SAND2020-8793C

Electrochemical memory for energy efficient computing

PRESENTED BY

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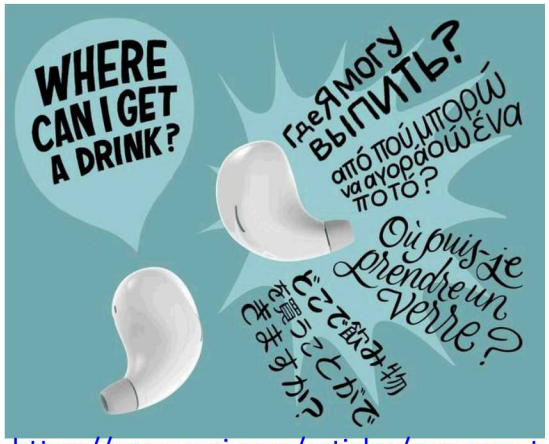
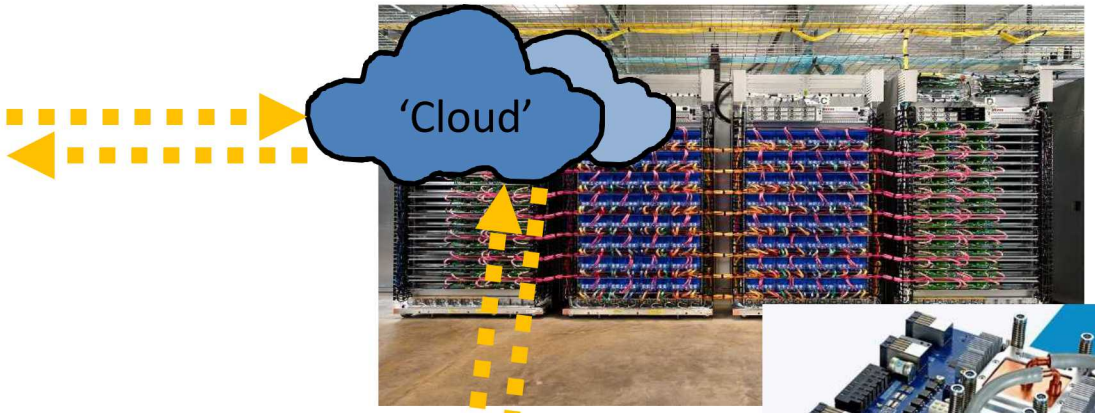
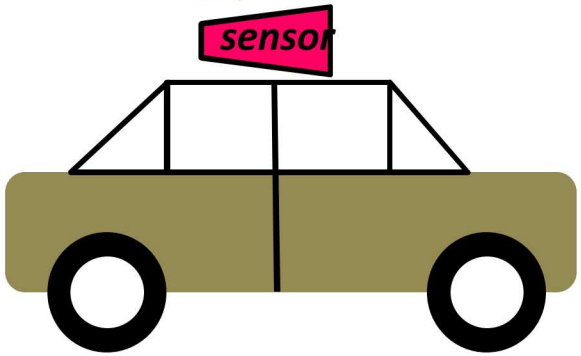
The need for low power computing

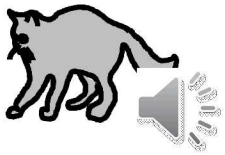


https://www.wsj.com/articles/can-smart-earbuds-instantly-translate-foreign-speech-1530279191

