Low Power Crossbar MRAM with Scalability

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Mechanical Engineering

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MSE
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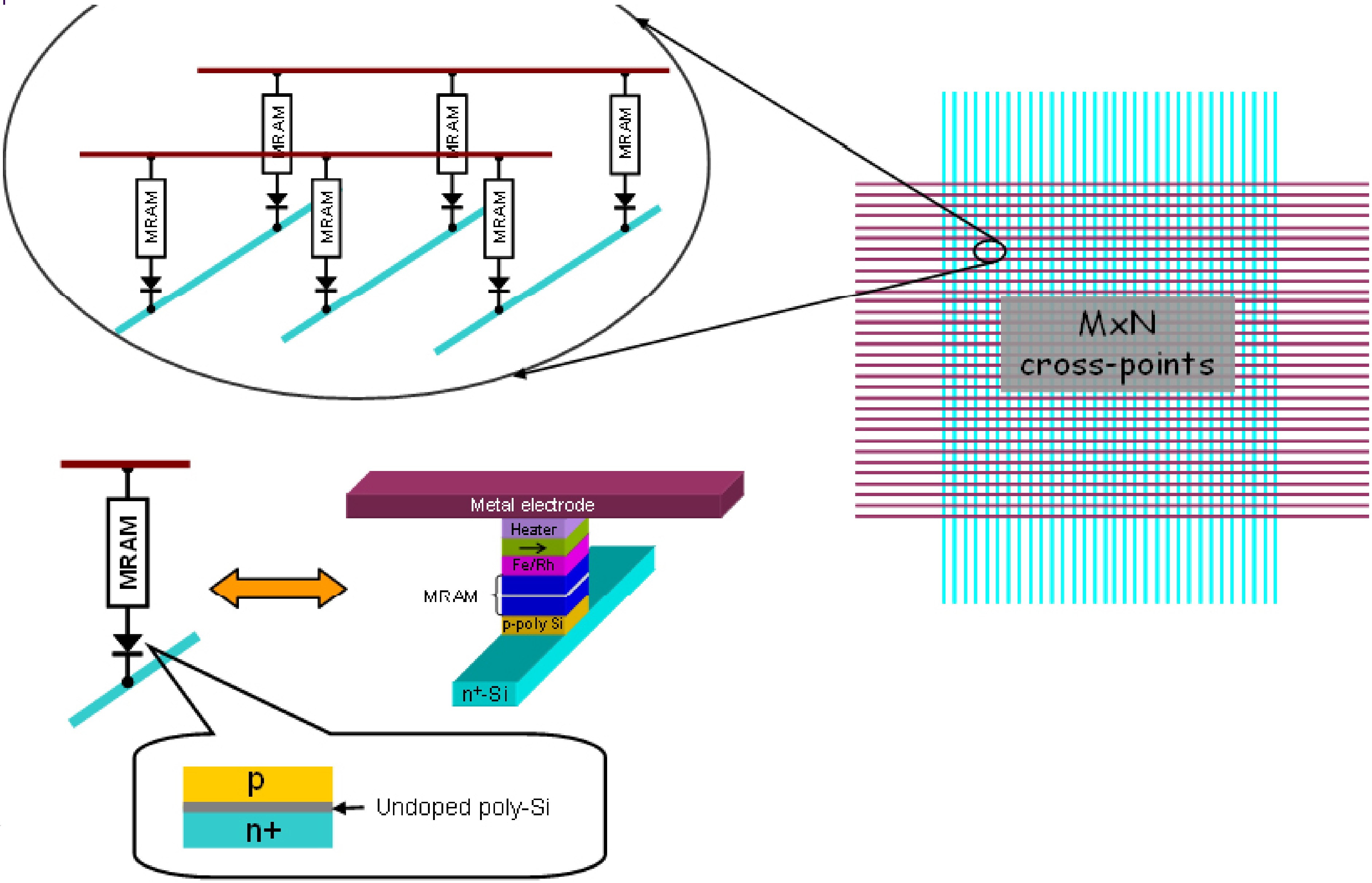
Department of Physics

