Design, Optimization, and Benchmarking for MRAM Technologies

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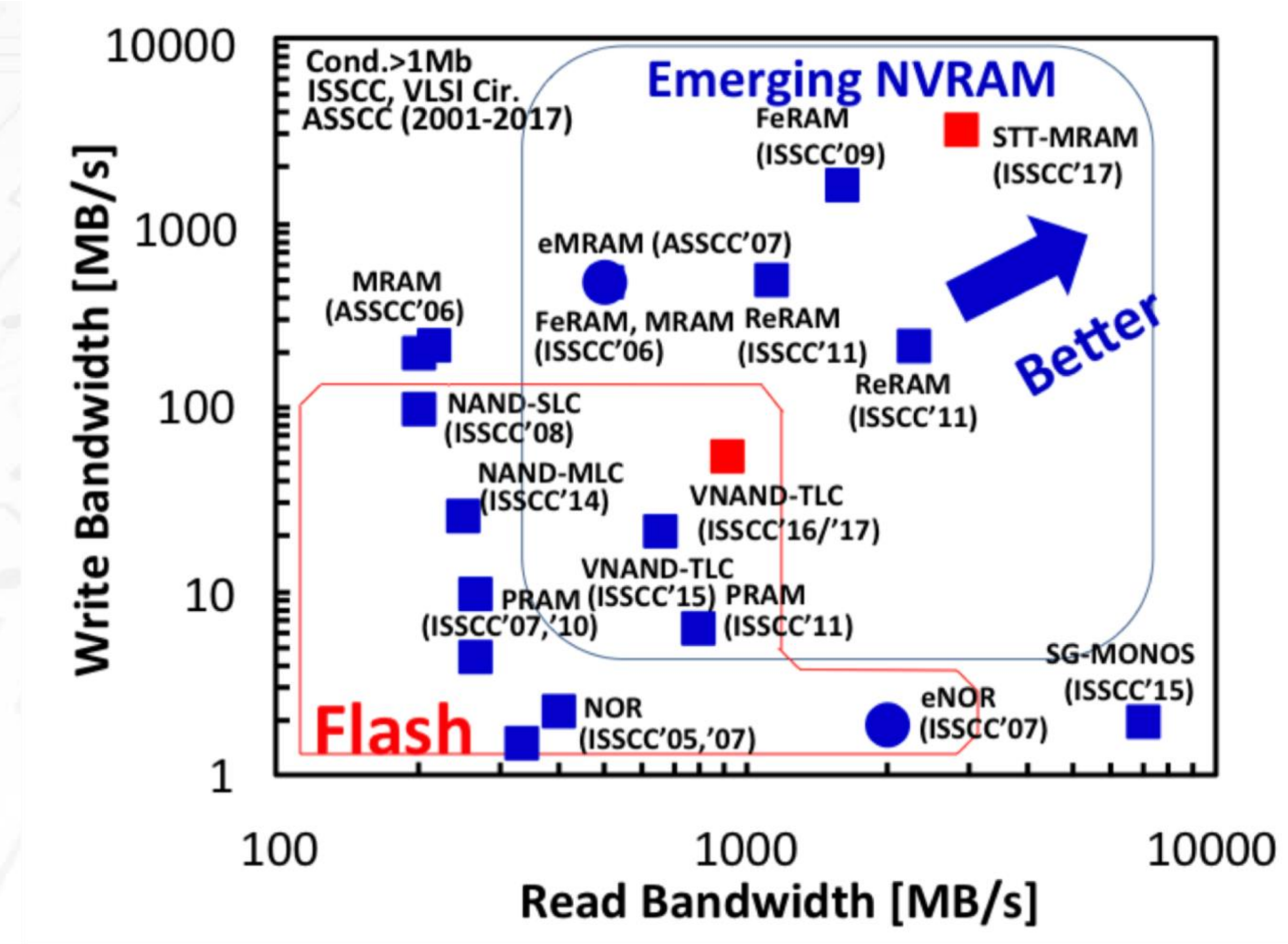
STT-RAM: A Promising Technology