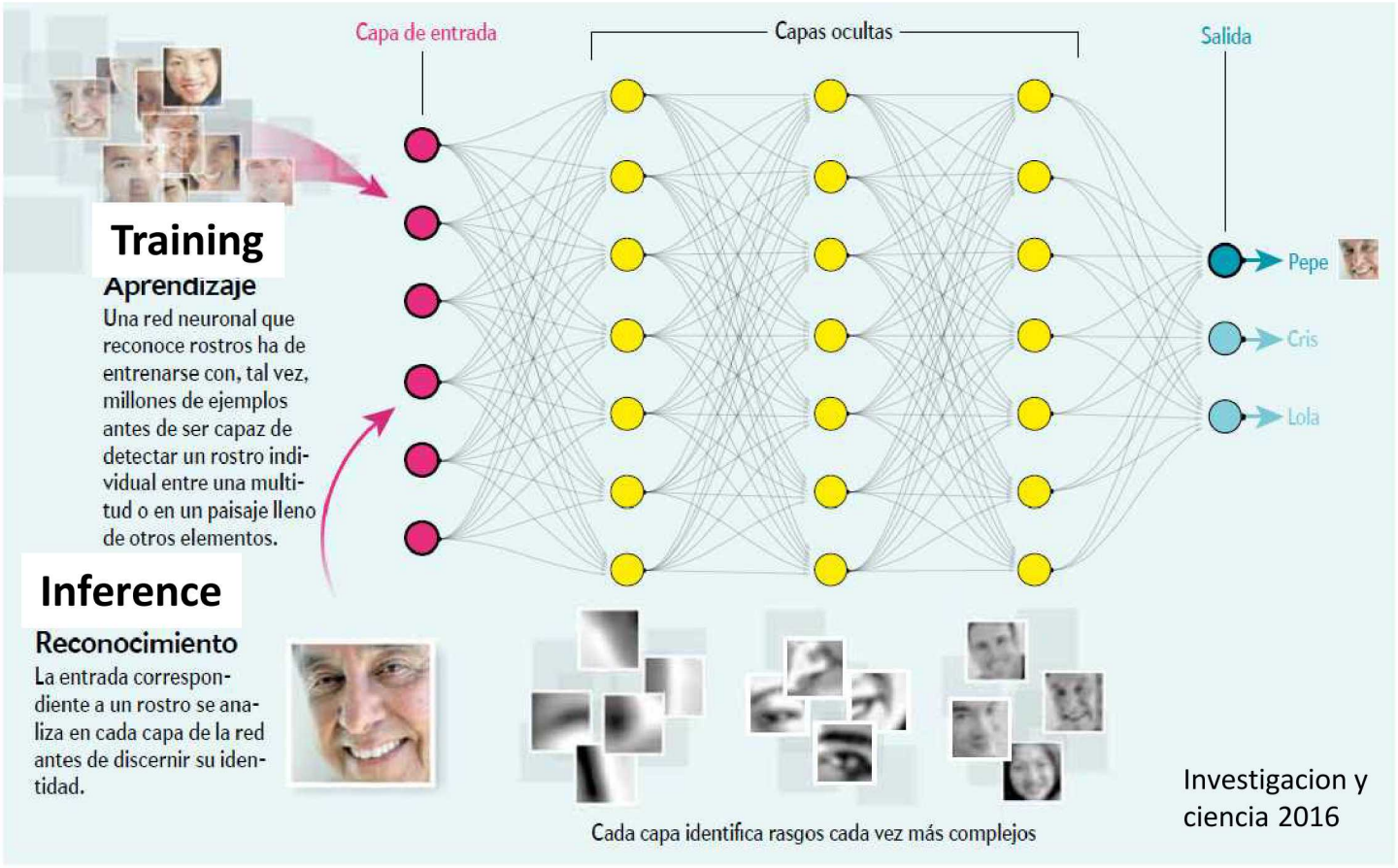


Google TPU



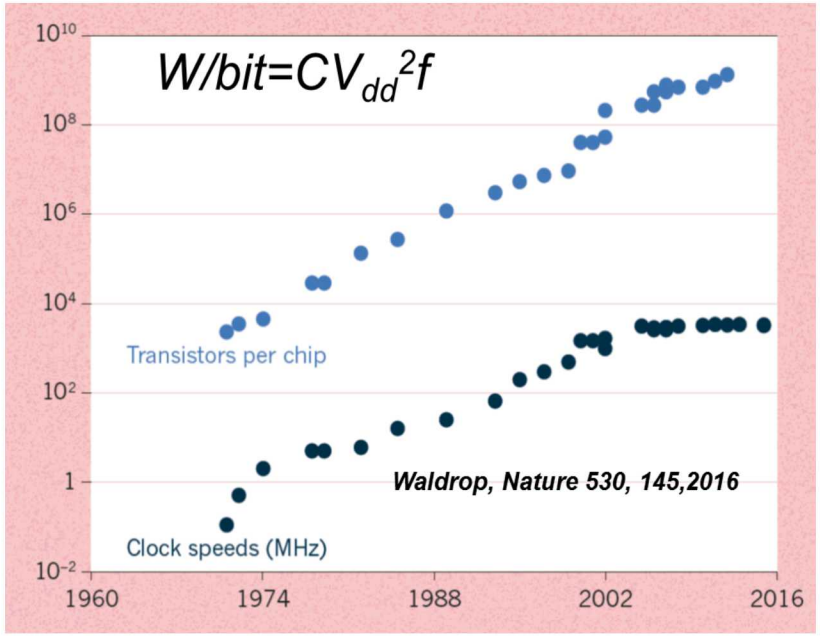


Artificial neural networks and deep learning



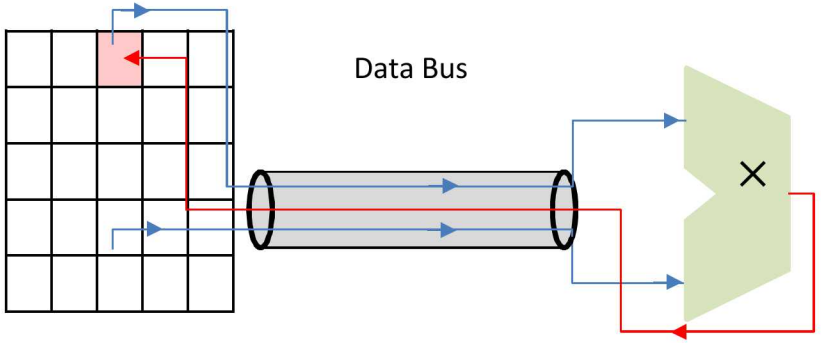
$$\begin{bmatrix} y_1 \\ \vdots \\ y_m \end{bmatrix} = \begin{bmatrix} w_{1,1} & \cdots & w_{1,n} \\ \vdots & \ddots & \vdots \\ w_{m,1} & \cdots & w_{m,n} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$$

Excess power limits IC performance

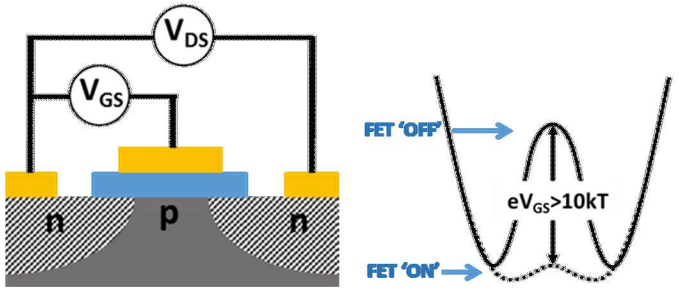


Year

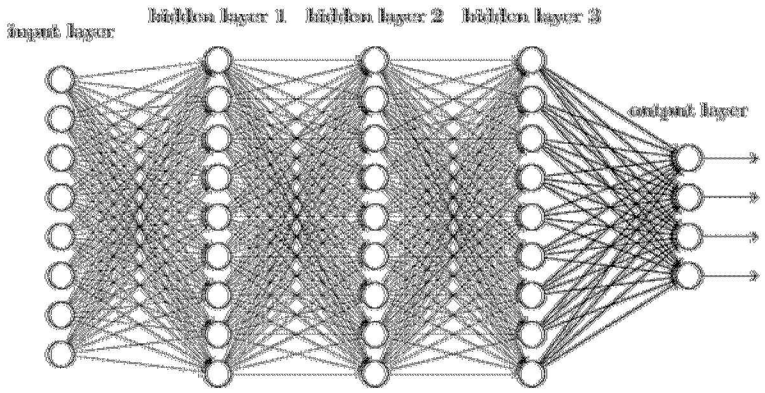
1) Data transfer logic<->memory



2) High switching voltage



Analog implementations of neural networks



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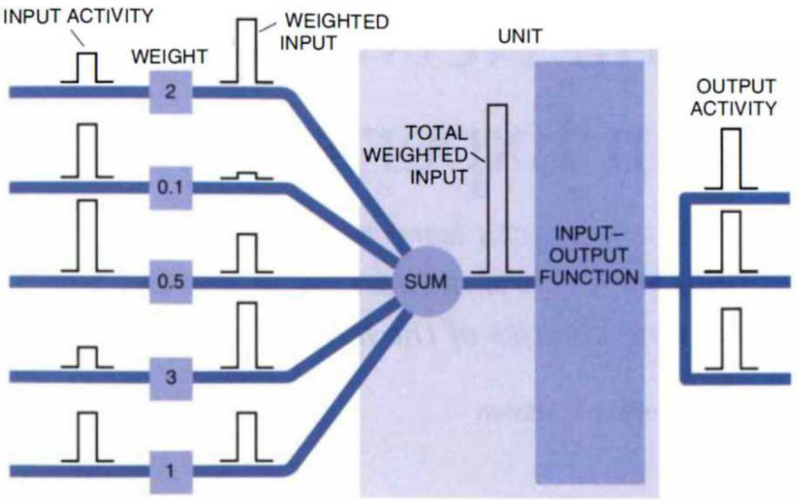
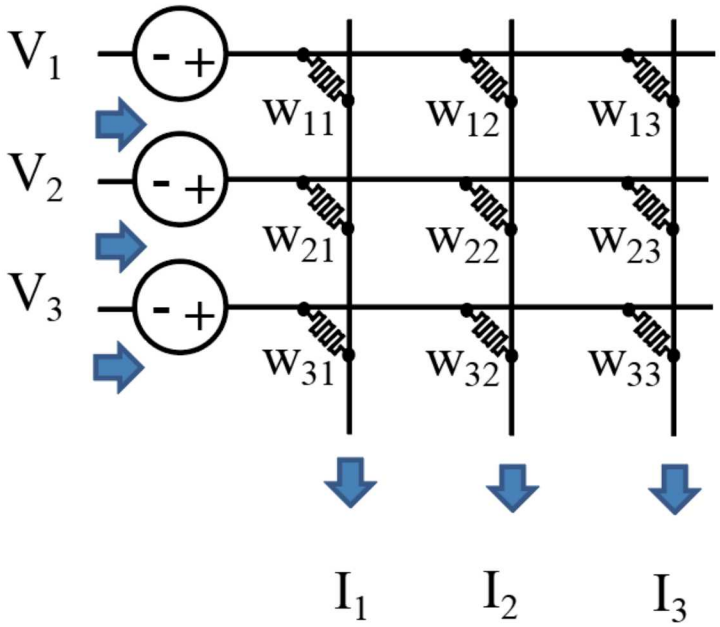
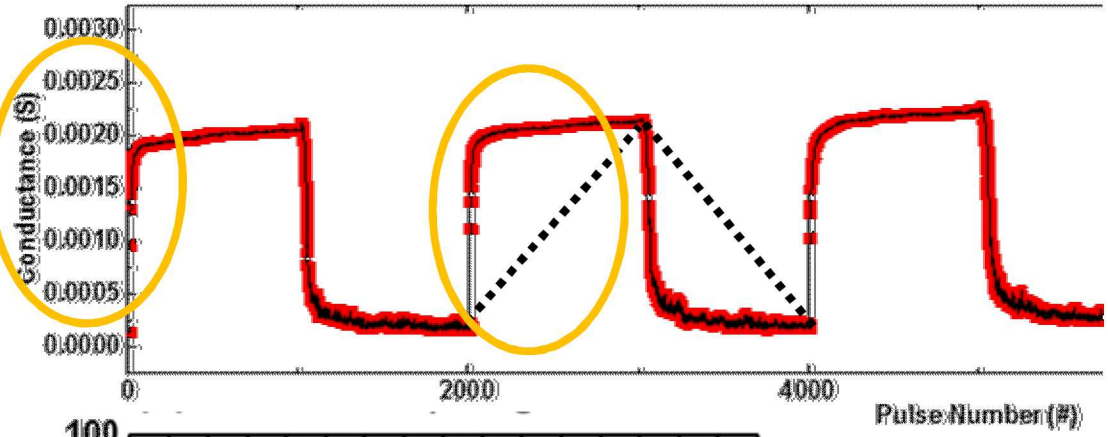