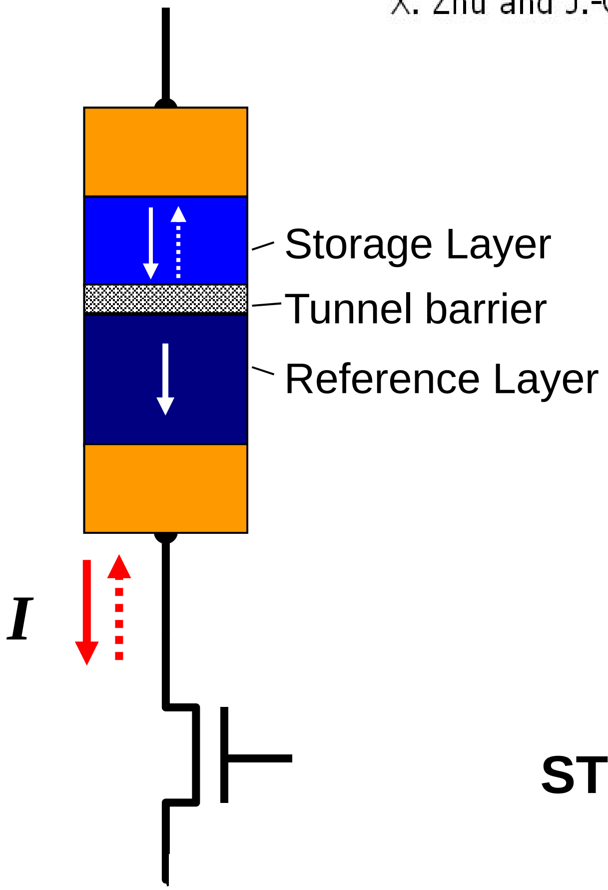
Department of Chemistry

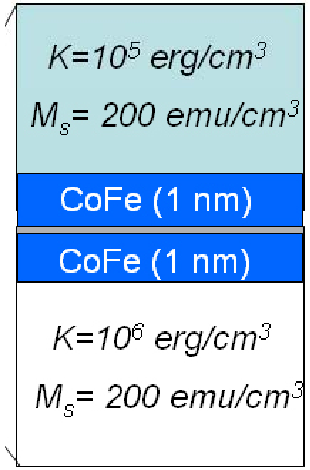
The Crossbar Design



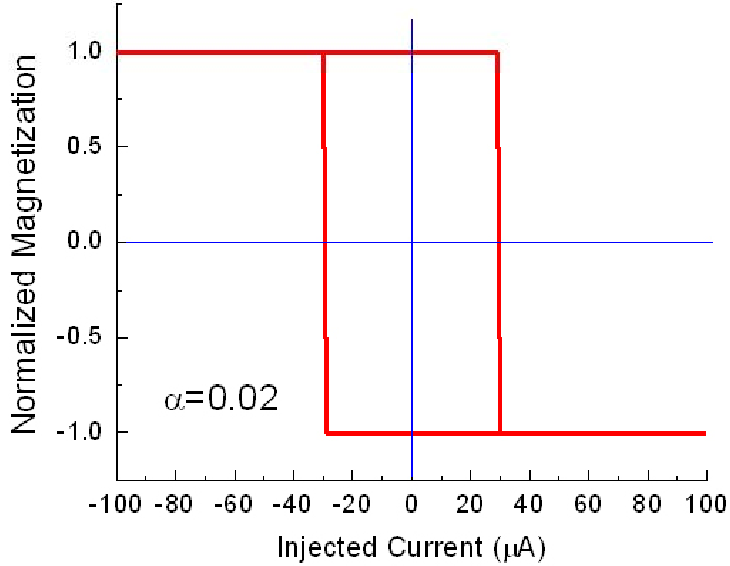
Present STT Driven MRAM

X. Zhu and J.-G. Zhu, IEEE Trans. Magn., 42, 2739 (2006)





Element Size: *40 x 40 nm²*

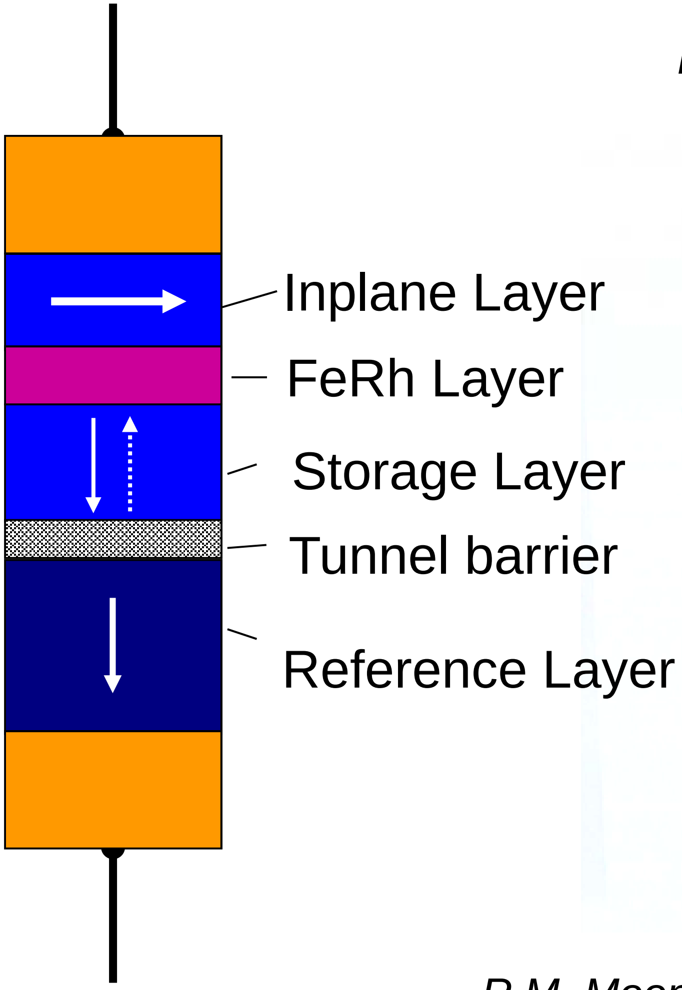


STT Switching:

$$I_{\text{switching}} = \left(\frac{2e}{\hbar}\right)\left(\frac{2\alpha}{\eta}\right)\Delta E_{\text{stored}}$$

