

Anitferromagnetic memory with ultrafast writing speed

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Manuel Baumgartner

Outline: From DC to THz Spintronics

(DC) Principles of operation of AFM memory device

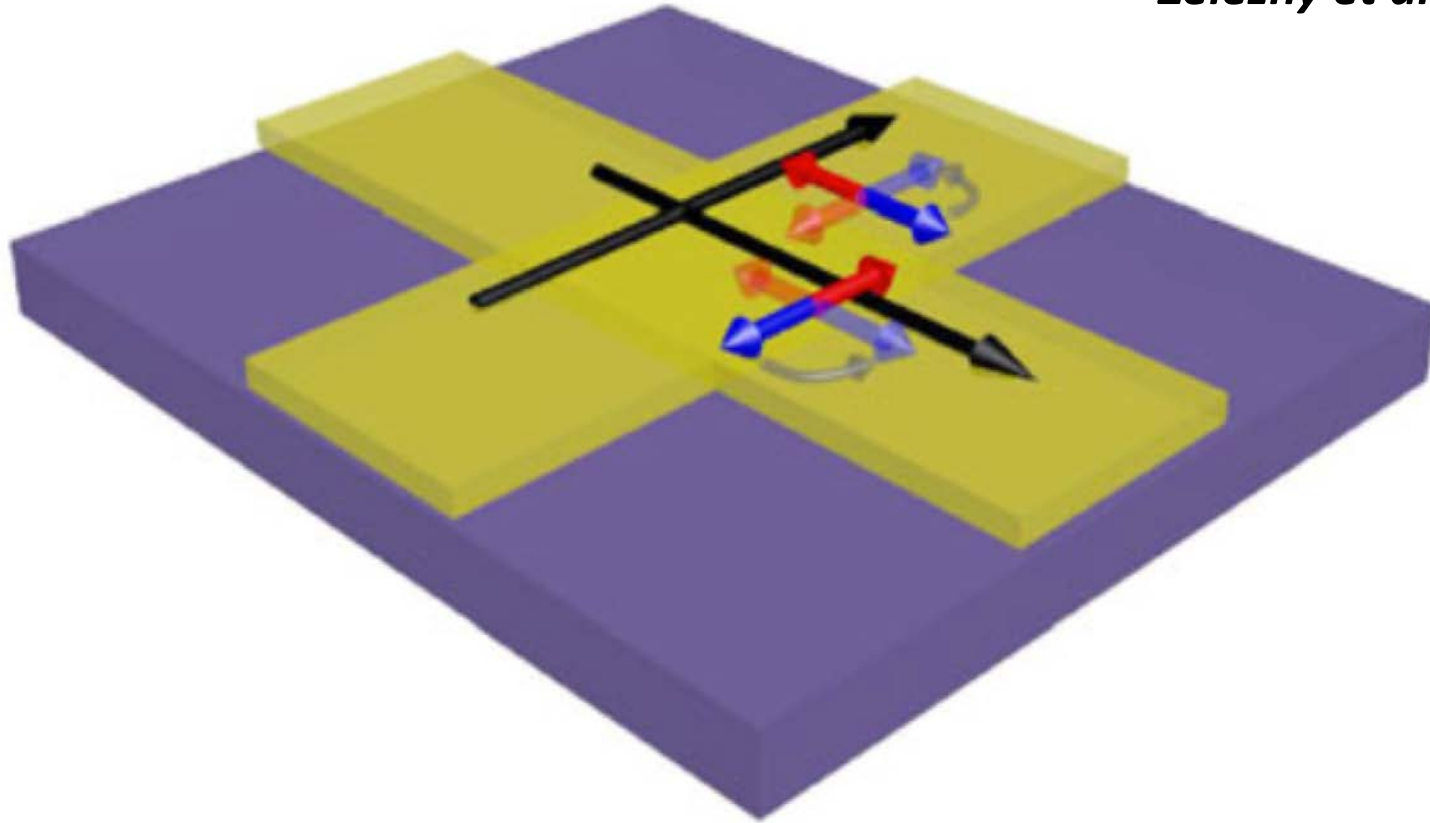
- 90 degree rotation with current induced SO fields
- reading with AMR
- multi-domain character

