Memristors: progress in understanding and integration

Janice H. Nickel
Cognitive Systems Laboratory, HP Labs

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Topics to touch on…

- Advantages of Memristive RRAM
- Properties of Memristive devices
  - Switching Speed
  - Switching Energy
  - Analogue Operation
- Advances in Integration
  - BEOL PoC devices
  - Integration with CMOS

Cohorts in R & D

HP Labs

Antonio Torrezan
Tsung Wen Lee
Hans S. Cho
John Paul Strachan
J. Joshua Yang
Fred Perner
Gilberto Ribeiro
R. Stanley Williams

SK Hynix

H.D. Lee, S.G. Kim, K. Cho, H. Hwang, H. Choi, J. Lee, S.H. Lee, H.J. Lee, J. Suh, S.-O. Chung, Y.S. Kim, K.S. Kim, W.S. Nam, J.T. Cheong, J.T. Kim, S. Chae, E.-R. Hwang, S.N. Park, Y.S. Sohn, C.G. Lee, H.S. Shin, K.J. Lee, K. Hong, H.G. Jeong, K.M. Rho, Y.K. Kim, S. Chung, J.H. Lee, S.K. Park, S.-J. Hong

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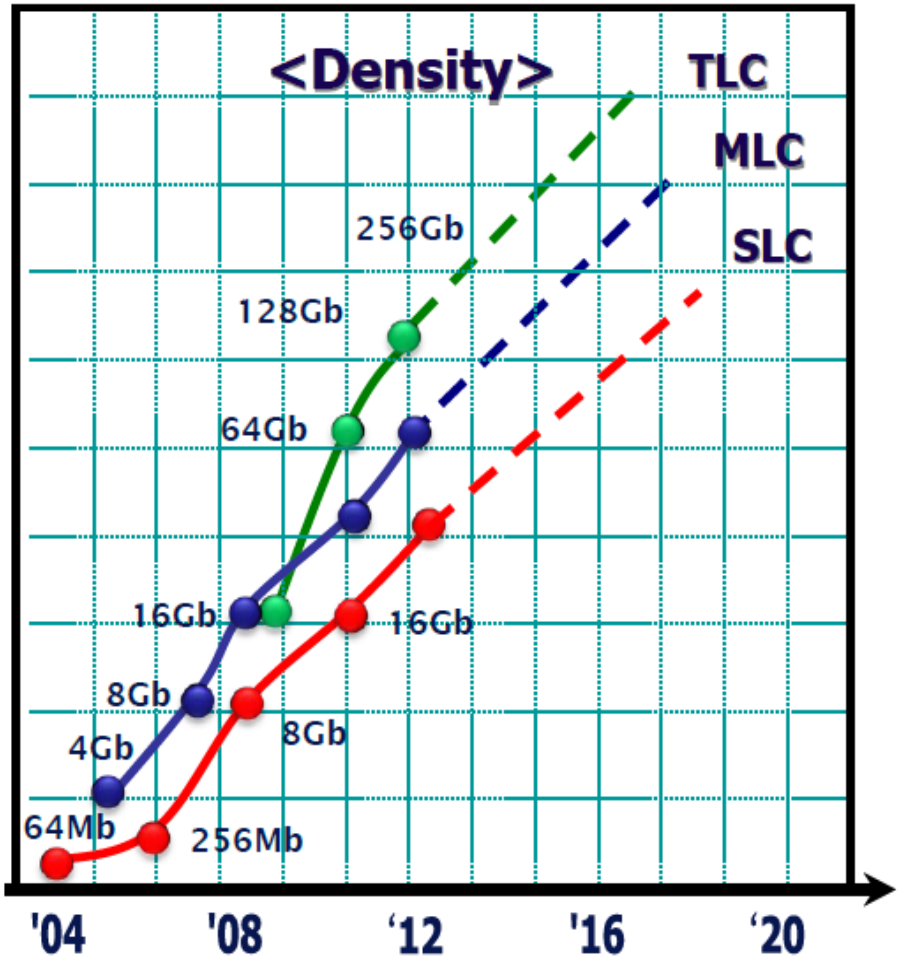
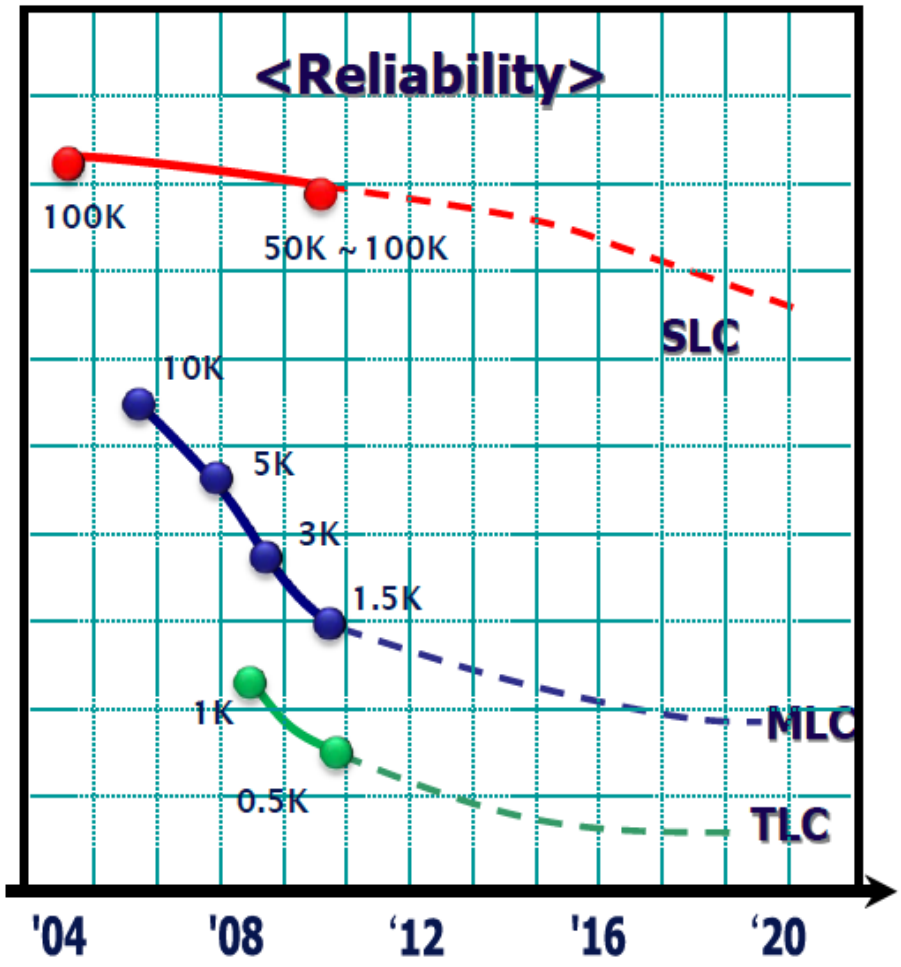
Industry Dilemma