Presently achieved: **Switching energy** ***0.1 pJ ~ 1 pJ***

FeRh: AF to F Transition



Inplane Layer

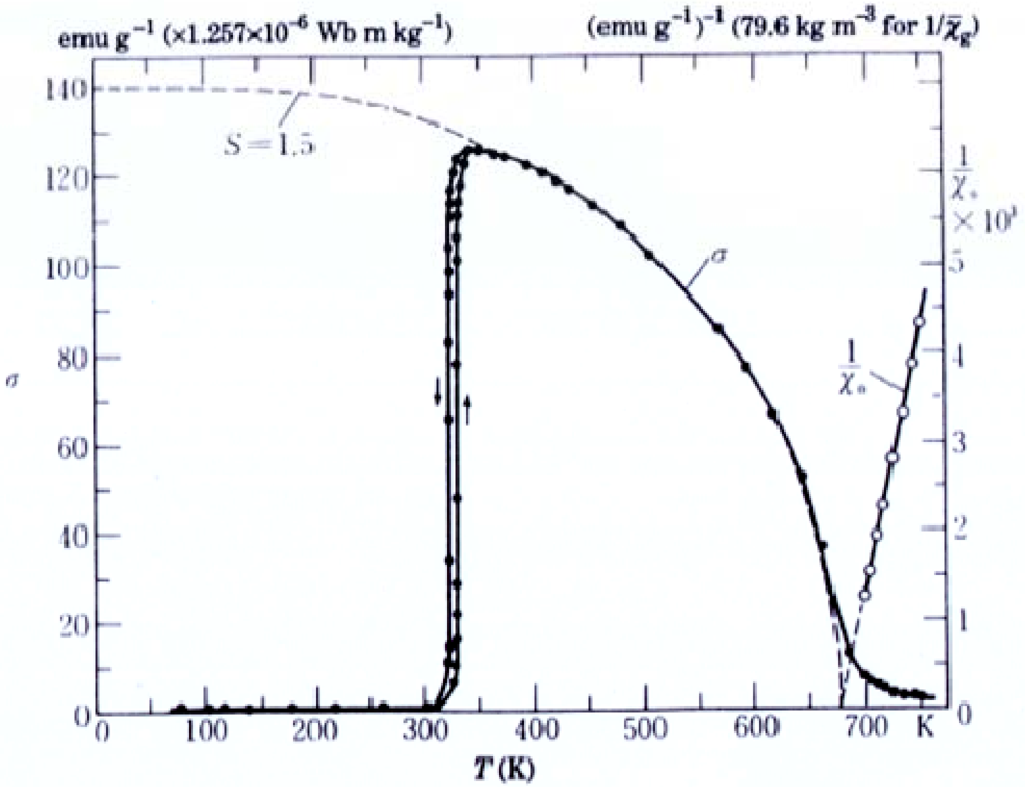
FeRh Layer

Storage Layer

Tunnel barrier

Reference Layer

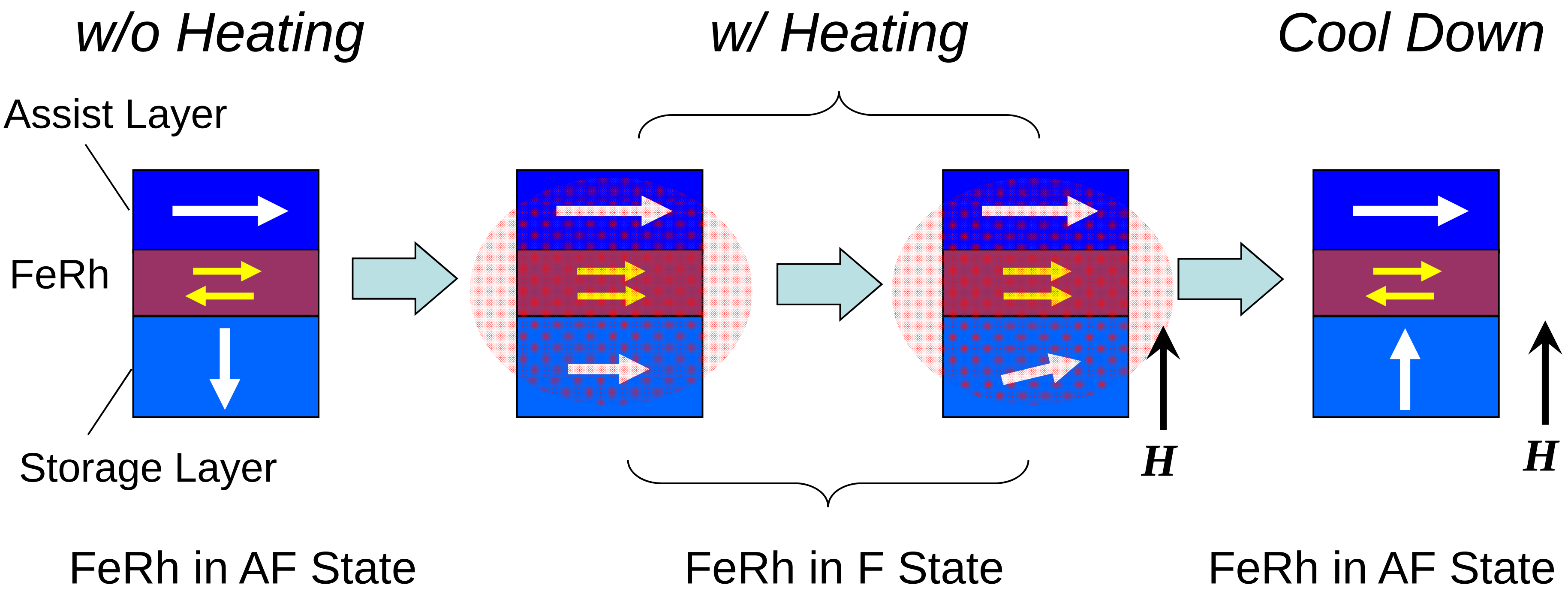