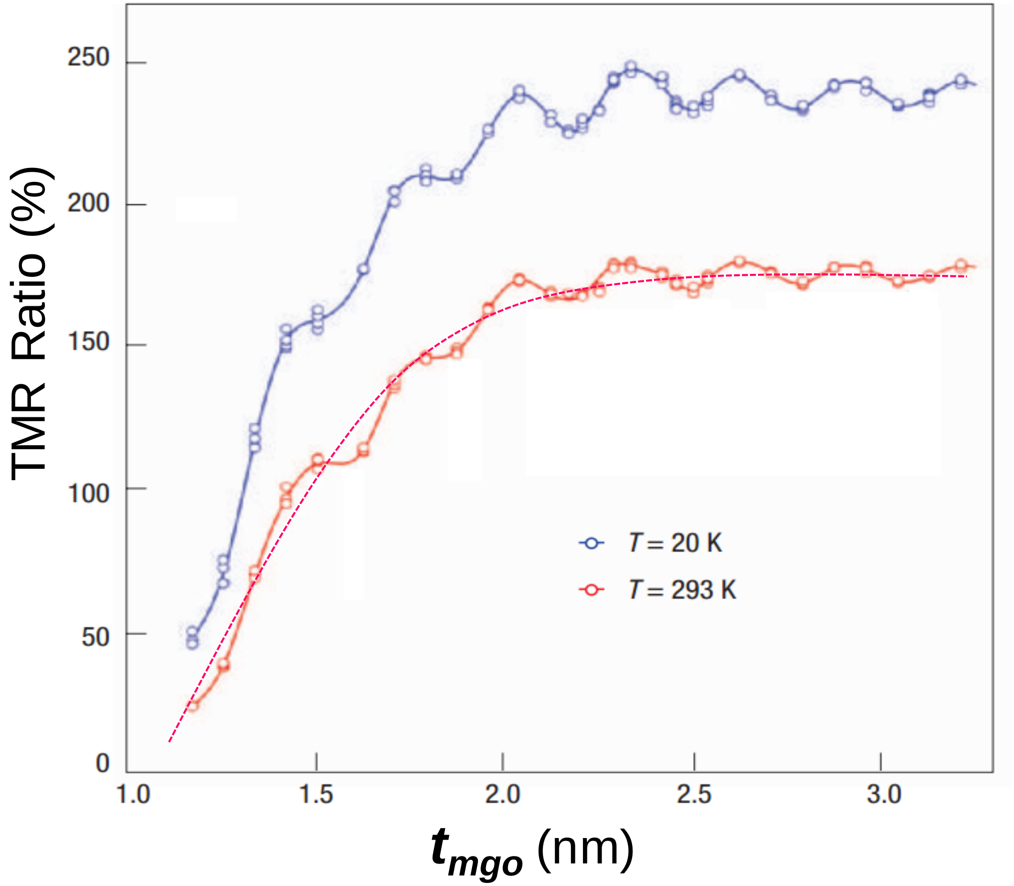


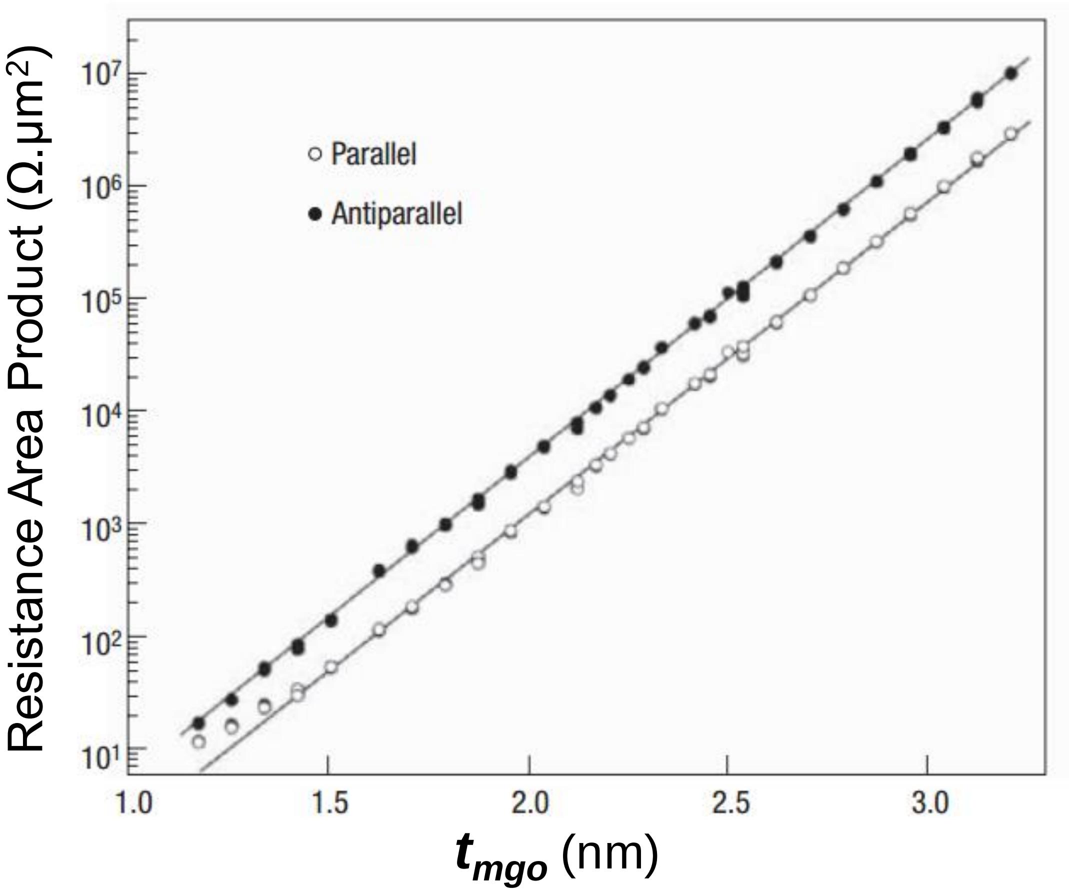
with Many Challenges

- Large write currents
- Cell area limited by transistors
- Difficult to scale transistors
- Small on-off ratios (TMR).
- Conflicting requirements for read and write operations.