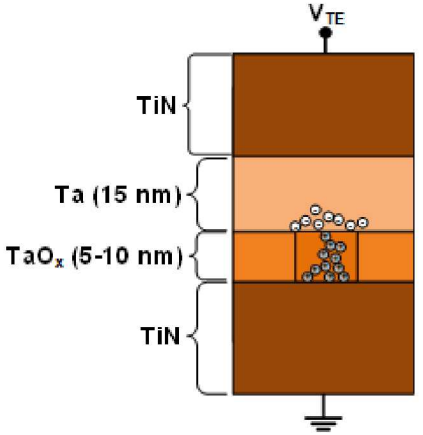
Hinton, Scientific American 1993

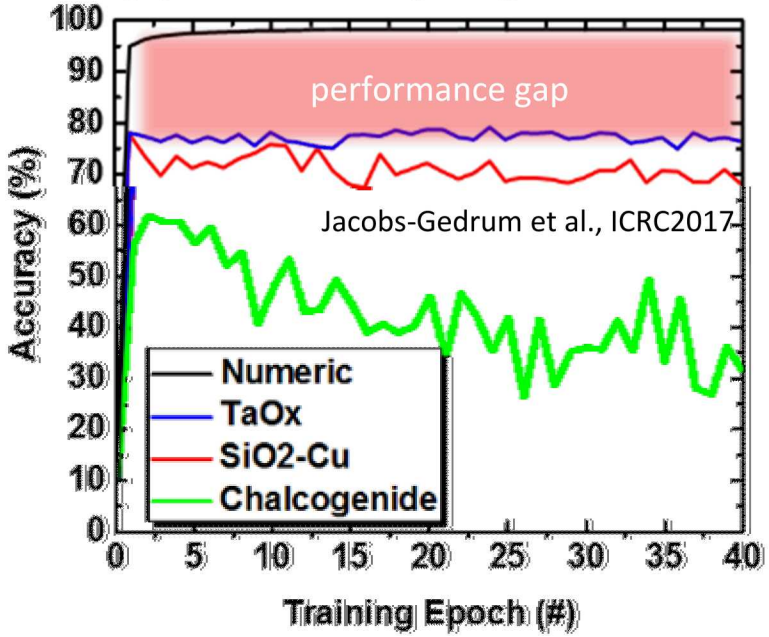


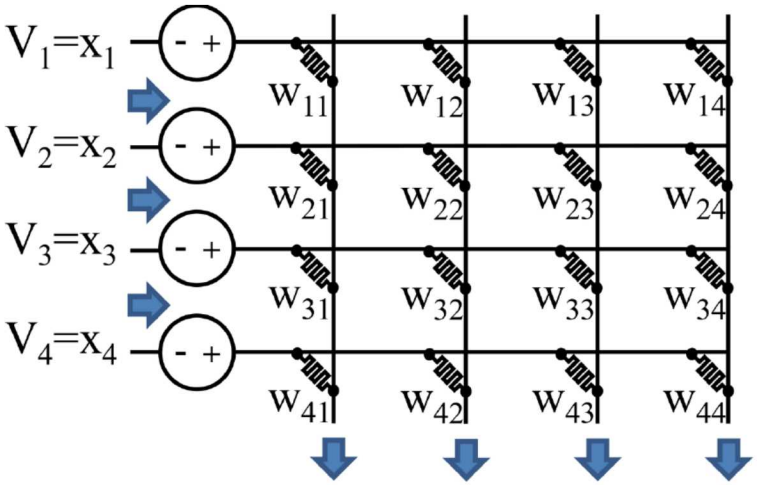
$I_1 = V_1W_{11} + V_2W_{21} + V_3W_{31}$

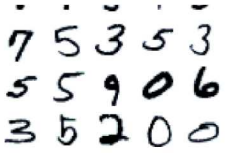
Non-linearity, high conductance limit accuracy, scaling