FeRh Magnetization vs. Temperature



R M. Moon, W.C. Koehler, and J. Farrel, J. Appl. Phys. 36 (1965), 978.

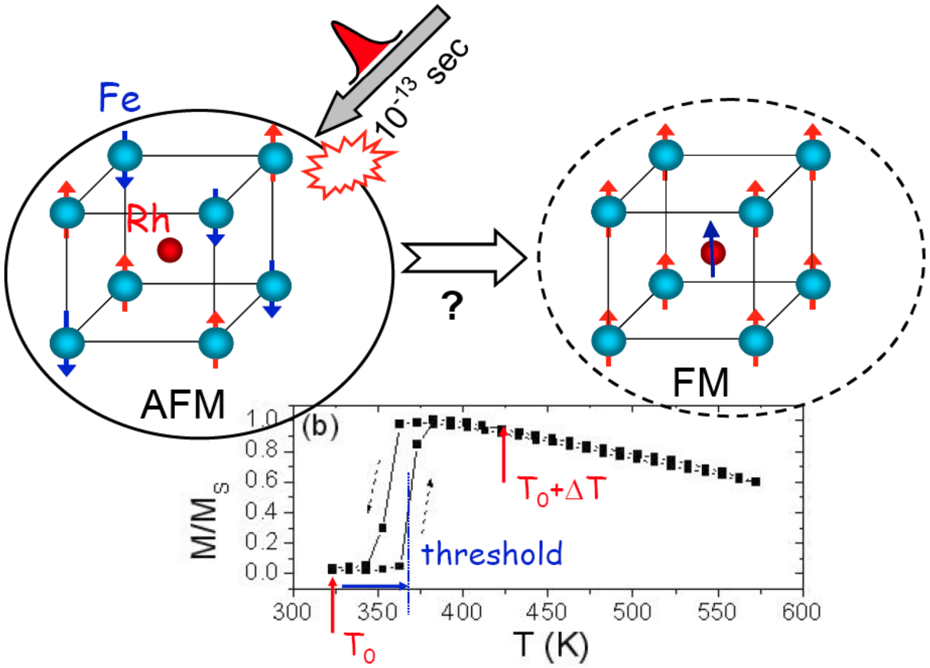
S. Chikazumi, Physics of Ferroagetism, Oxford Science Publications, 2nd Ed., 190.