- **Lithography shrink slows, NAND Reliability degrades**





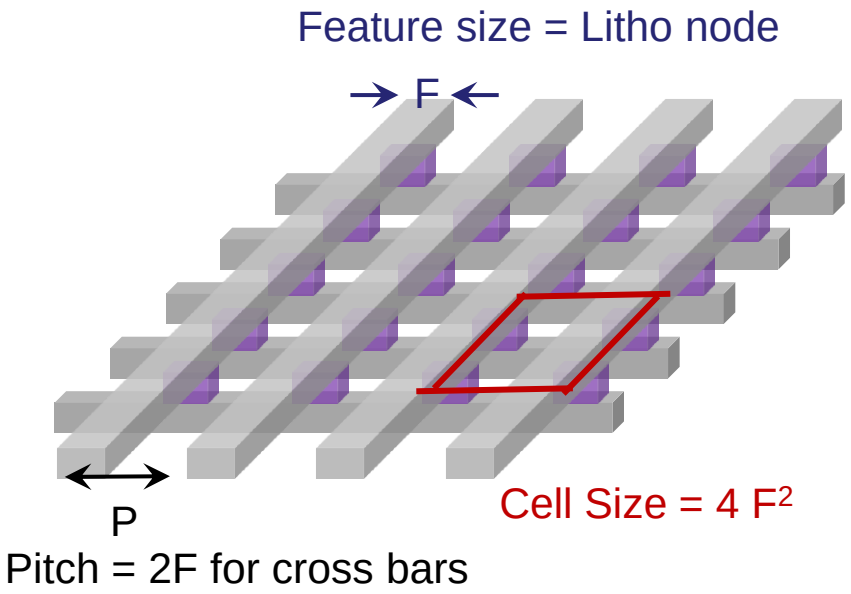
* SLC : Single level cell, MLC : Multi level cell, TLC : Triple level cell

Why are memristors candidate replacements?

Enables true crossbar structures

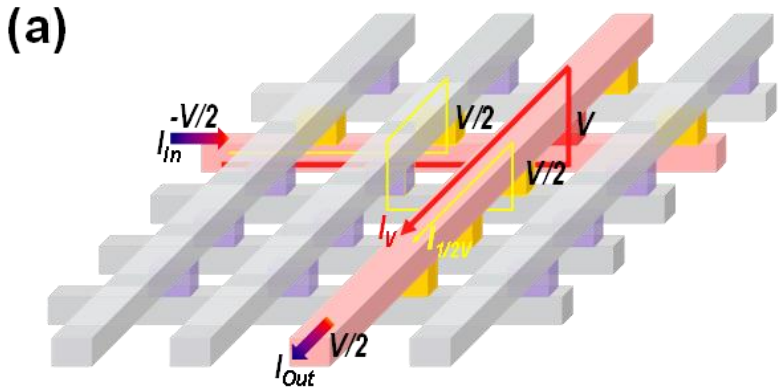
- Does not require transistors or other access devices
- Removes Silicon requirement
  - Stack arrays on top of each other:

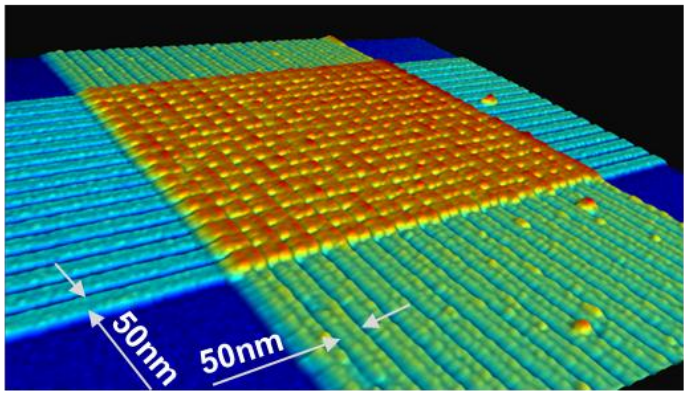
    cell sizes < $4F^2$
  - Improve density
  - Reduce power consumption
  - Integrate with compute processors
  - Reduce total area



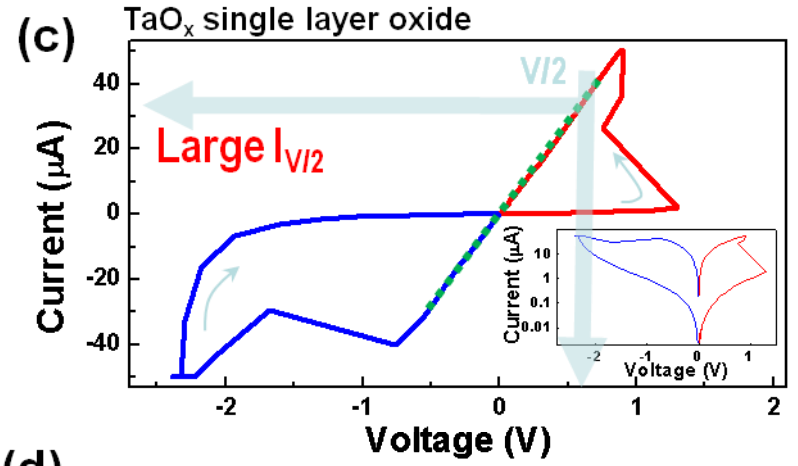
Non-linear operation

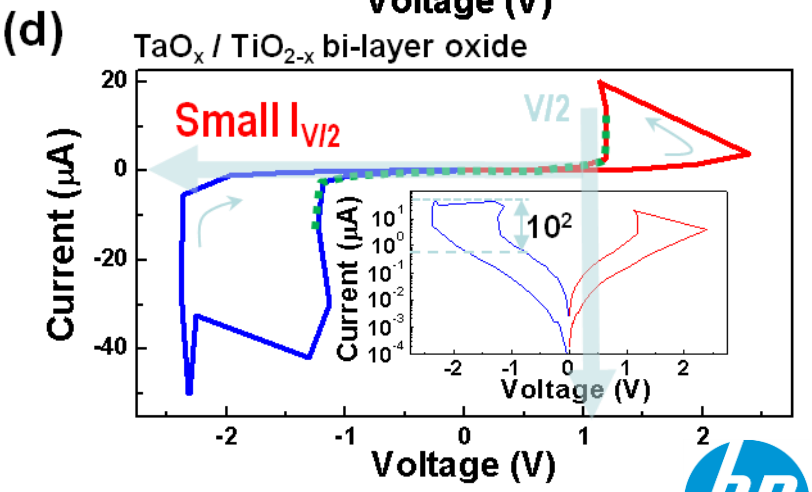
Reduces current sneak paths





Nonlinearity $K_w = I_V / I_{V/2}$





J.J. Yang, et al., *Appl. Phys. Lett.* **100**, 113501 (2012)