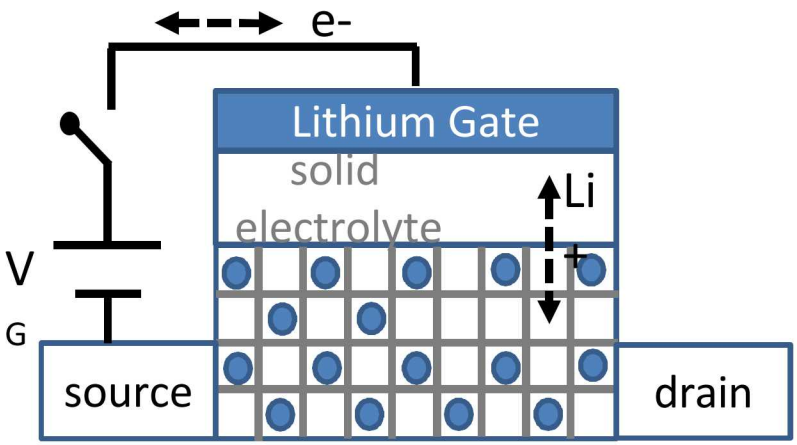


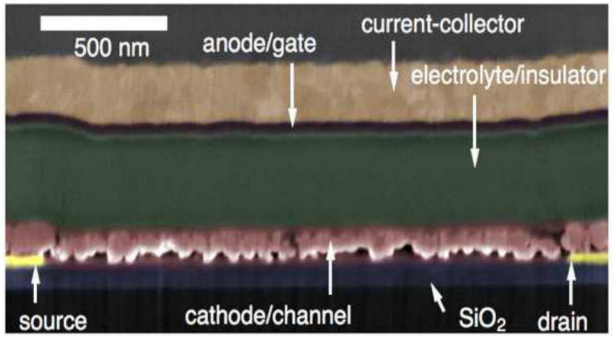


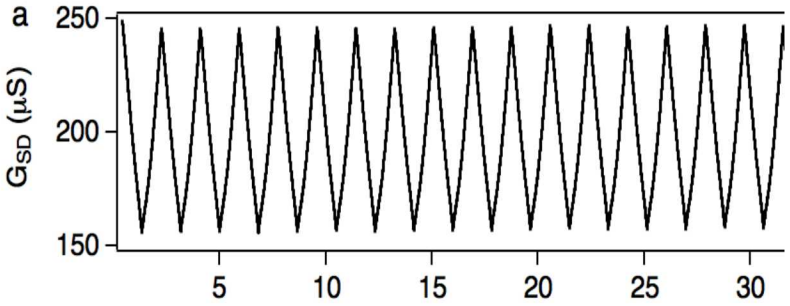


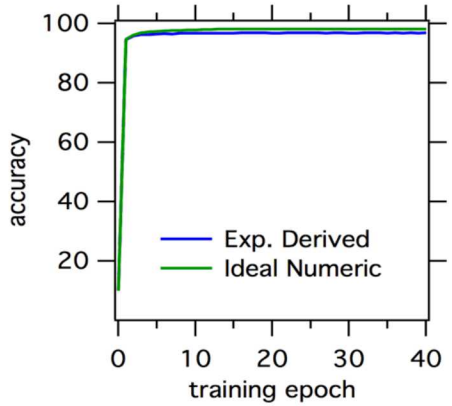
Data set	# Training Examples	# Test Examples	Network Size
MNIST Large Digits	60,000	10,000	784×300×10

Ion-insertion electrodes for neuromorphic computing



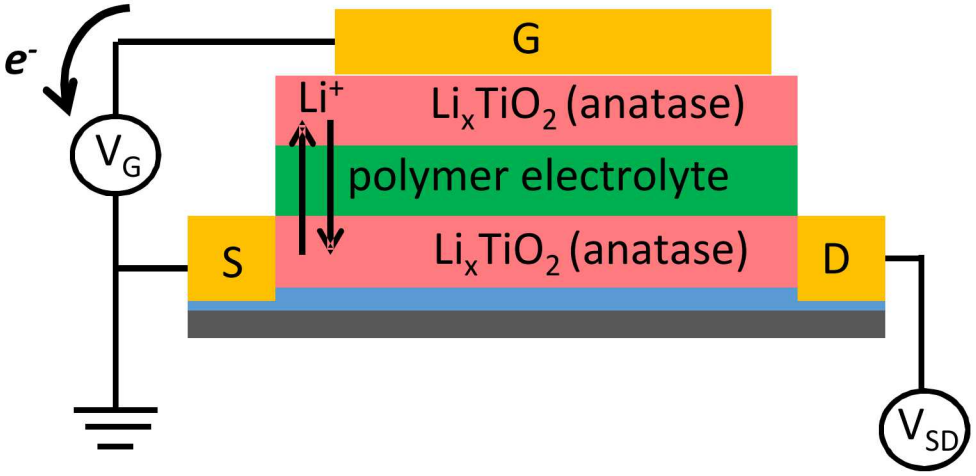


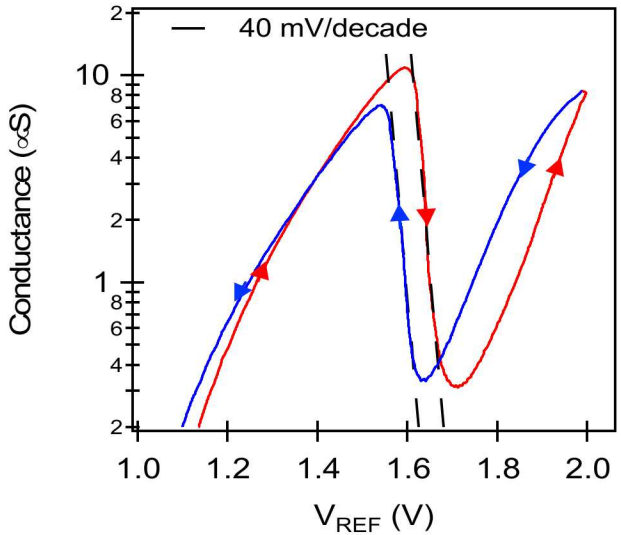


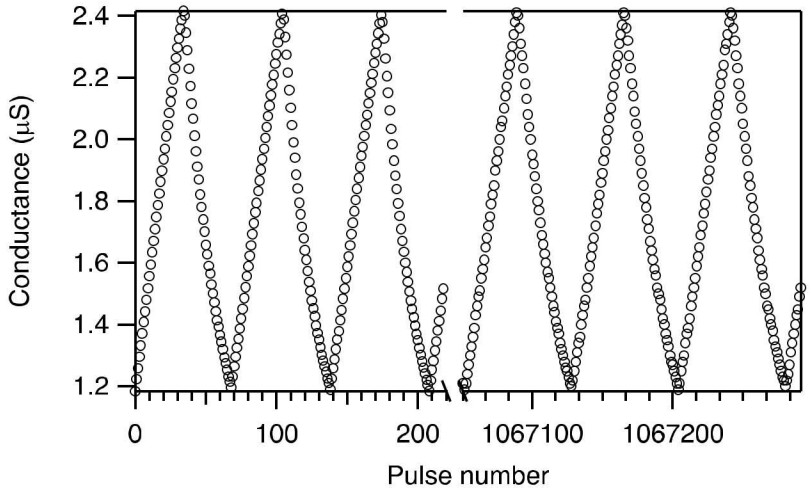


E. J. Fuller, F. El Gabaly, F. Léonard, S. Agarwal, S. J. Plimpton, R. B. Jacobs-Gedrim, C. D. James, M. J. Marinella, A. A. Talin, Adv. Mat., 29, 1604310, 2017