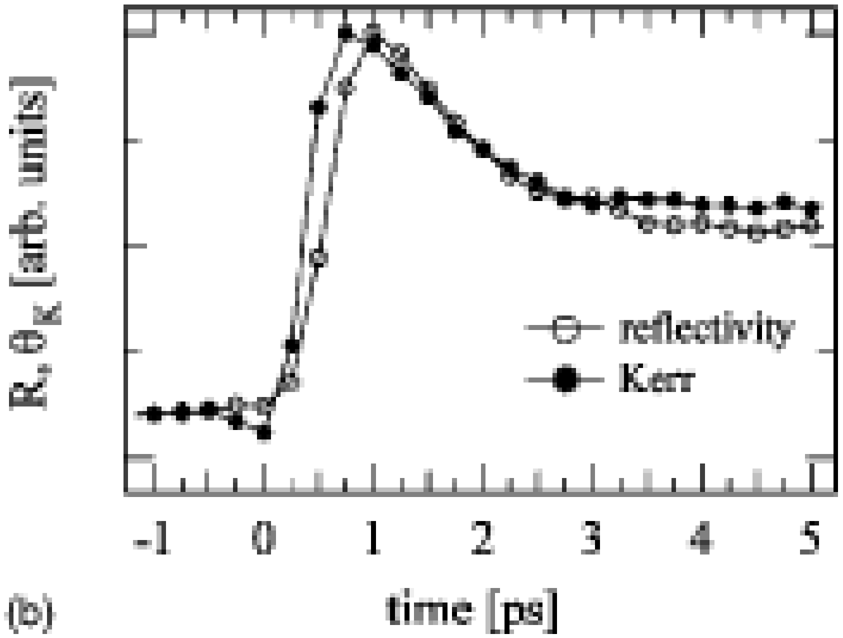
Operating Mechanism



- ***A temperature controlled switch for magnetic coupling!***

How Fast ?

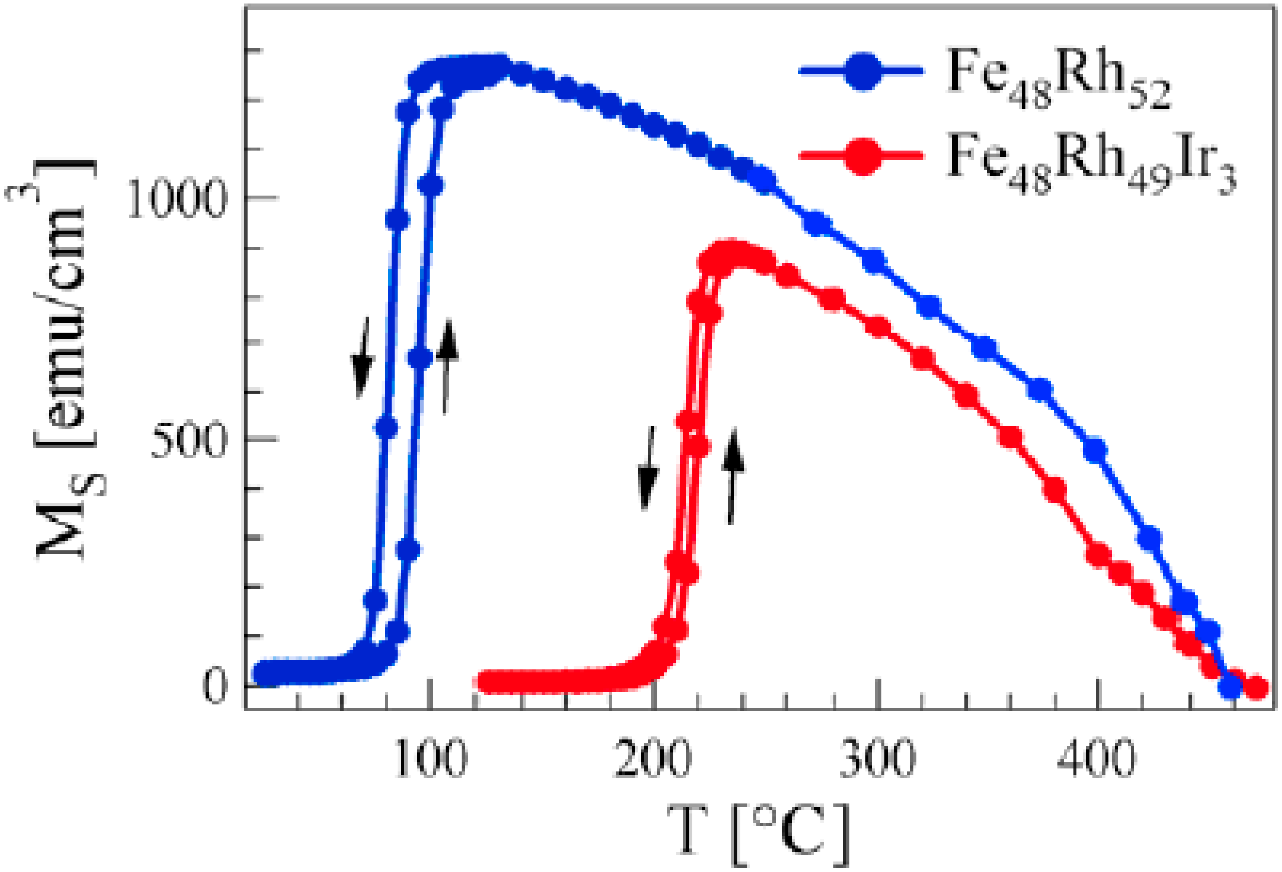




Thiele, Buess, and Back Appl. Phys. Lett., Vol. 85, No. 14, 4 October 2004

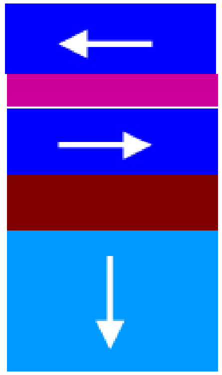
Tuning T_{AF-F}

-



J.-U. Thiele, S. Maat, and E. E. Fullerton, *APL*, vol. 82, p. 2859 (2003)