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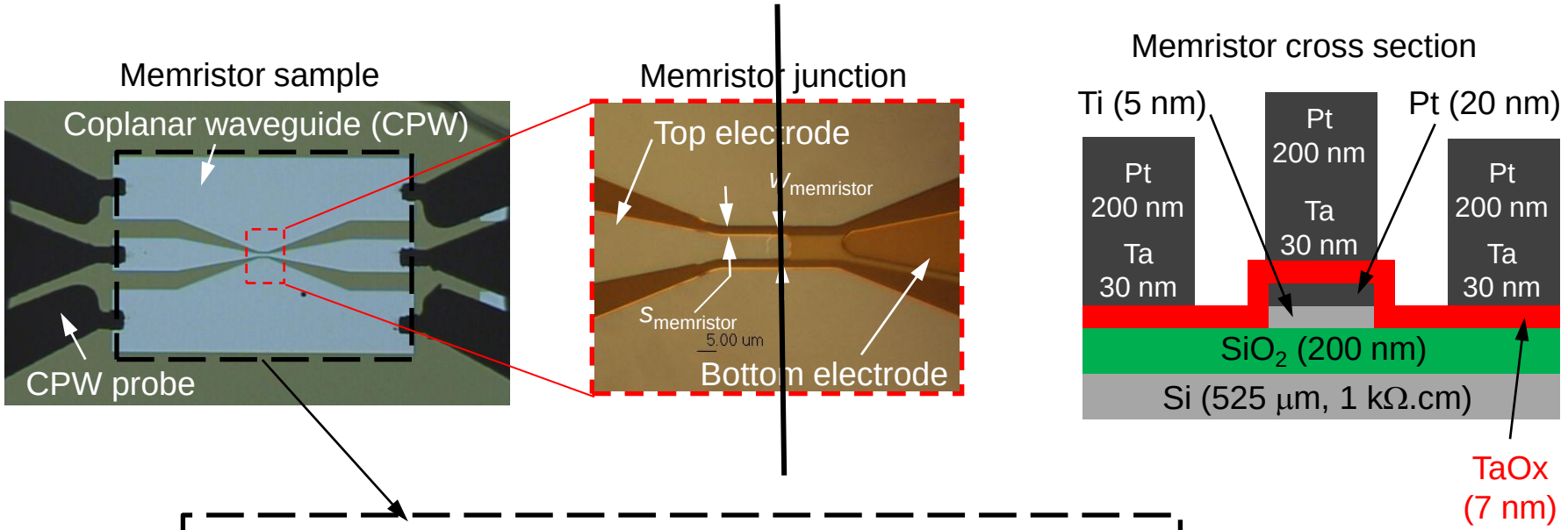
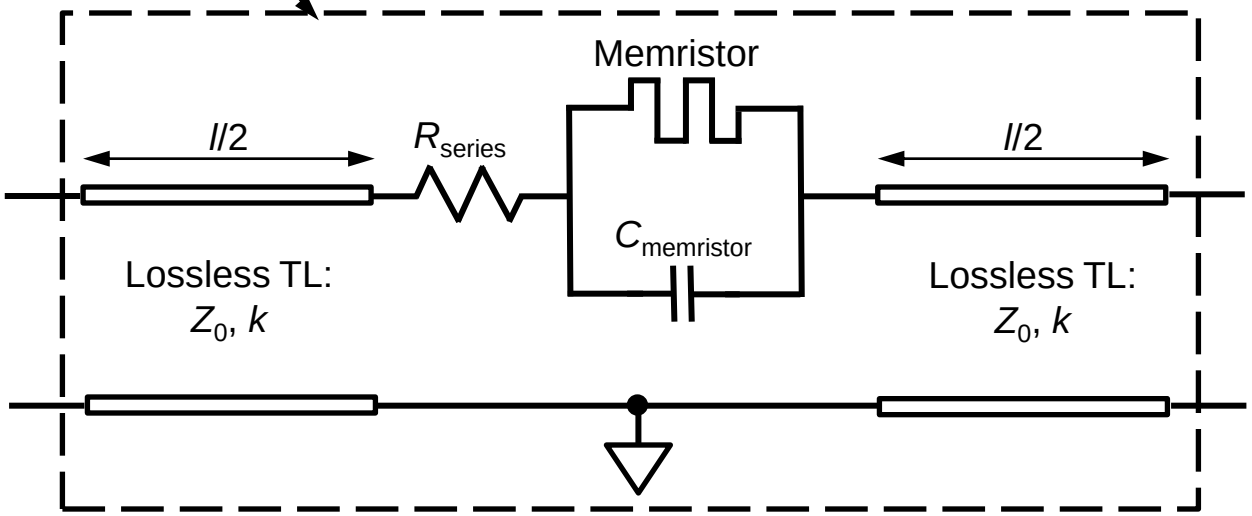
Measuring inherent switching speeds