http://isscc.org/wp-content/uploads/2018/06/2017_Trends.pdf

Impact of MgO Thickness

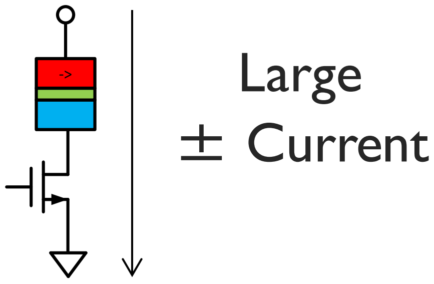


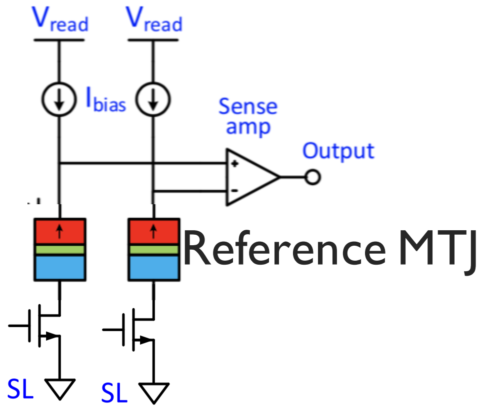


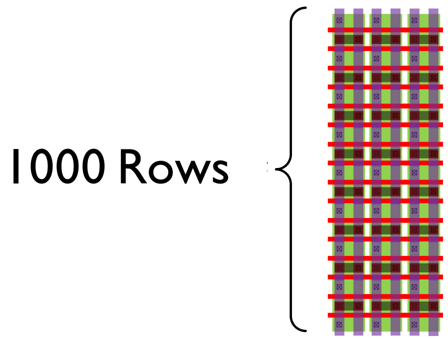
MTJ oxide thickness has a major impact on TMR and RA values.

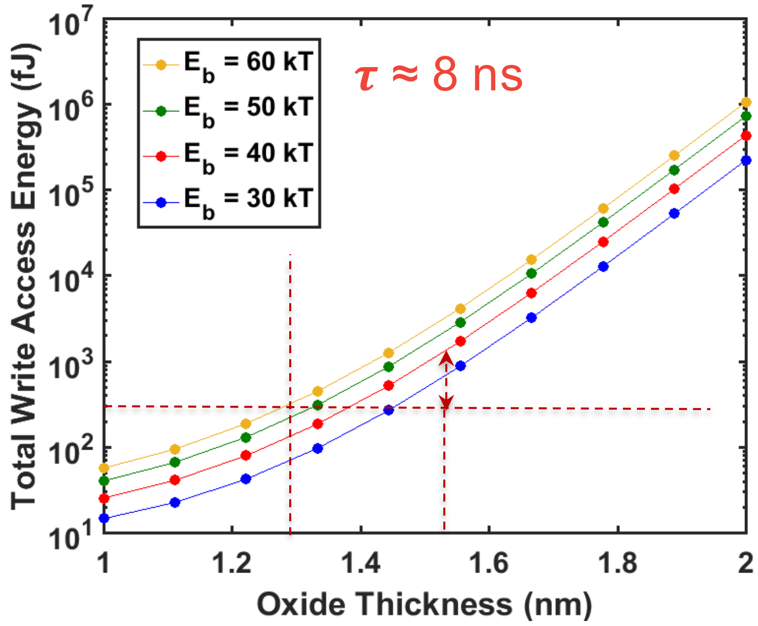
Yuasa, Shinji, et al. *Nature materials* 3.12 (2004): 868-871.