Can Also Use CoIr



Inplane mag-layer

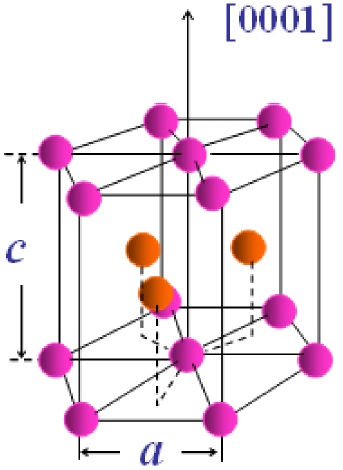
Ru

Inplane mag-layer

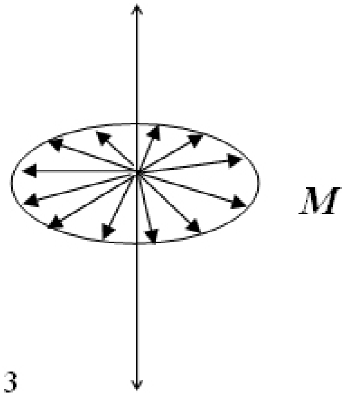
FeRh

e.g. CoIr

$\mathrm{Co_{80}Ir_{20}}$



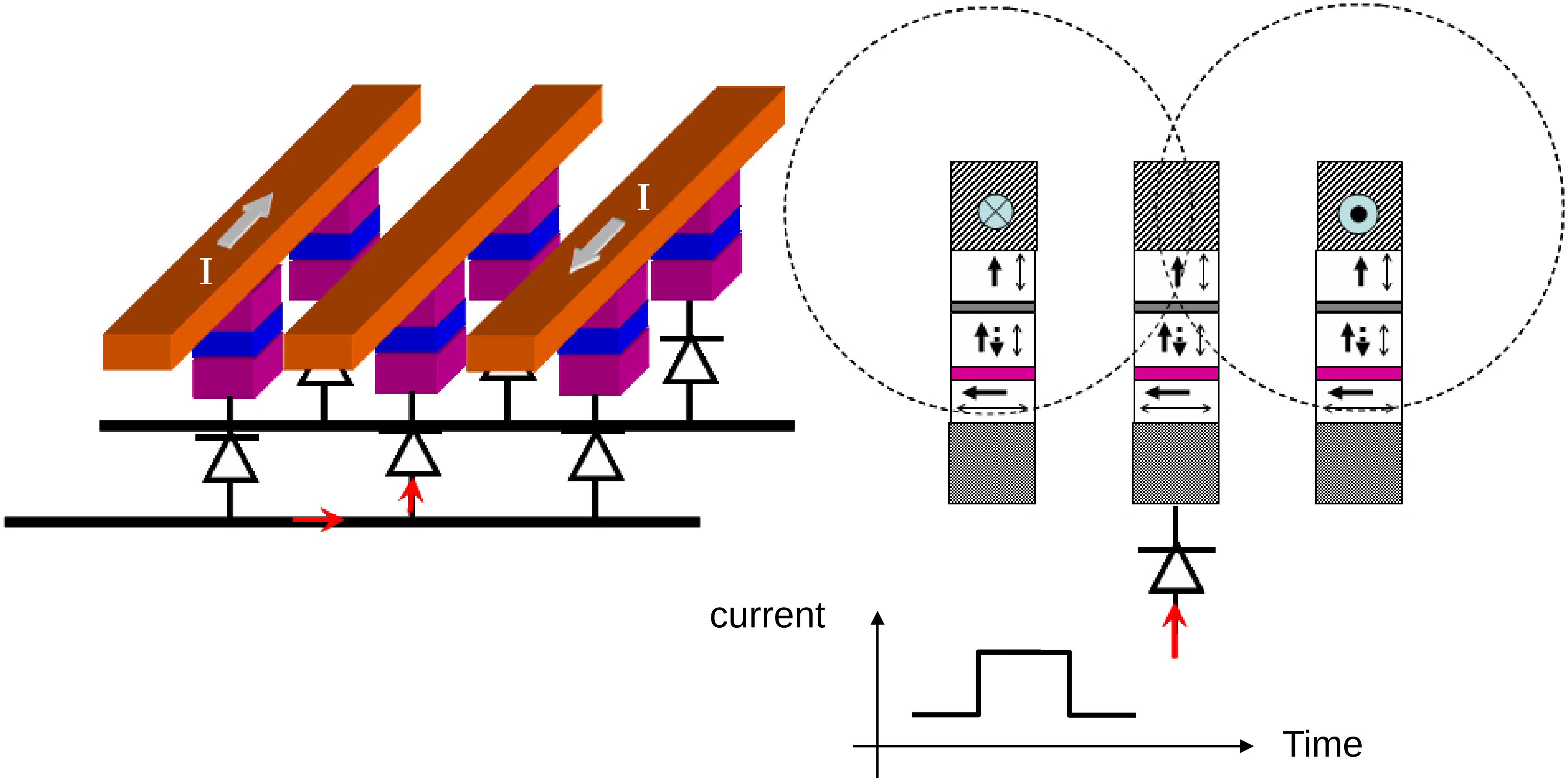
$$E_{\text{anisotropy}} = K \sin^2 \theta$$