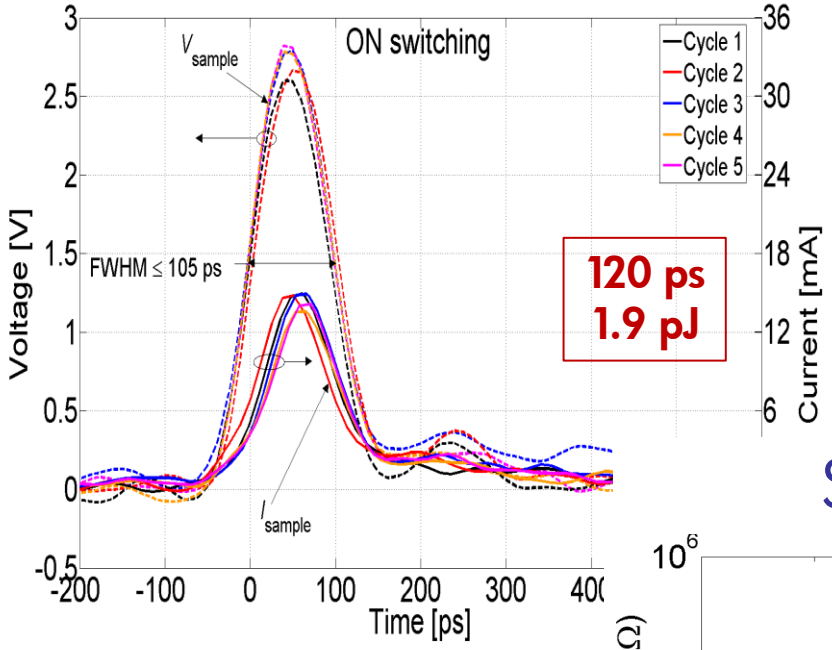


A.C. Torrezan, *et al.*, *Nanotechnology*, 2011, 22, (48), pp. 485203

ON and OFF switching times

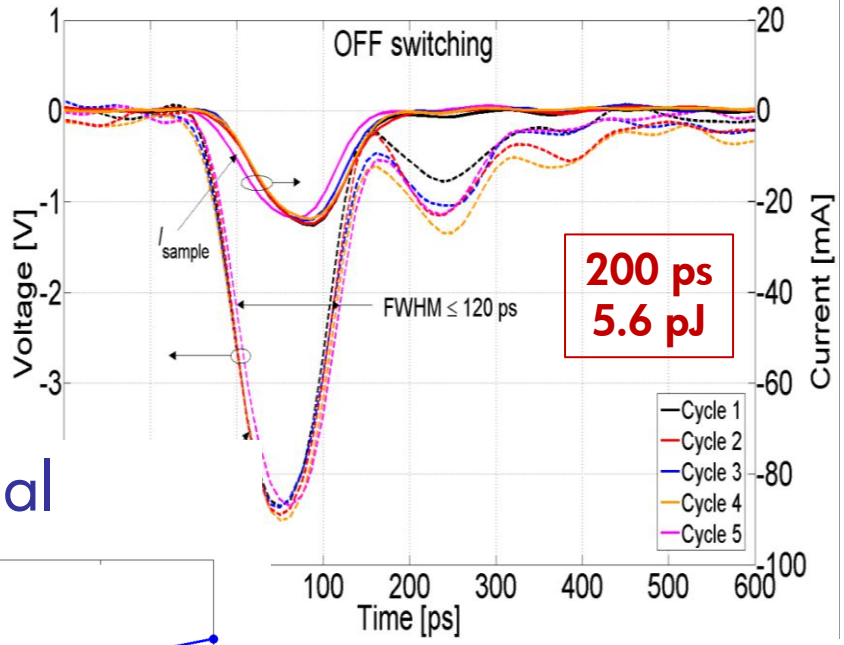
Switching times are not device limited

ON switching



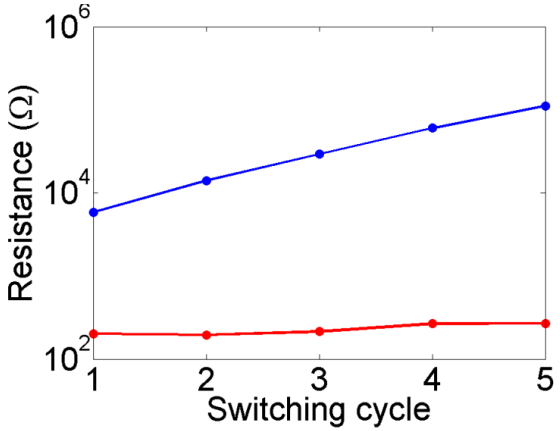
120 ps
1.9 pJ

OFF switching



200 ps
5.6 pJ

Signal

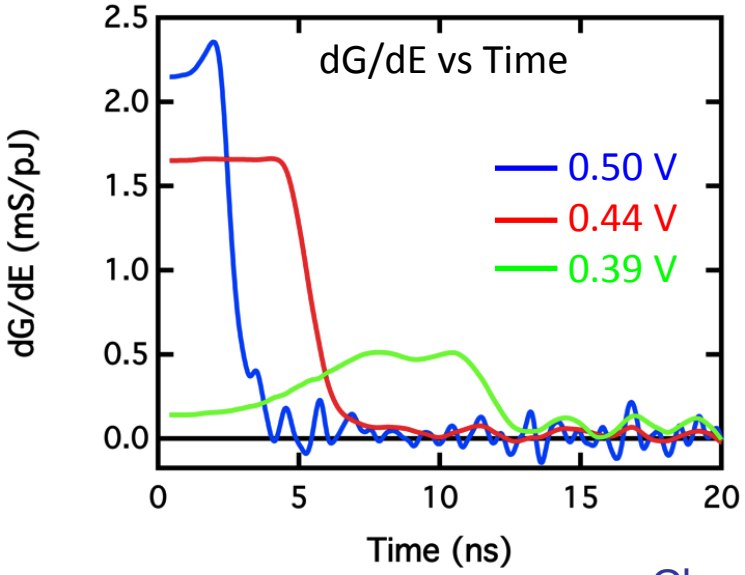


2 um x 2 um device size;
TaO_x only device

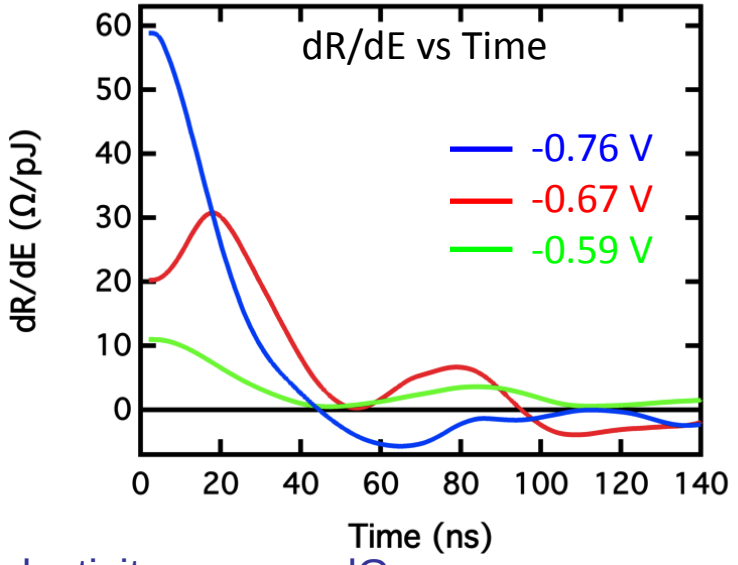
Energy analysis