(THz) Speed of writing

- magnetic dynamics of FM and AFM
- ultrafast (THz) switching

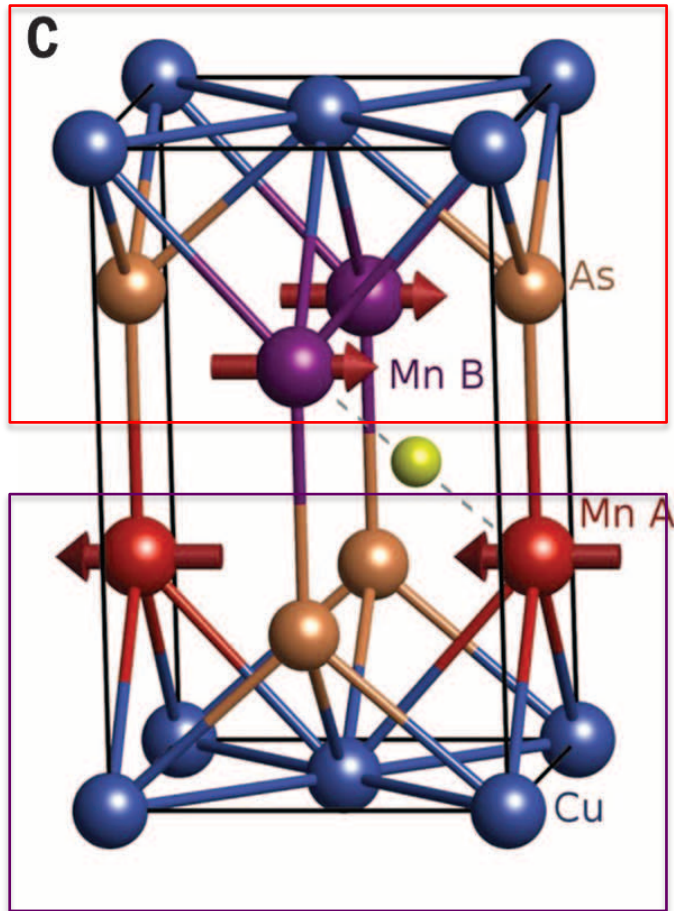
AFM memory device proposal

Železný et al. PRL 2014



Néel SO fields writing
AMR reading

SO fields in tetragonal CuMnAs

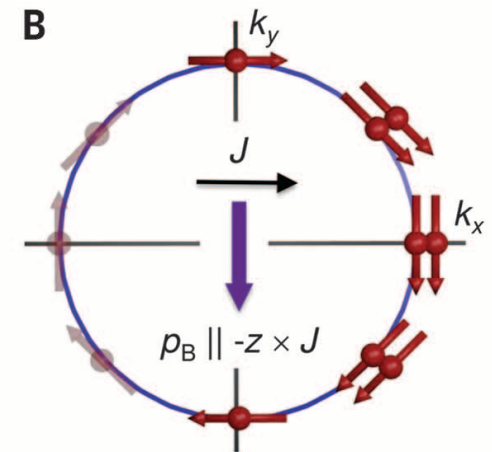
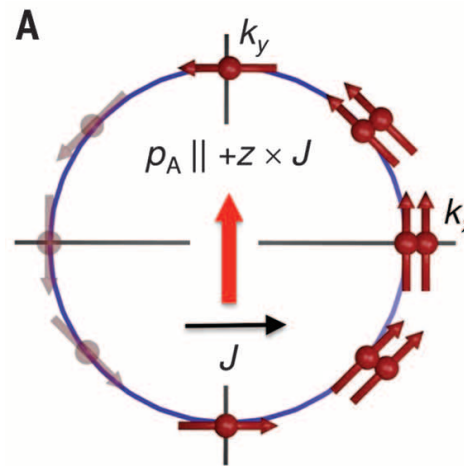


Condition for Neel SO field:

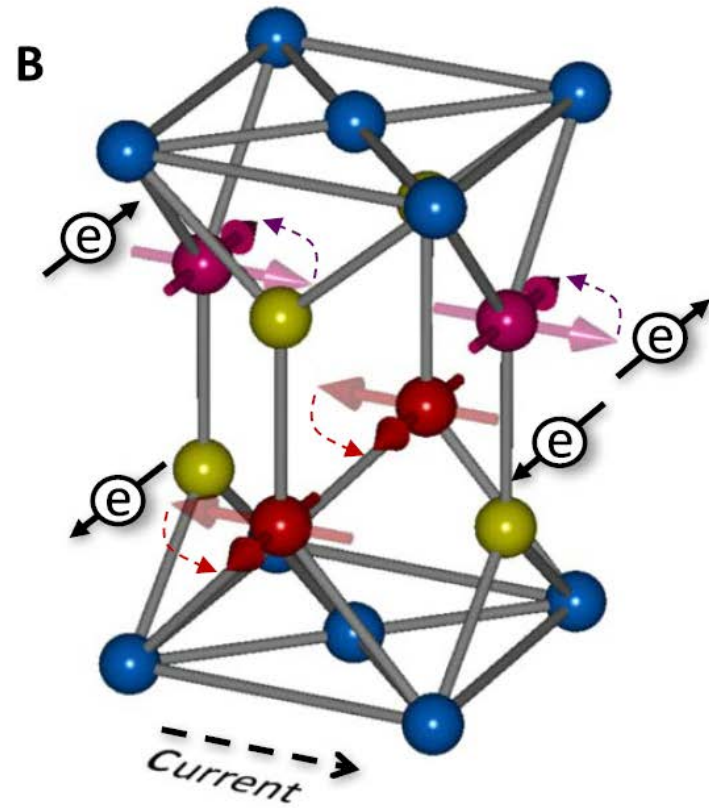
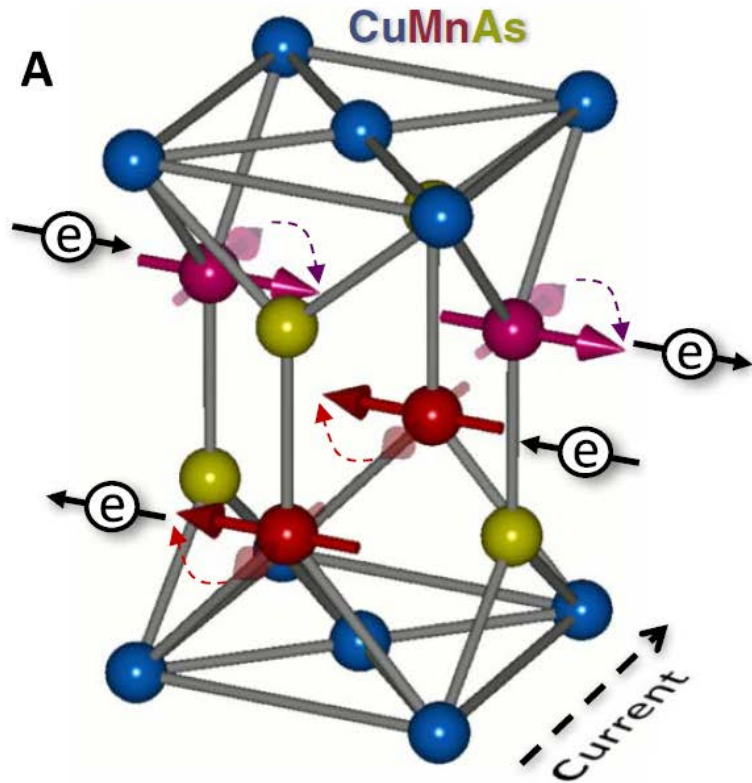
- local inversion asymmetry

Condition for effective switching:

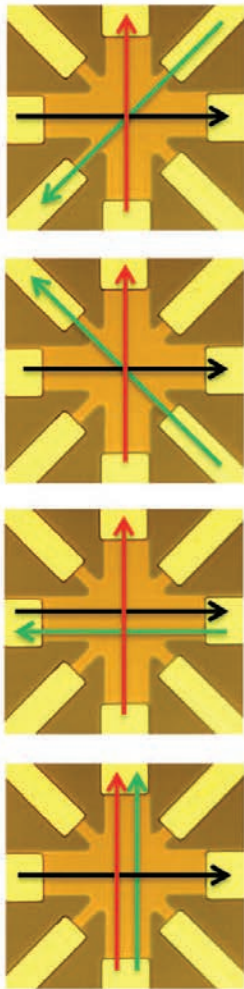
- AFM sub-lattices occupy inversion partner lattice sites