Li_xTiO_2-Li_xTiO_2 symmetric redox transistor





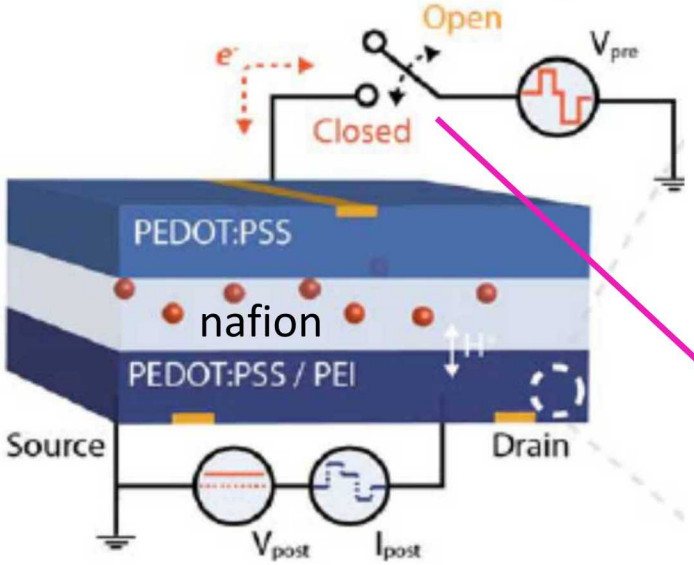


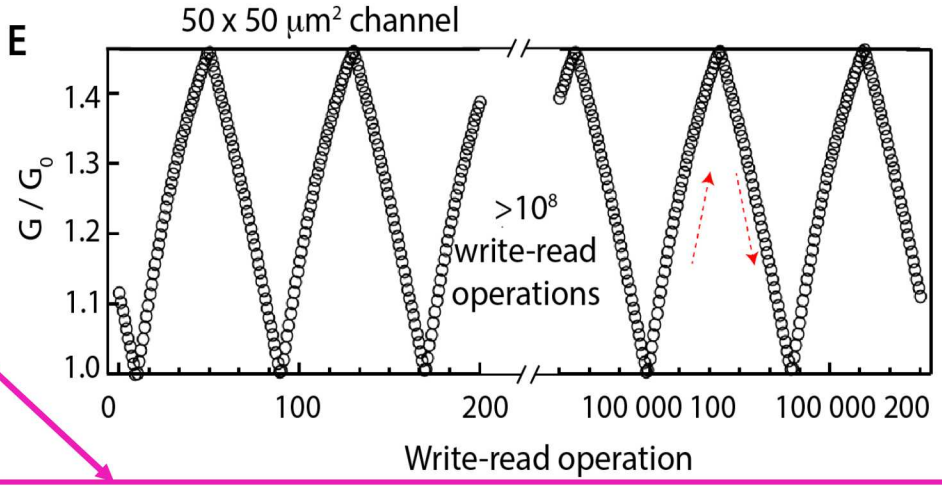
Gate: $Li_xTiO_2 \rightarrow Li_{x-\Delta x}TiO_2 + \Delta xLi$

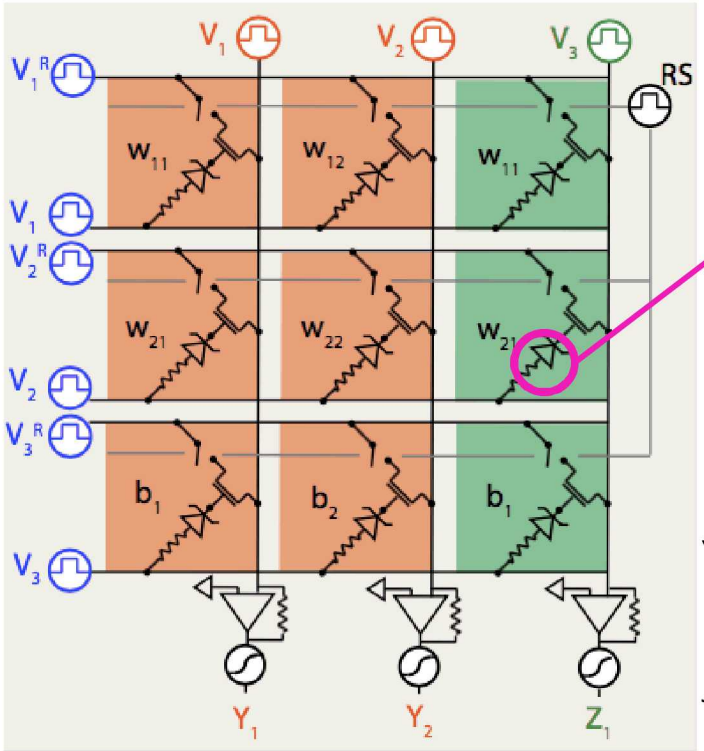
Channel: $Li_xTiO_2 + \Delta xLi \rightarrow Li_{x+\Delta x}TiO_2$

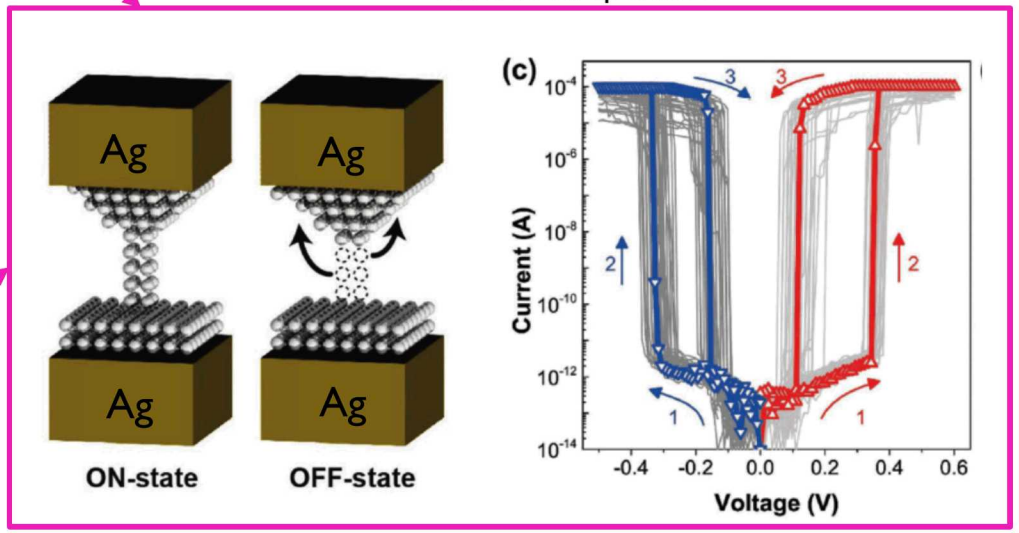
Y. Li, E. J. Fuller, S. Asapu, S. Agarwal, T. Kurita, J. J. Yang, A. A. Talin, ACS App Mat Int., 11, 38982, (2019)