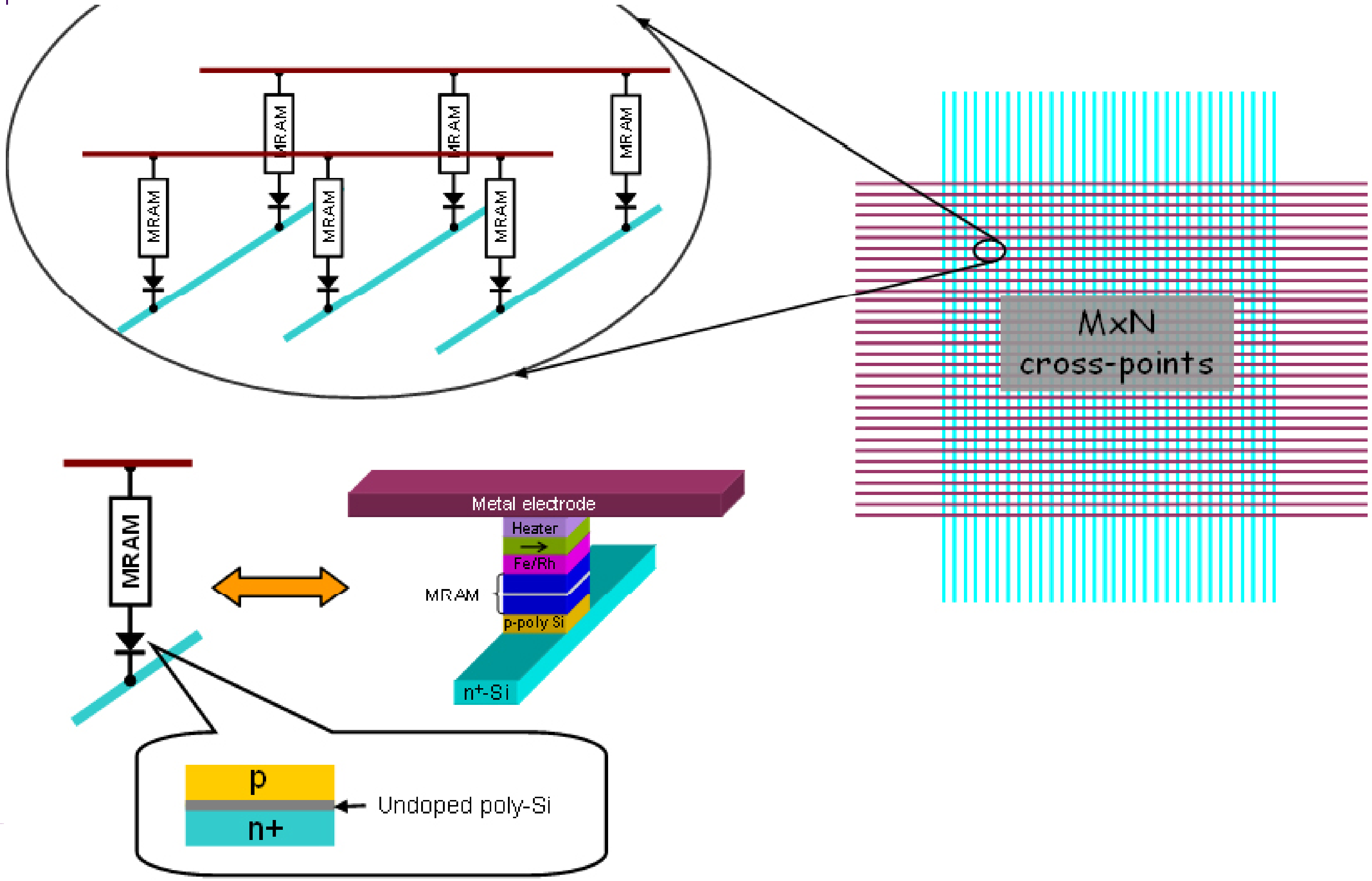
$$K \approx -7 \times 10^6 \quad \mathrm{erg/cm^3}$$