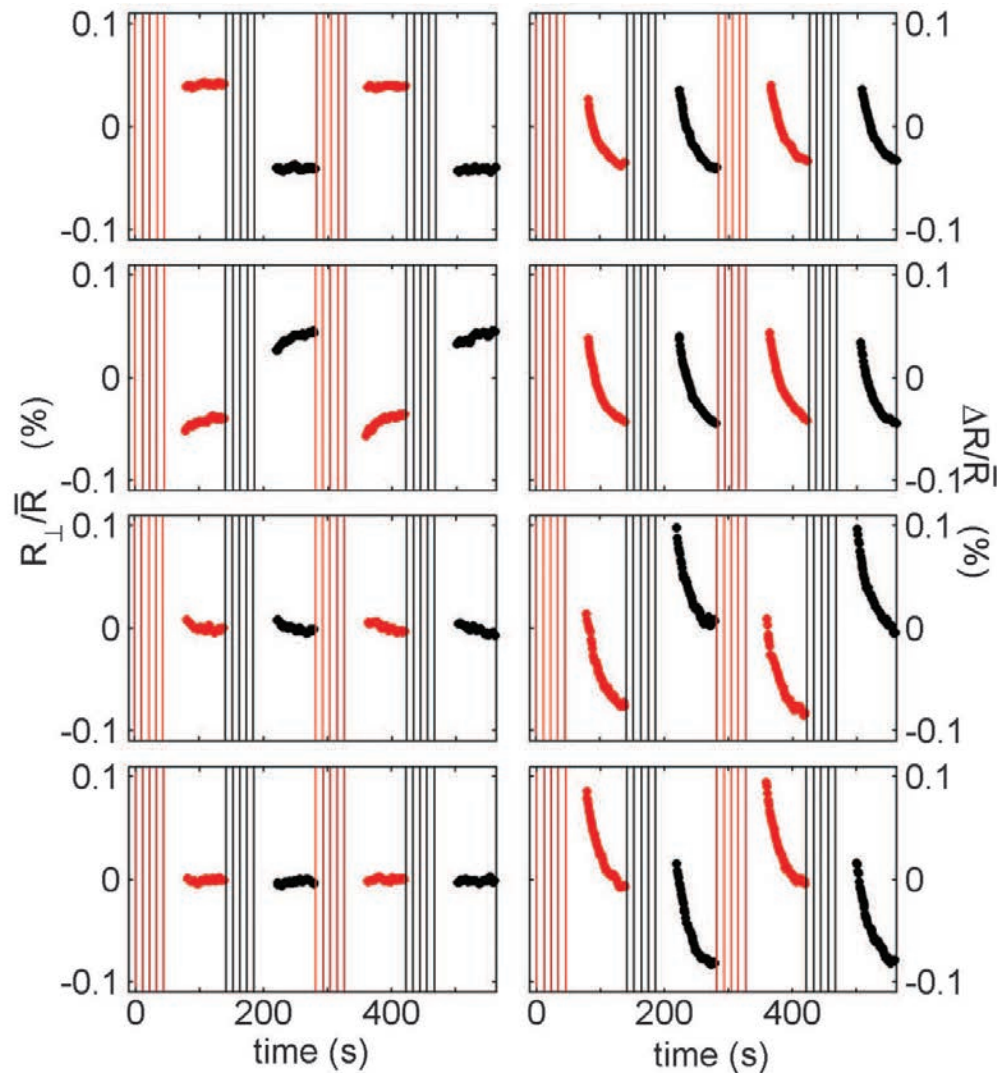
90 degree switching



AMR signal due to perpendicular pulses

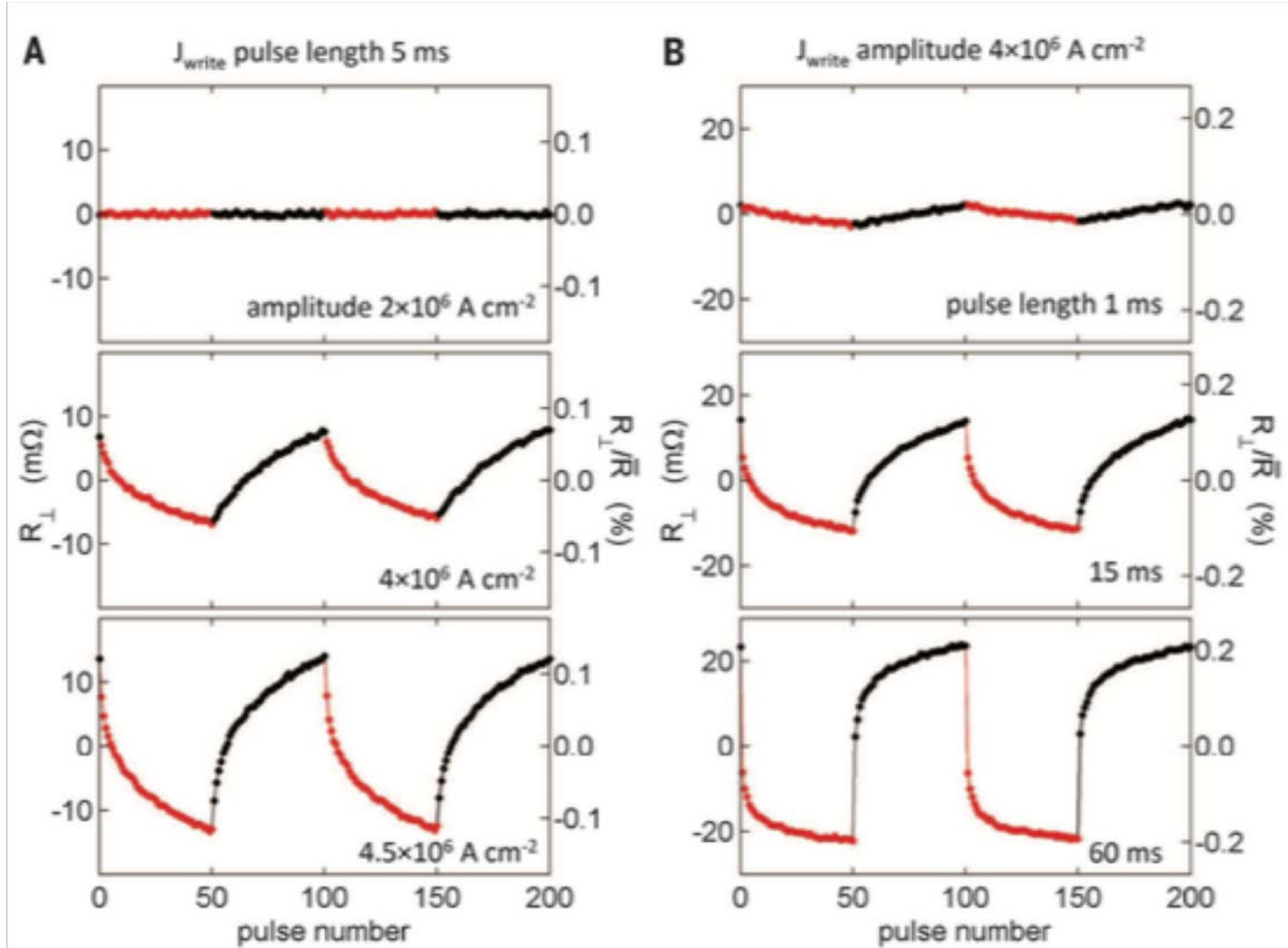