Polymer redox transistor





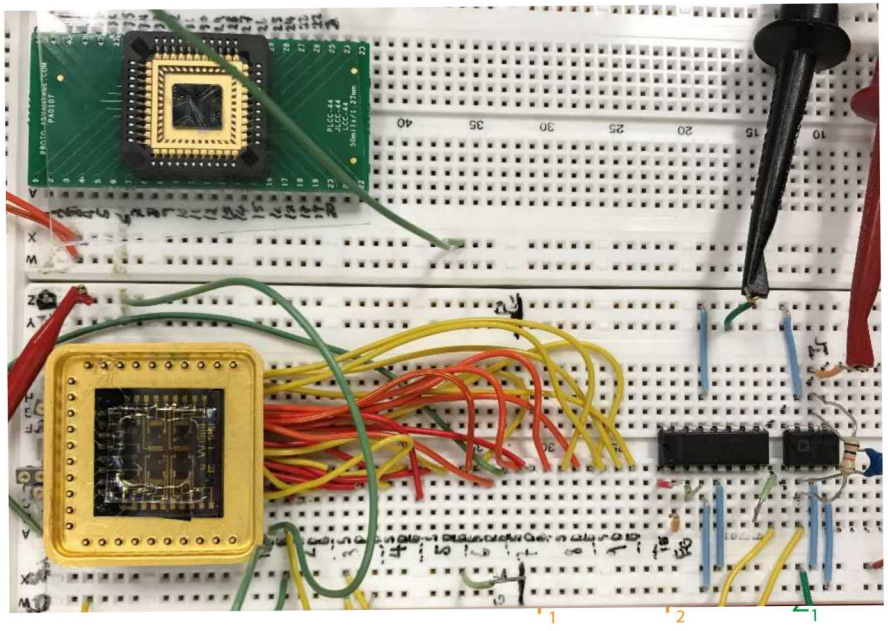


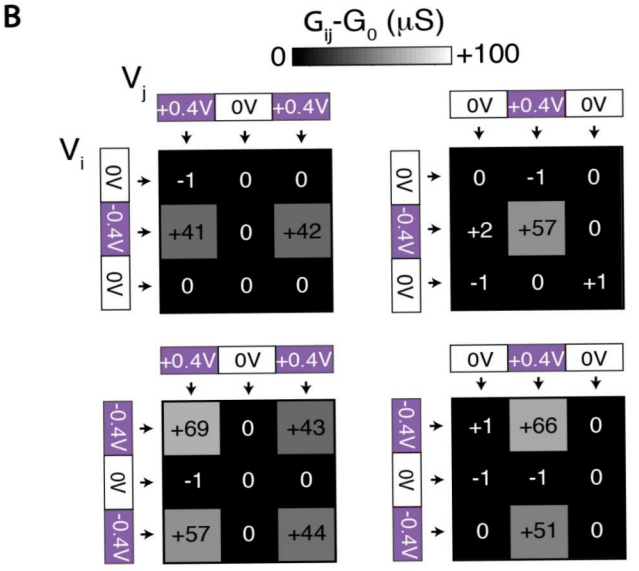


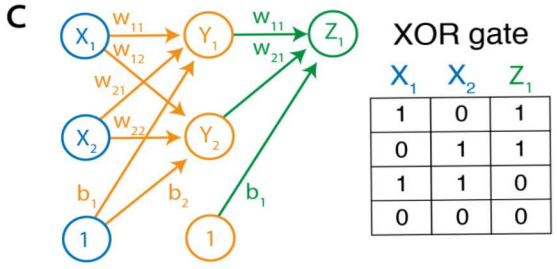
Y.B. van de Burgt, E. Lubberman, E.J. Fuller, S.T. Keene, G.C. Faria, S. Agarwal, M.J. Marinella, A.A. Talin*, A. Salleo*, Nature Materials 16, 414, 2017

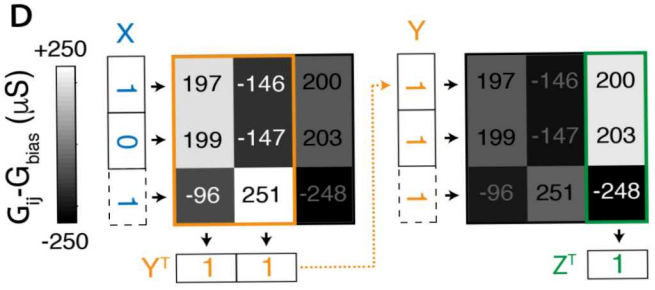
E. J. Fuller, S. T. Keene, A. Melianas, Z. Wang, S. Agarwal, Y. Li, Y. Tuchman, James, M. J. Marinella, J. J. Yang, A. Salleo, A. A. Talin, *Science* 364, 570, (

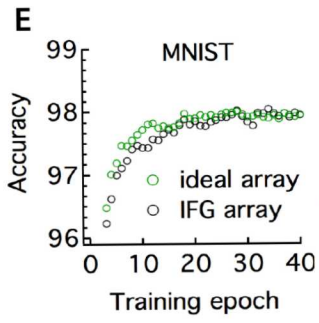
Parallel updates in a 3x3 array, 'XOR' operation

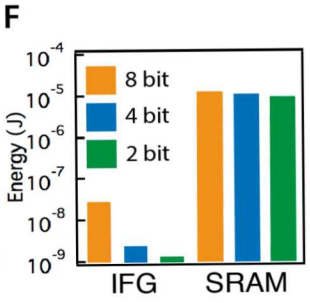


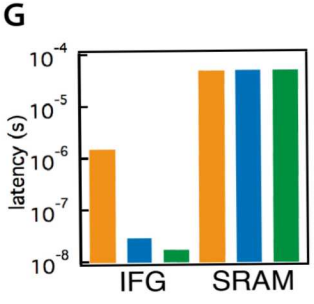


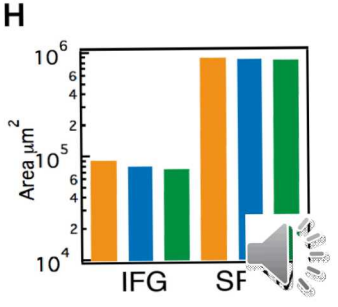










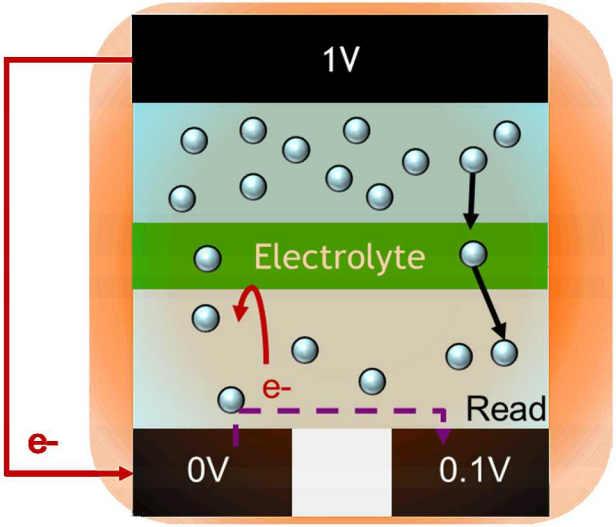


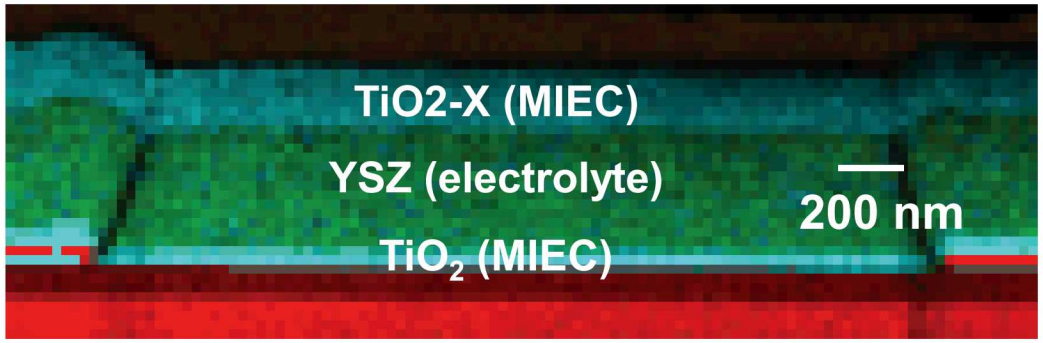
E. J. Fuller, S. T. Keene, A. Melianas, Z. Wang, S. Agarwal, Y. Li, Y. Tuchman, C. D. James, M. J. Marinella, J. J. Yang, A. Salleo, A. A. Talin, *Science* 364, 570, (2019).