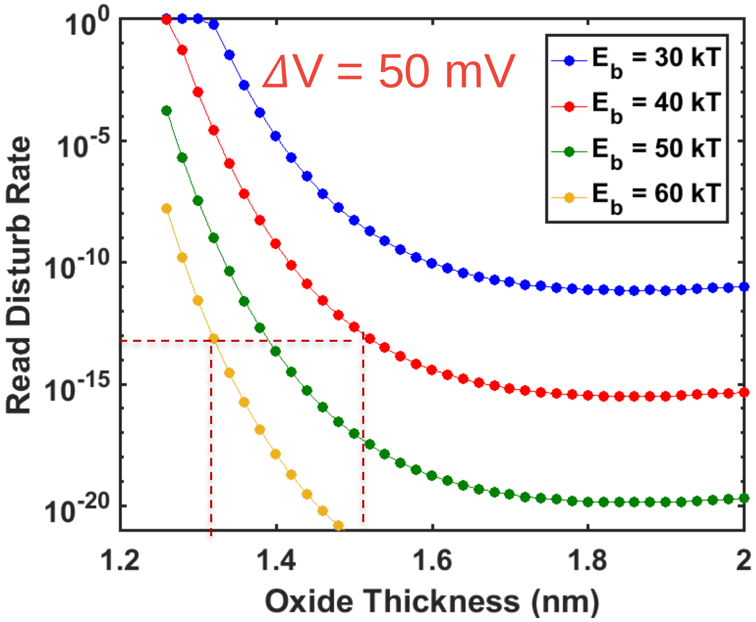
Conflicting Read and Write Requirements

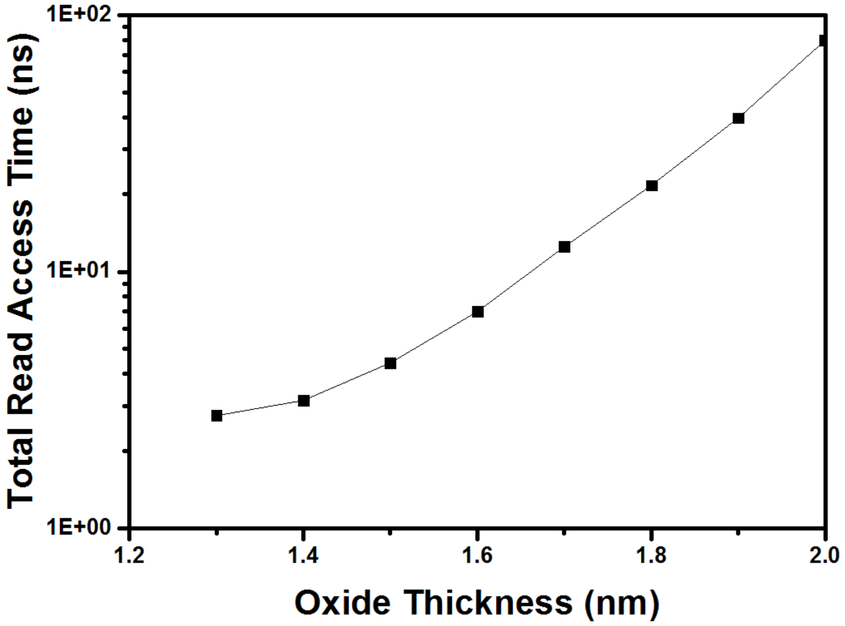








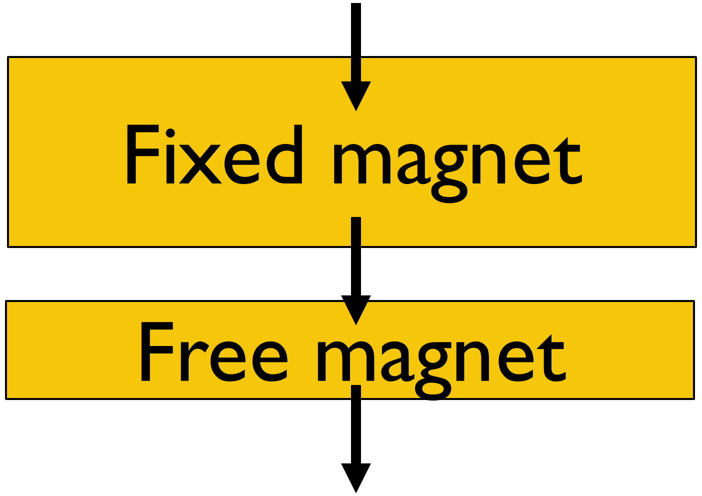




Can novel technologies disentangle these interdependencies?

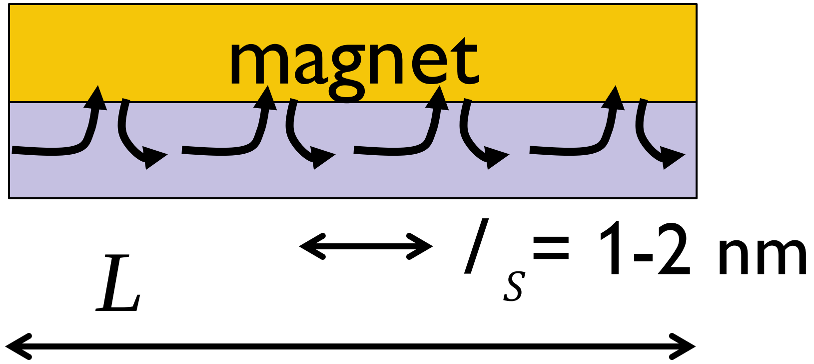
Spin-Transfer Torque vs. Spin-Orbit Torque

Each electron can transfer at most one unit of spin.



Spin-transfer torque per unit charge (in units of $\hbar/2$) <1.

Each electron can transfer more than one unit of spin.

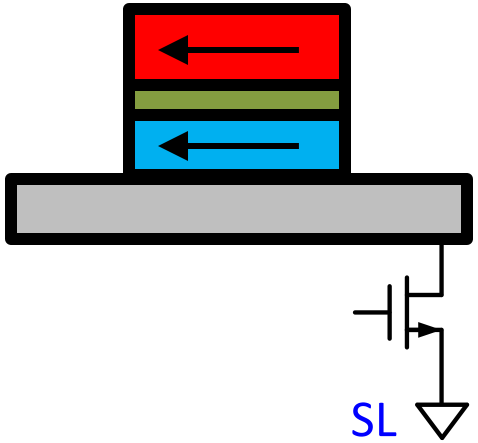


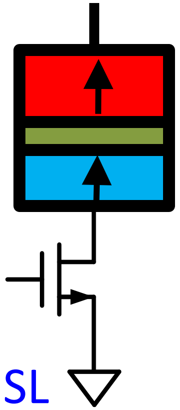
Spin-transfer torque per unit charge (in units of $\hbar/2$) ~ $x_{DL}^{J} \dfrac{L}{l_s}$

with $x_{DL}^{J} = 0.3 - 50$.

