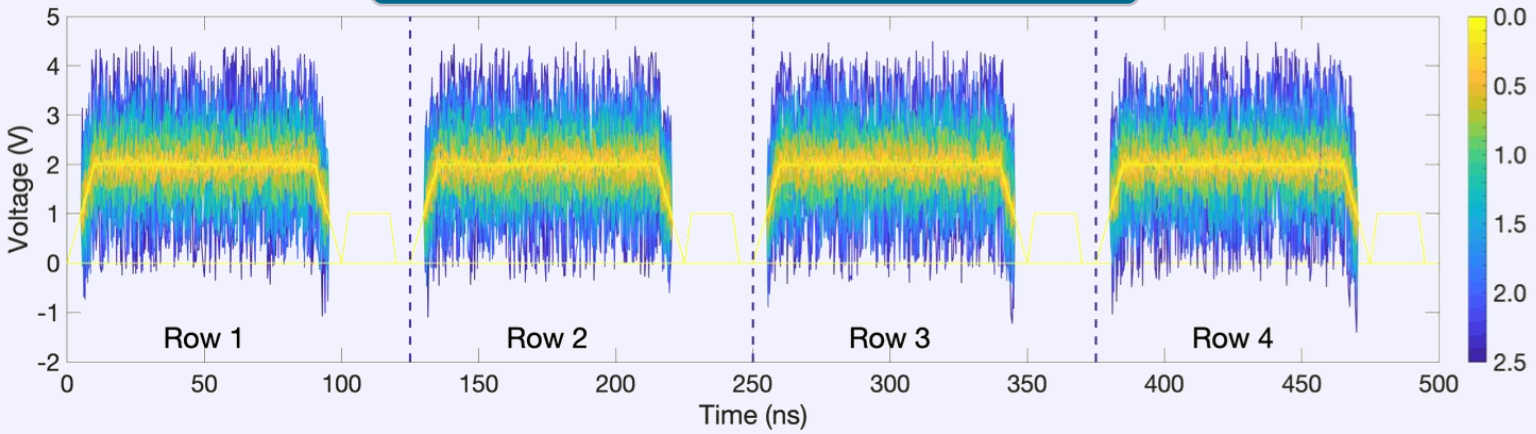
[Ntinas, V., Rubio, A., Sirakoulis, G. Ch., Cotofana, S. ISCAS 2019]



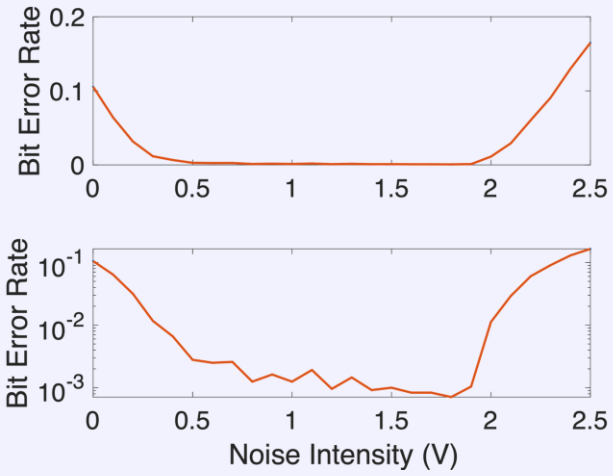
[Ntinas, V., Rubio, A., Sirakoulis, G. Ch., Rodriguez, R., Nafria, M. NANOARCH 2019]

SR-based Performance Enhancement

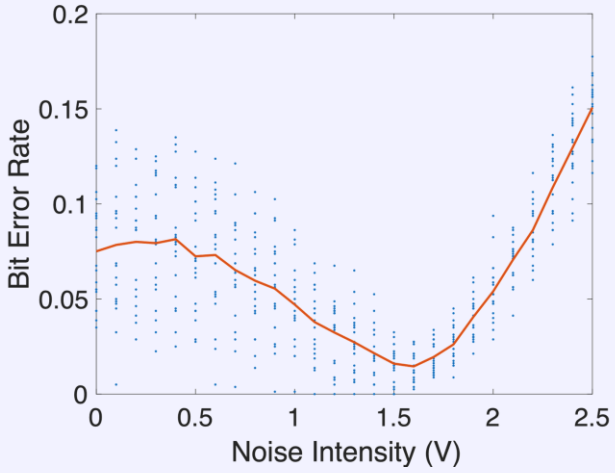
Noisy Write Signal Applied to Each Row



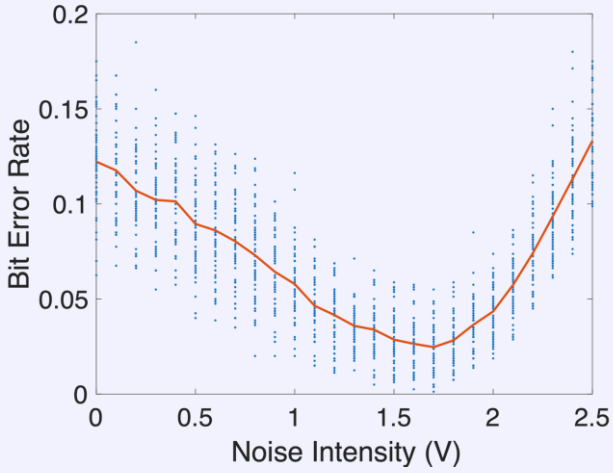
SR vs Cycle-to-Cycle Variability



SR vs Device-to-Device Variability



SR vs Both kinds of Variability



Conclusions

- High levels of **fabricated memristor's variability** postpones the scaling of memristor-based memories
- A **noisy disturbance** delivers **reduced Bit-Error-Rate** by assisting the writing process of the devices in the Memristor Crossbar Array.

Future Work

- A **transistorless** Memristor Crossbar configuration will be investigated
- **Experimental** demonstration of SR-based Performance Enhancement using externaly applied **white noise**

Thank you for your attention

NANOxCOMP - Marie Skłodowska-Curie grant agreement No 691178