$$\Delta R_{XY} \sim \sin(2\phi) \quad \Delta R_{XX} \sim \cos(2\phi)$$



Multi-level memory

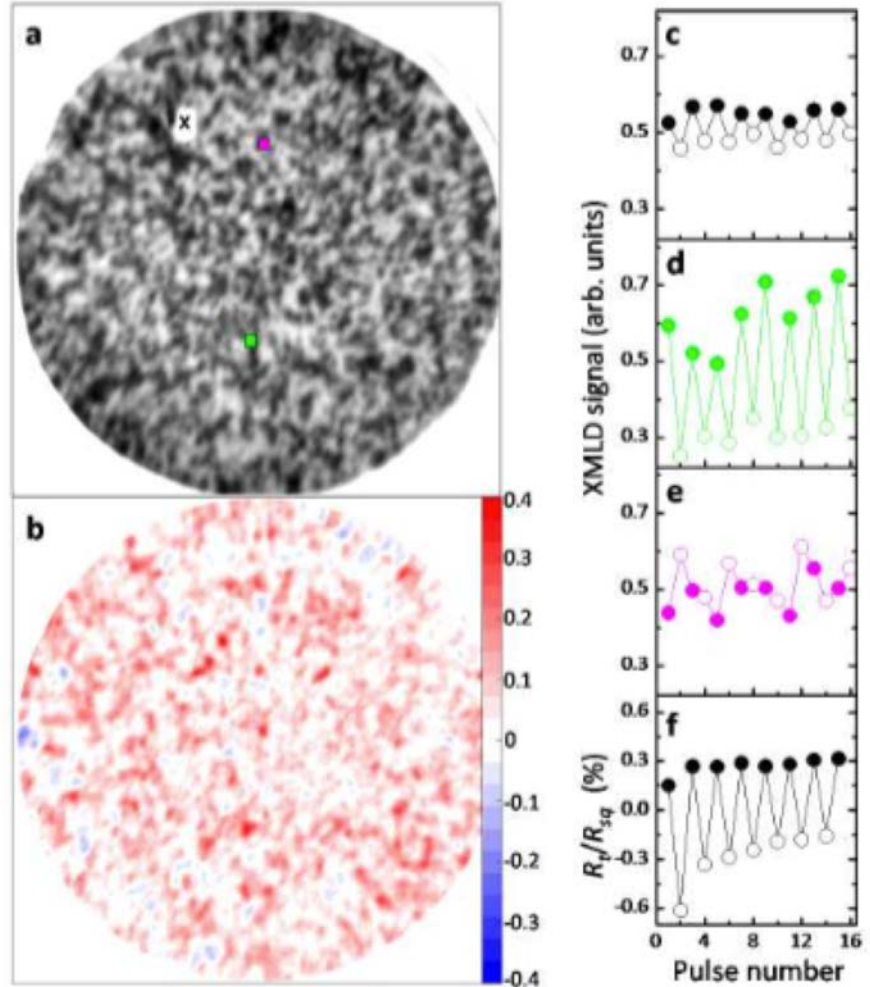