After Dan Ralph at Cornel University.

SOT Material Options

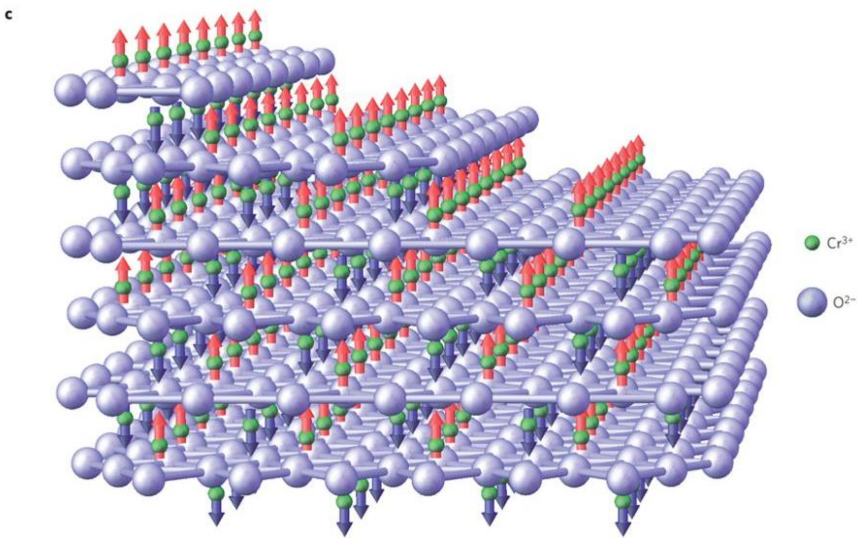


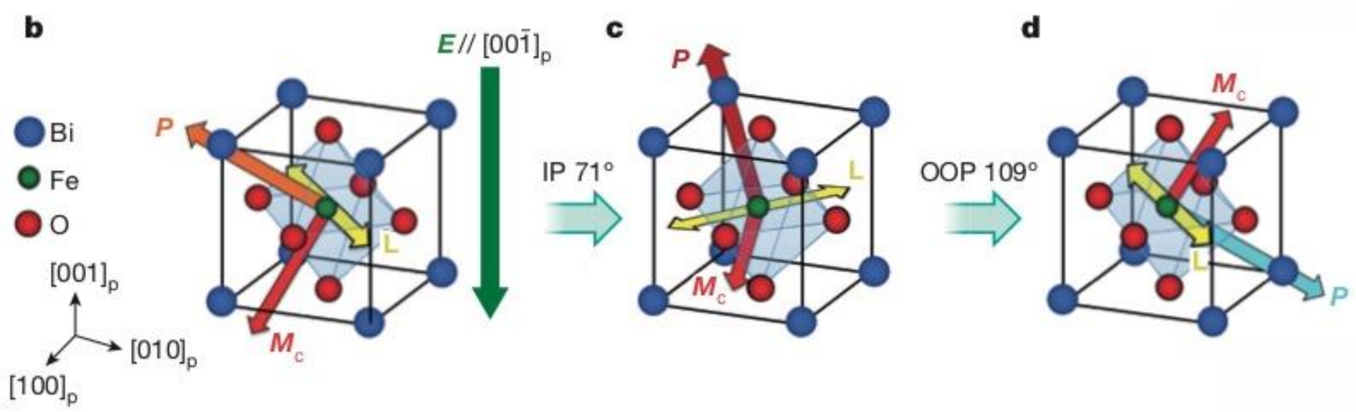


Class of Materials	SOT Material	ρ (μΩ·cm)	SOT Eff.
Heavy Metals	W	260	0.2-0.4
Topological Insulators	$BiSe_x$ (4nm)	12800	18.6
	$BiSe_x$ (8nm)	2152	2.88

← Not competitive, Needs large voltages

Voltage-Controlled Magnet Switching





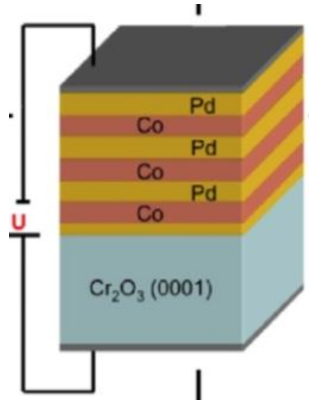
Stable and switchable boundary magnetization in Chromia.

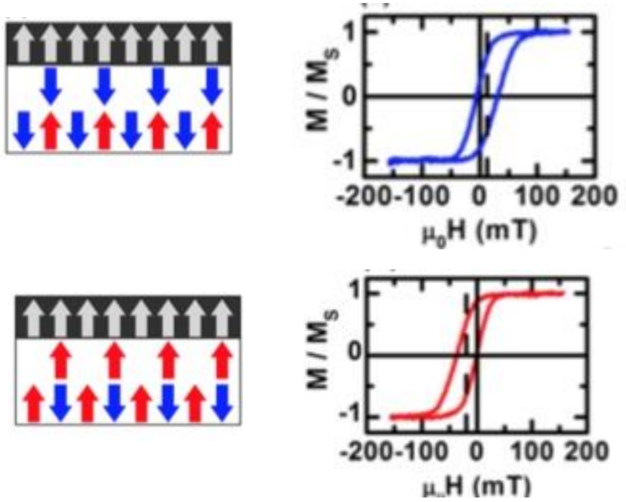
Coupling of the electric polarization and antiferromagnetic order in BFO