How many Ohms per picoJoules?

ON switching



OFF switching



Want: $\frac{\text{Change in Conductivity}}{\text{Energy injected}} = \frac{dG}{dE}$

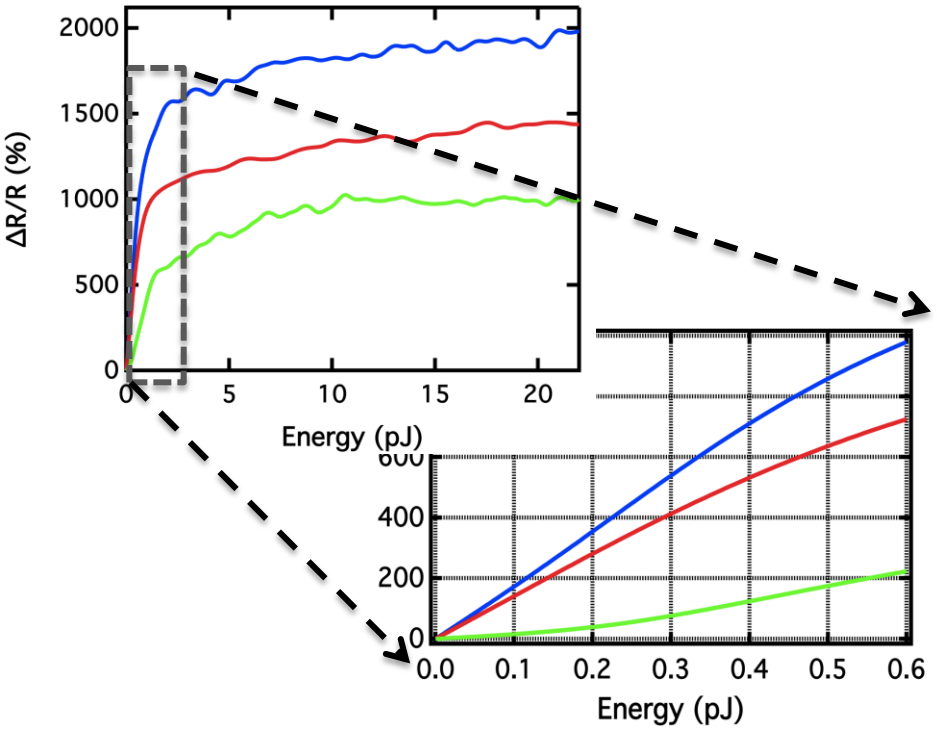
- Power applied also heats, possibly damages or over-drives the device.
- 10^{10} cycles: >99% energy was wasted or damaged the device when switching

J. P. Strachan, *et al. Nanotechnology* 22, 505402 (2011).

Energy analysis

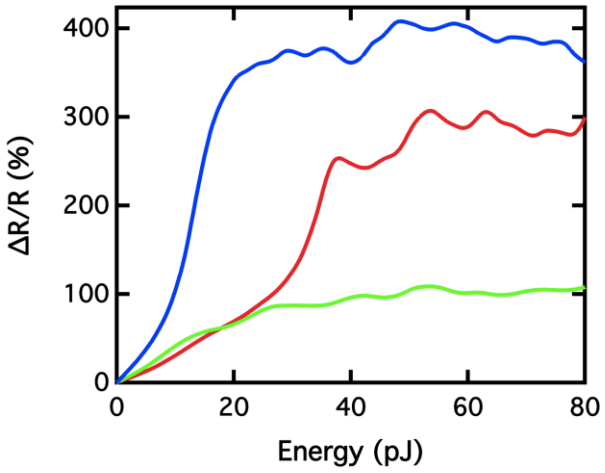
How many Ohms per picoJoules?