Oxygen vacancy redox transistor

(ECRAM, bulk-ReRAM)

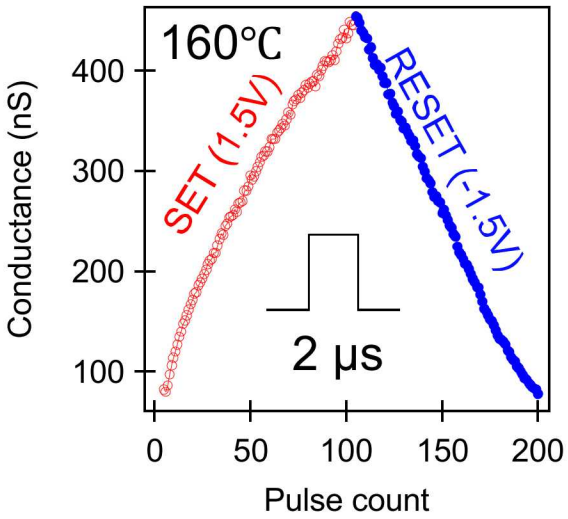
Y. Li, E. J. Fuller, J. D. Sugar, S. Yoo, D. S. Ashby, C. H. Bennett, R. D. Horton, M. S. Bartsch, M. J. Marinella, W. D. Lu, A. A. Talin, Adv. Mat., accepted)

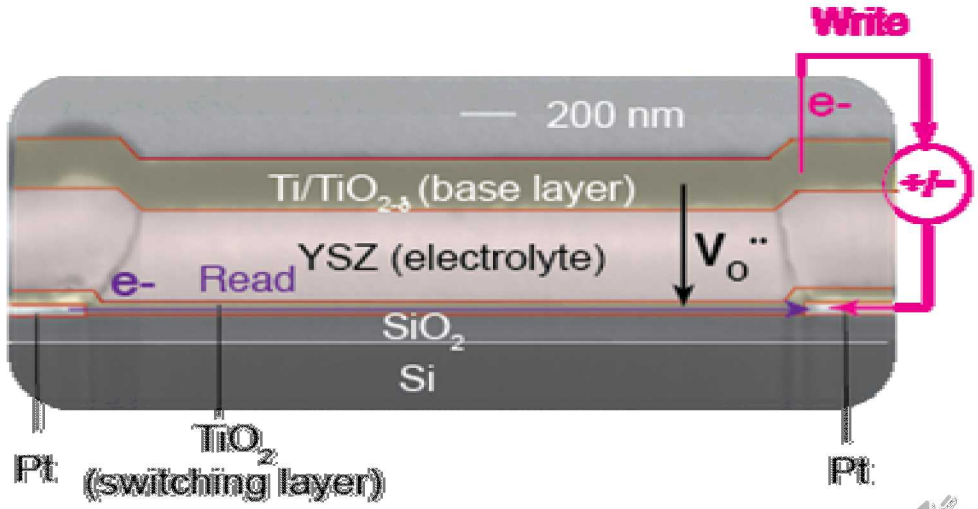




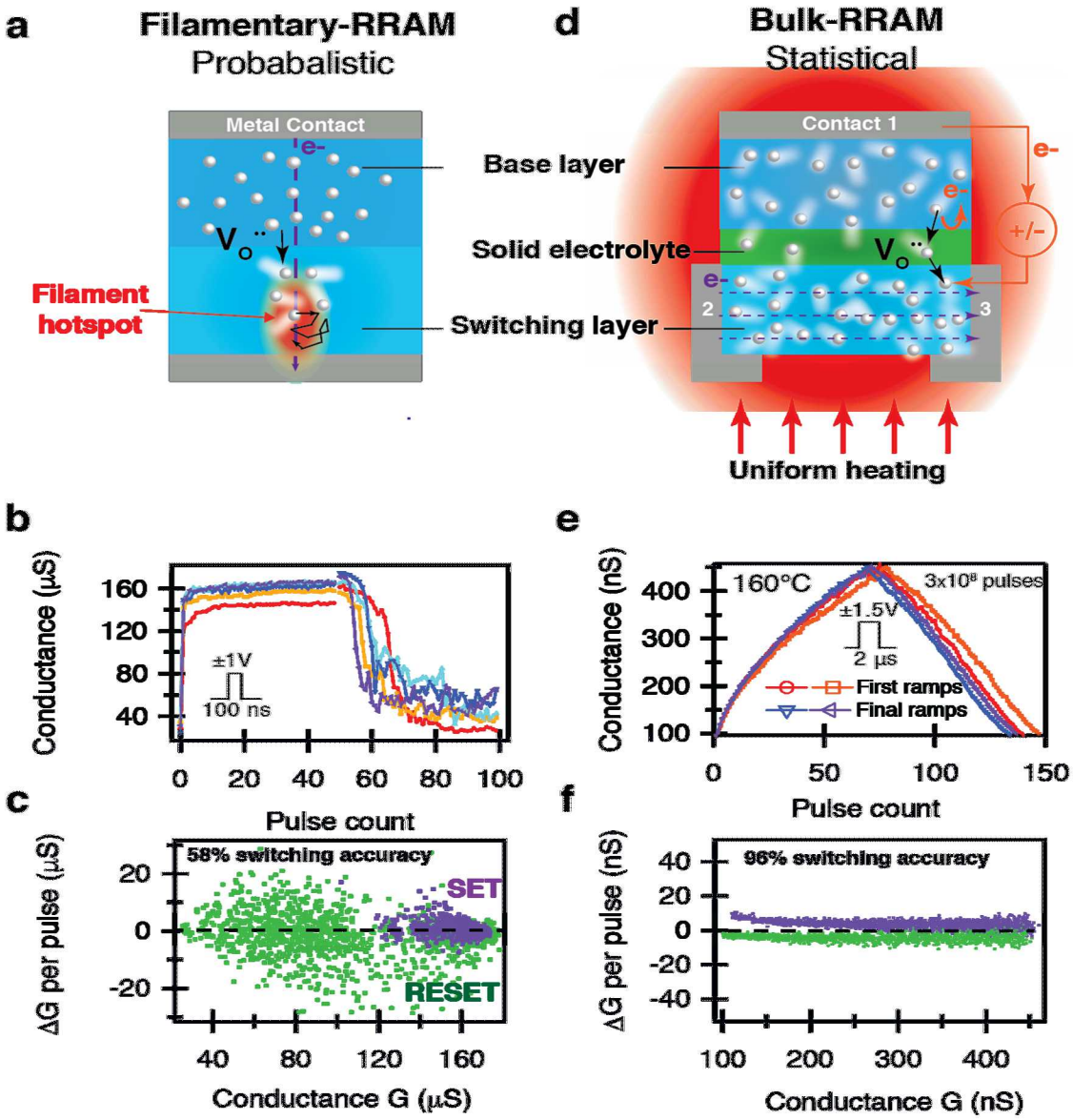
Si Ti Zr

V Pt





Deterministic switching through bulk vacancy control

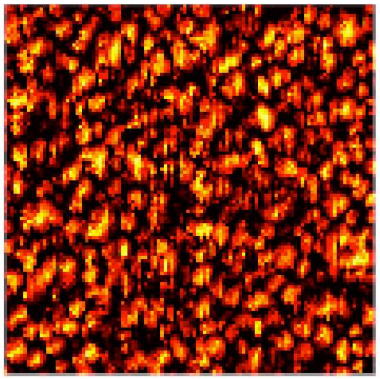


Y. Li, E. J. Fuller, J. D. Sugar, S. Yoo, D. S. Ashby, C. H. Bennett, R. D. Horton, M. S. Bartsch, M. J. Marinella, W. D. Lu, A. A. Talin, Adv. Mat, accepted)