X. He et al., Nat. Mat. 9, 579 (2009)

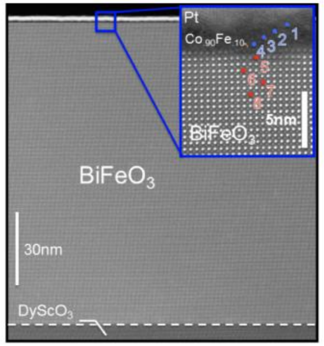
J. Heron et al., *Nature* vol. 516, pages 370–373

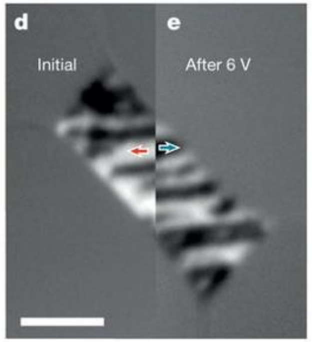
Magnetoelectric Memory



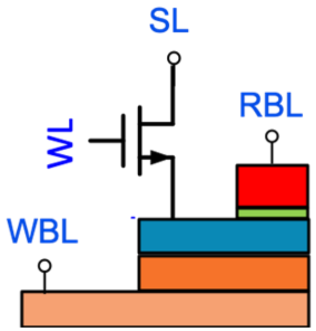


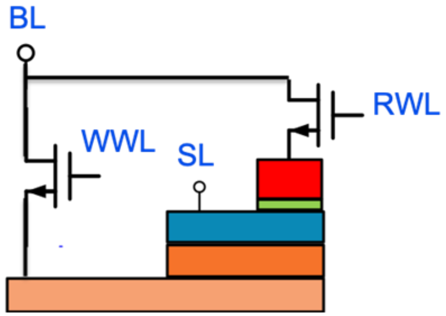
PRL 111, 187204 (2013)





J. Heron et al., *Nature* vol. 516, pp. 370–373



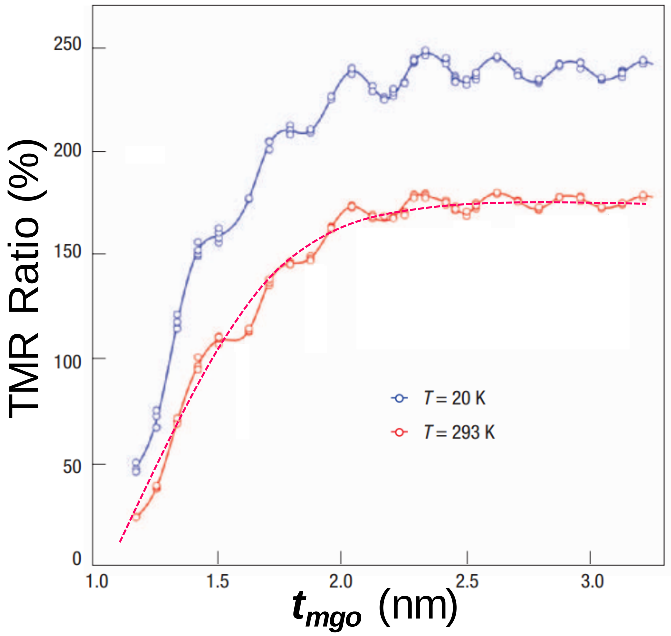


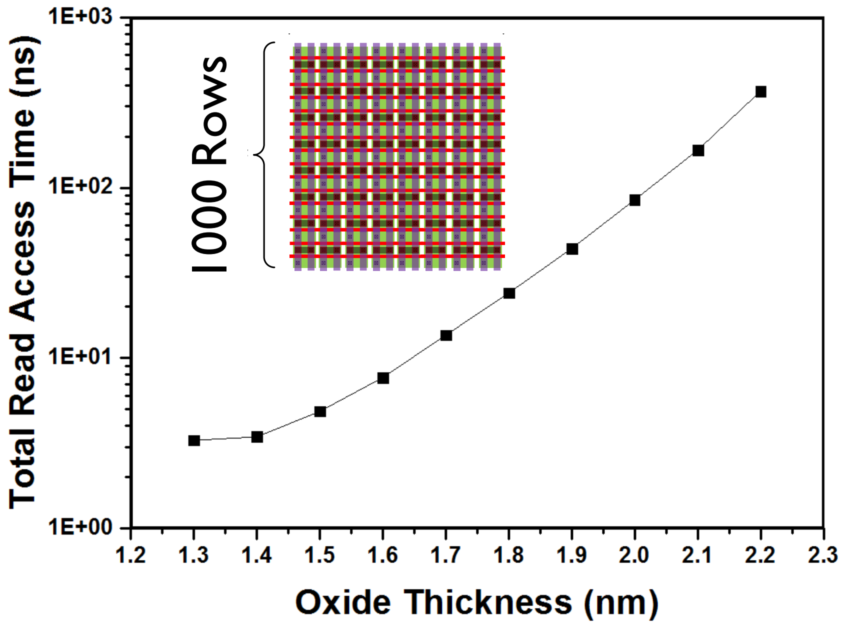
Can eliminate large currents needed in STT or SOT RAM.