Writing Scheme

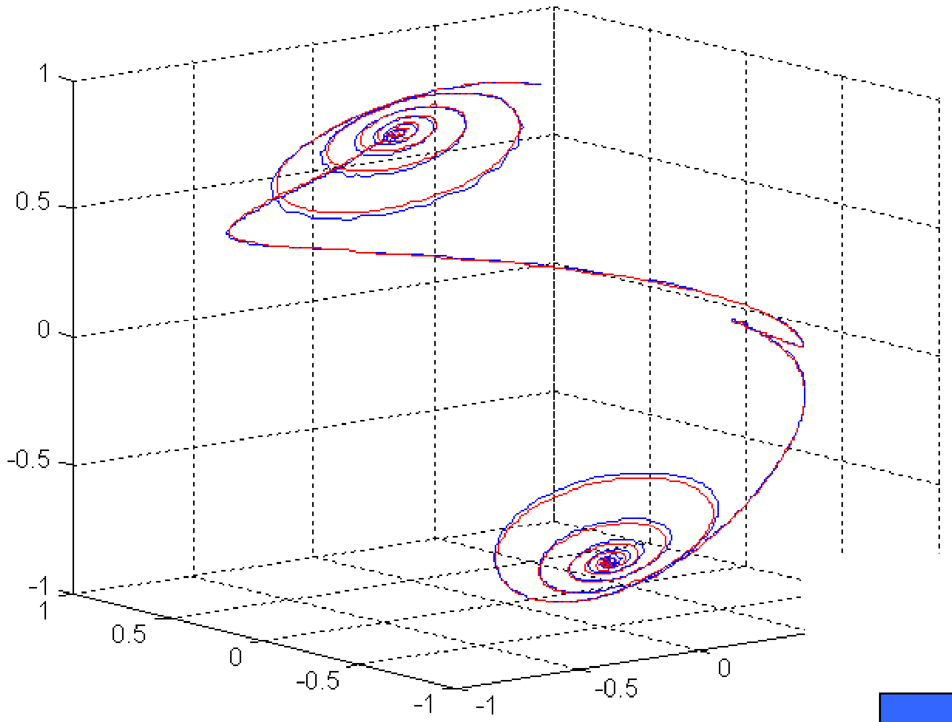
Write energy/bit: 0.01pJ



The Crossbar Design



Simulated Switching

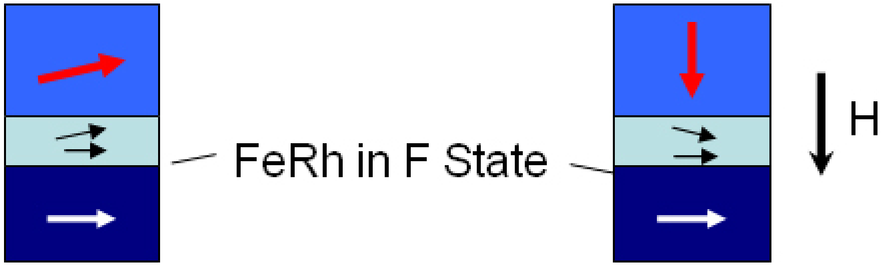


$H_{k,\ perp}=10^3$ Oe

$H_{k,\ inplane}=5x10^3$ Oe

$H_{applied}=10$ Oe

With heating


FeRh in F State

Density Estimation

- True $4F^2$ memory cell
- Zero transistor per cell
- Memory element should be stable even below 10nm

At 10 nm element size:

Area Density > 1.5 Tbits/in^2

⇨ ***Enabling Tbits Chip Memory Device !!!***

Acknowledgements

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UNITED STATES OF AMERICA

NSF

magic
TECHNOLOGIES

HITACHI
Inspire the Next

SAMSUNG
SISA

WD Western Digital

SHOWA
DENKO

SAE

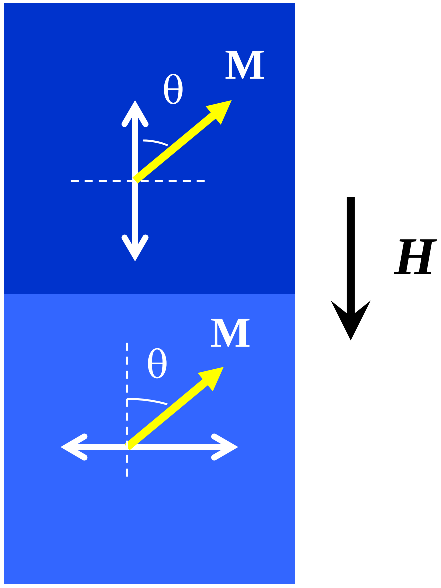
Seagate

TDK

Headway
Technologies

Concept

Two exchange coupled grains with orthogonally oriented easy axes:



Energy Consideration:

$$E = K\sin^2\theta + K\sin^2\left(90^o - \theta\right) + 2MH\cos\theta$$
$$= K\sin^2\theta + K\cos^2\theta + 2MH\cos\theta$$
$$= K + 2MH\cos\theta$$

Switching Field Threshold :

$$H_S = 0$$

Energy Barrier for State Retention:

$$\varepsilon_b = 0$$

Operation Mechanism