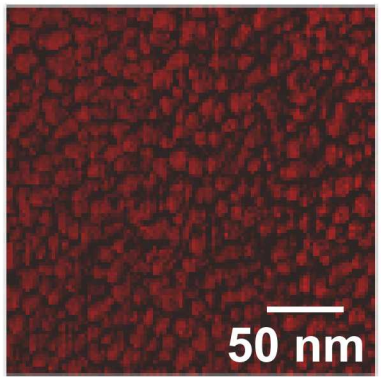
Conductive-AFM shows uniform switching

Y. Li, E. J. Fuller, J. D. Sugar, S. Yoo, D. S. Ashby, C. H. Bennett, R. D. Horton, M. S. Bartsch, M. J. Marinella, W. D. Lu, A. A. Talin, Adv. Mat., in revision)

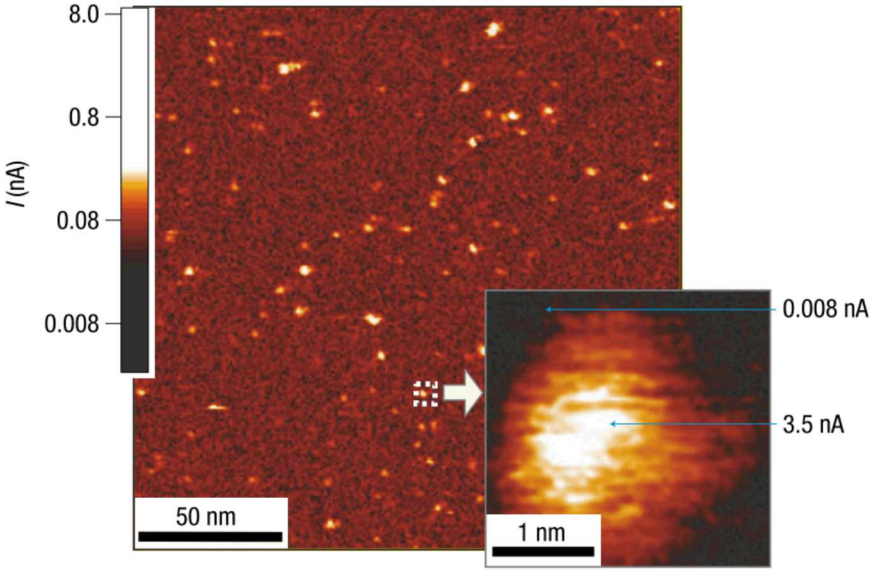
High-conductance state



Low-conductance state



Filamentary-RRAM shows conductive filaments

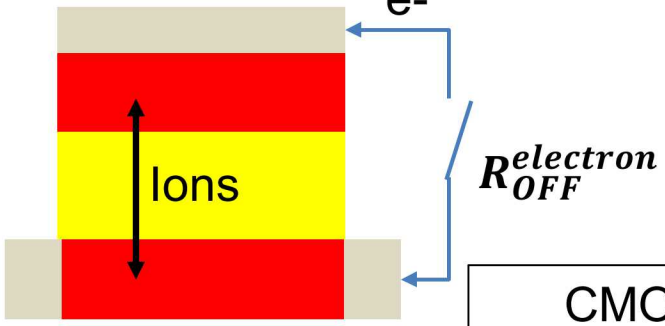


Szot et al. *Nat. Mater.* 5, 312 (2006)

Retention time of Li, H vs O ECRAM

Switching requires movement of both electron & ion
Retention requires one or both be blocked

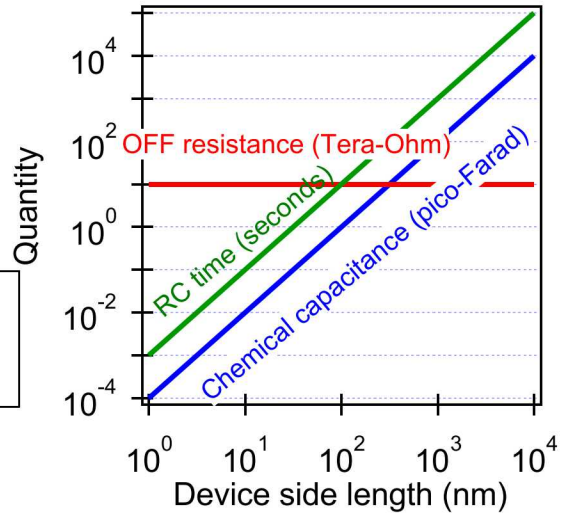
Li+, H+



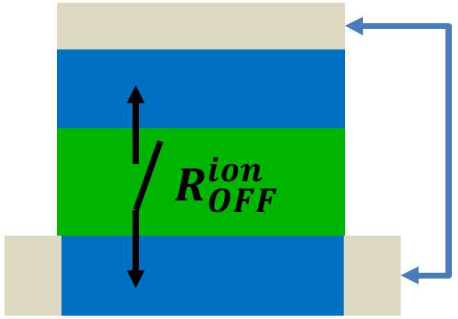
Ions can flow freely
Electrons blocked by switch
Sensitive to electronic conductivity in electrolyte

CMOS incompatible

Poor retention for at smaller sizes



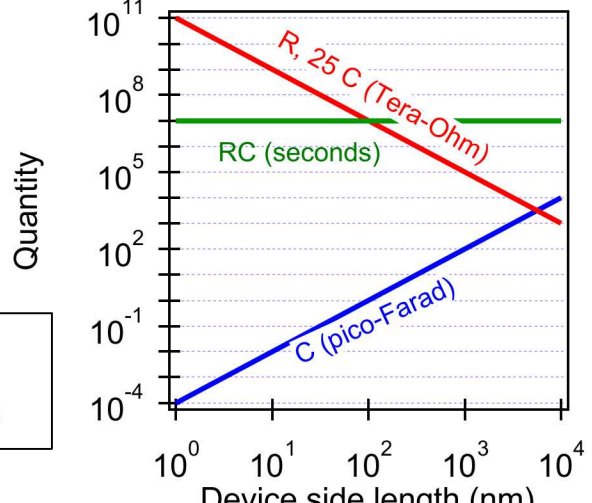
$V_O^{\circ\circ}$



Ions are blocked;
Electrons do not matter

CMOS compatible

Size-independent retention



Contributors:

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