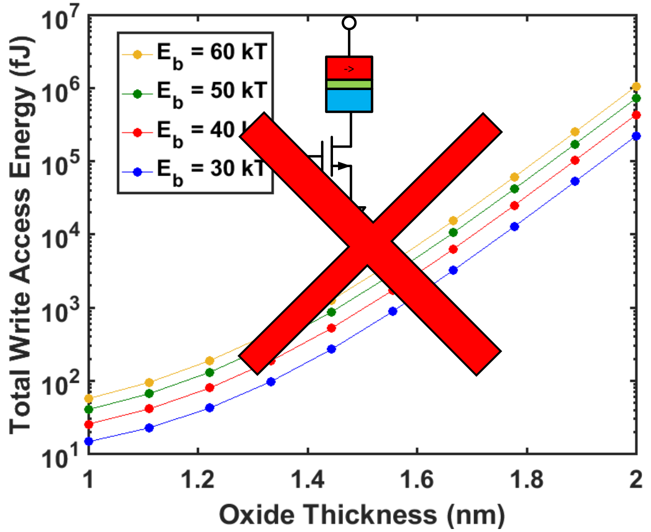
Write voltage depends on how thin the ME layer can be made without much leakage or losing desired properties.

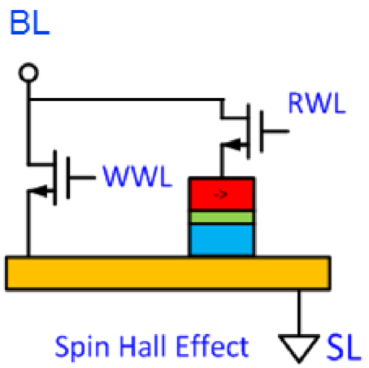
Promising in terms of scalability and energy efficiency.