ON switching



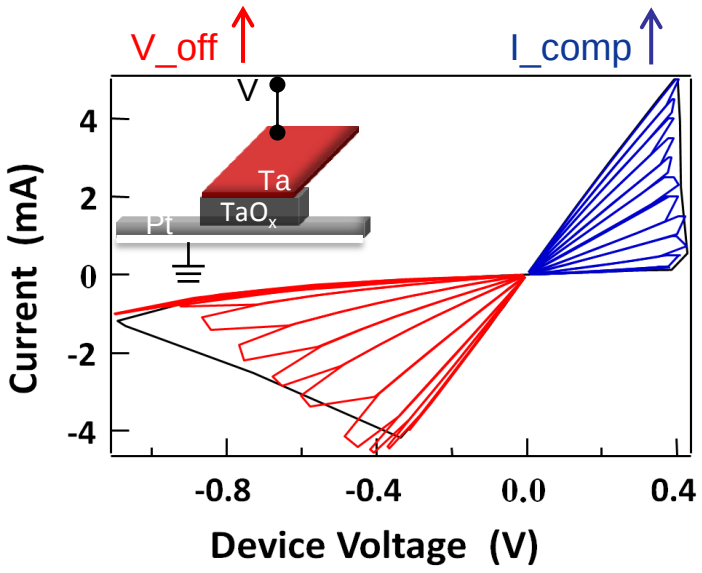
2 um x 2 um device size; TaO_x only device

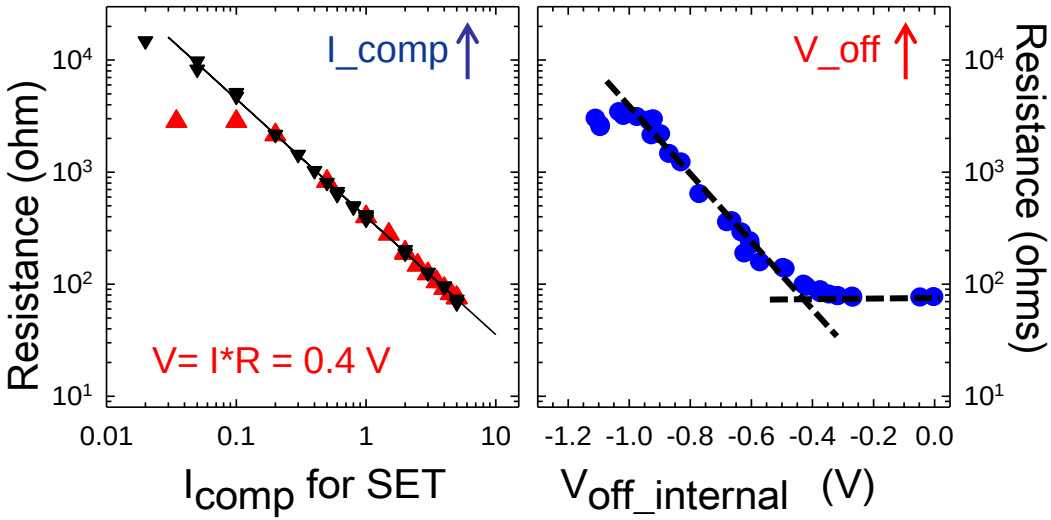
OFF switching



- 200% resistance change with 110 femtoJoules of energy!
- OFF switching is two orders of magnitude higher in energy due to slower speed and higher currents