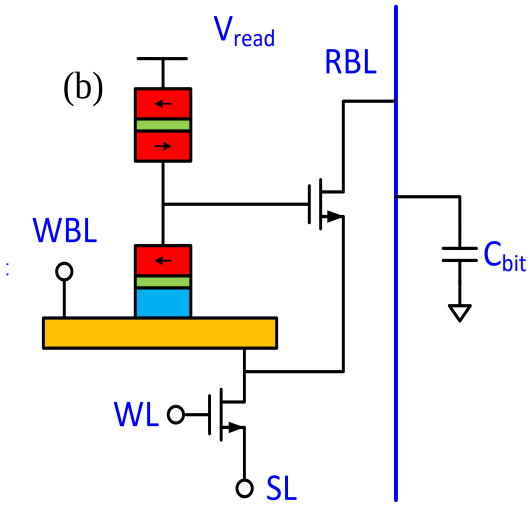
Mitigate the Large RC of the Bit-line



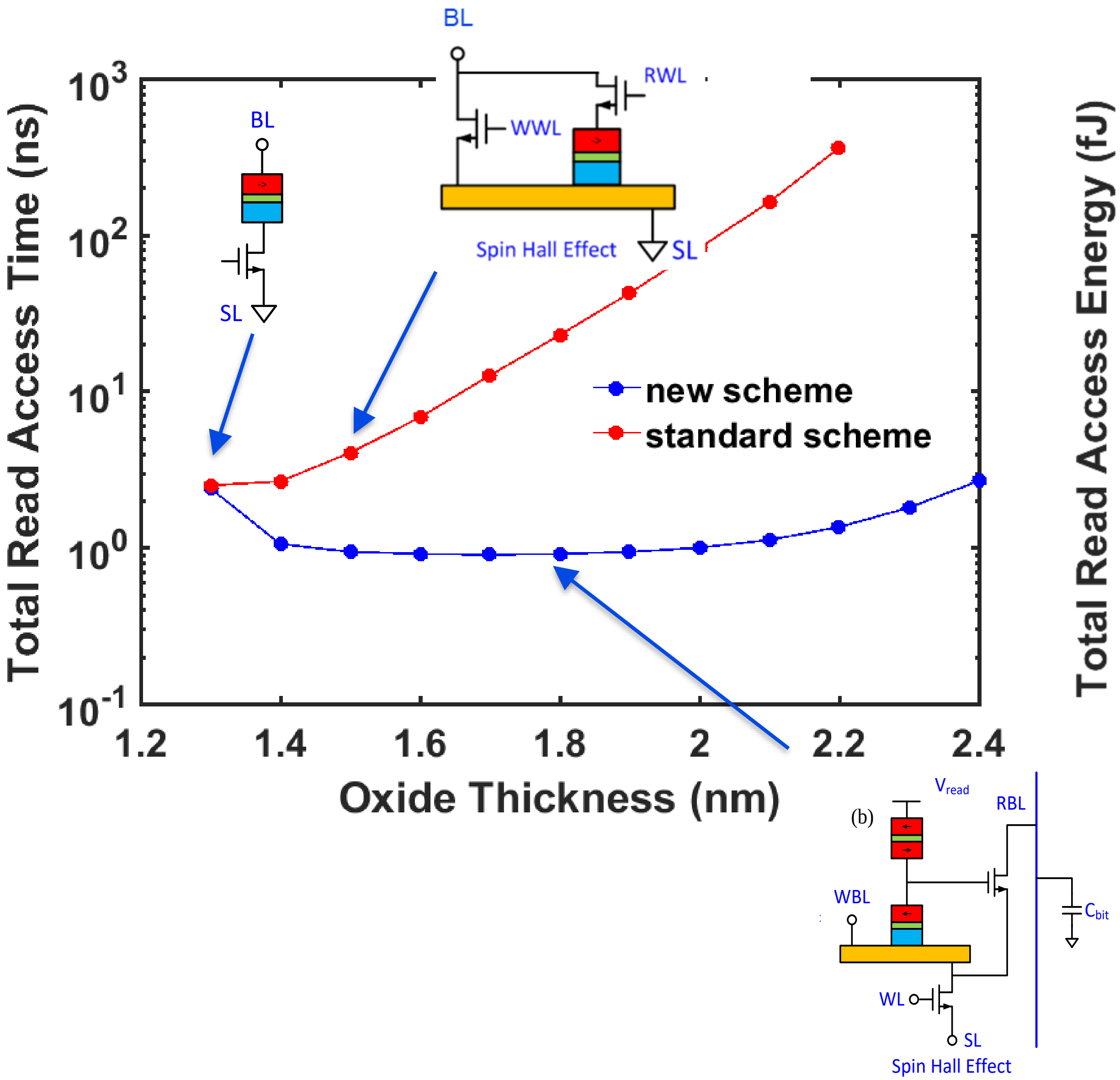


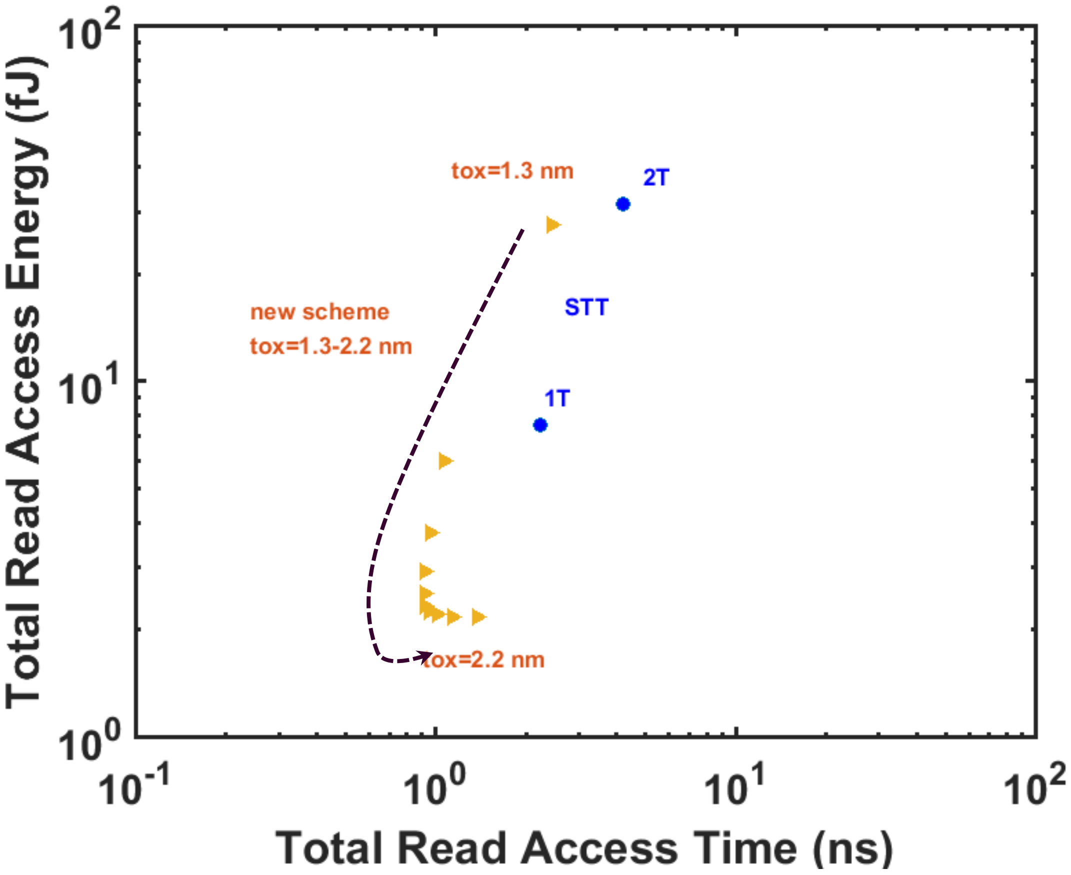






Rearranging the Two Transistors





Conclusions

STT-RAM suffers from large write currents and conflicting requirements for read and write.

Emerging SOT materials with large spin angles and moderate conductivity are quite promising.

SOT-RAM with in-plane magnets suffer from low energy barriers and variability imposed by lithography.

ME-RAM can eliminate large write currents and enable scalability energy and high density.

By rearranging the 2 transistors in ME-RAM and SOT-RAM, sub-nanosecond read operations.