Analogue Operation



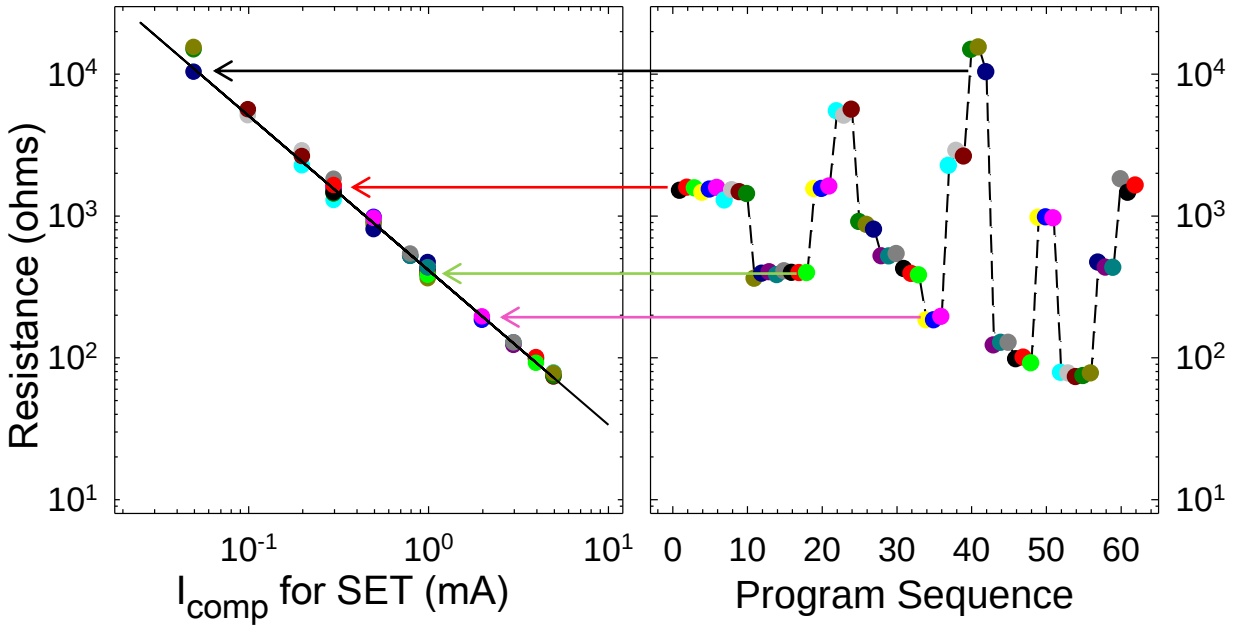


Device resistance can be continuously varied, controlled by compliance current

1.5 um x 1.5 um device size; TaO_x only device

T.-W. Lee and J. H. Nickel, *IEEE Electron Device Lett., to be published Oct. 2012.*

Analogue Operation



Device resistance precisely controllable; accurate and reproducible

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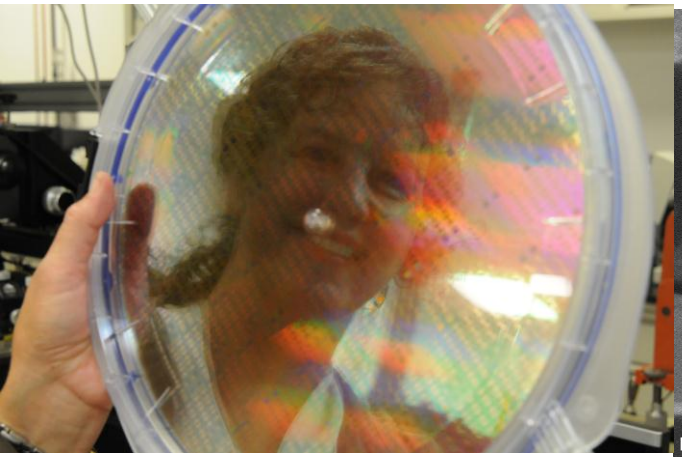
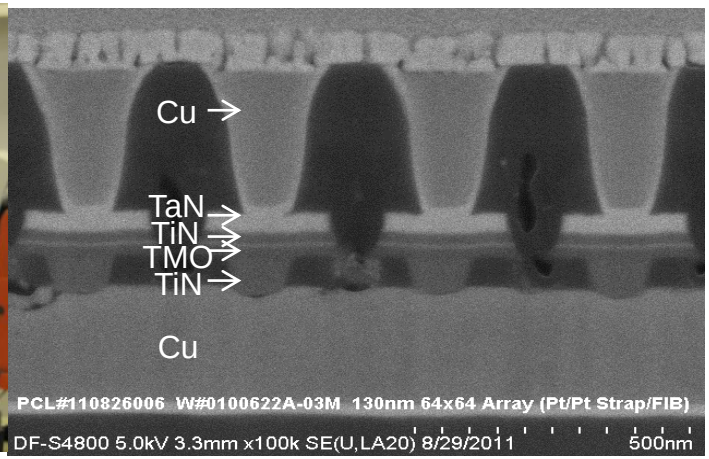
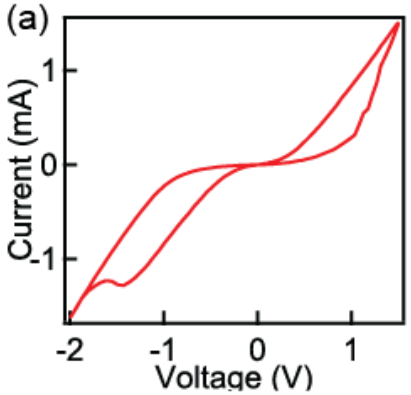
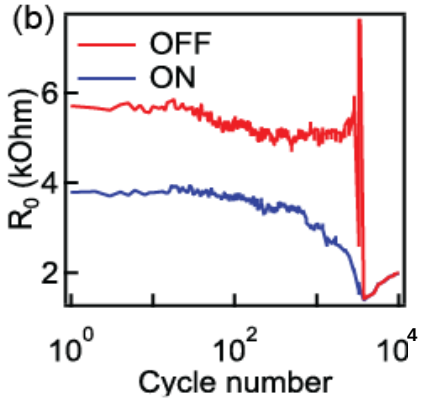
CMOS compatibility

Fabrication friendly materials and processes









Fully BEOL compatible processes and materials fabricated at SVTC Technologies 300 mm line, 130 nm node

TMO = Ti_4O_7 / TaO_x

Thank you