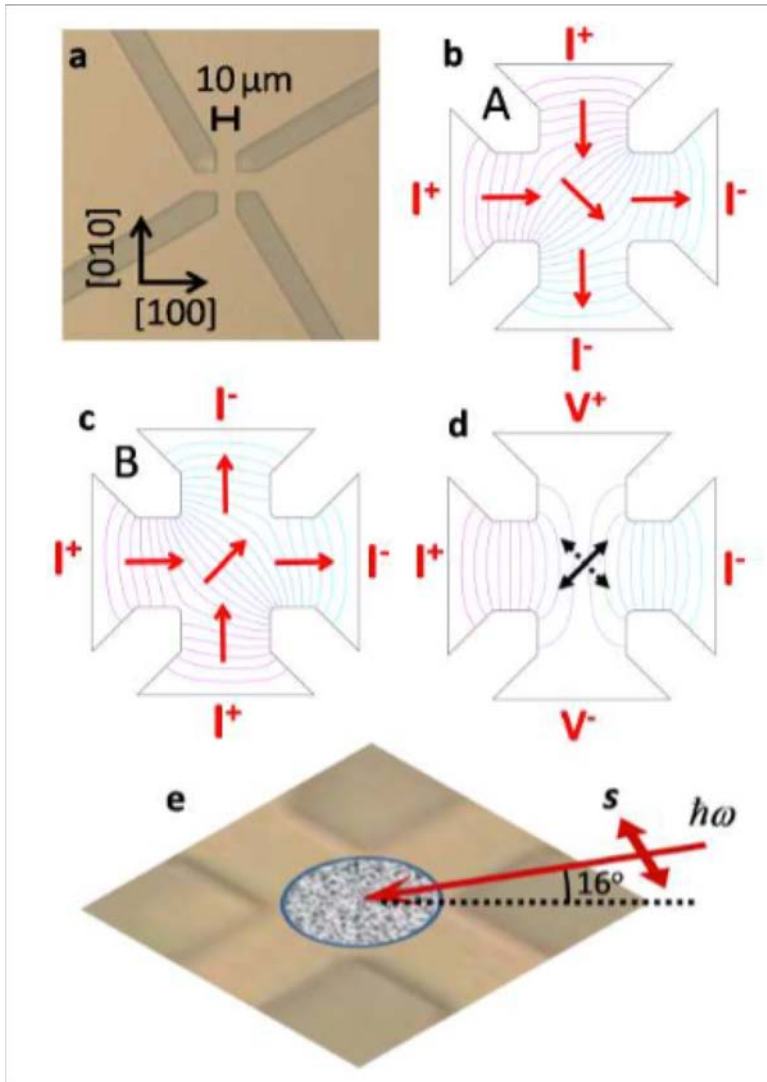
Amplitude of pulse current



Length of pulses

Magnetic domains in CuMnAs

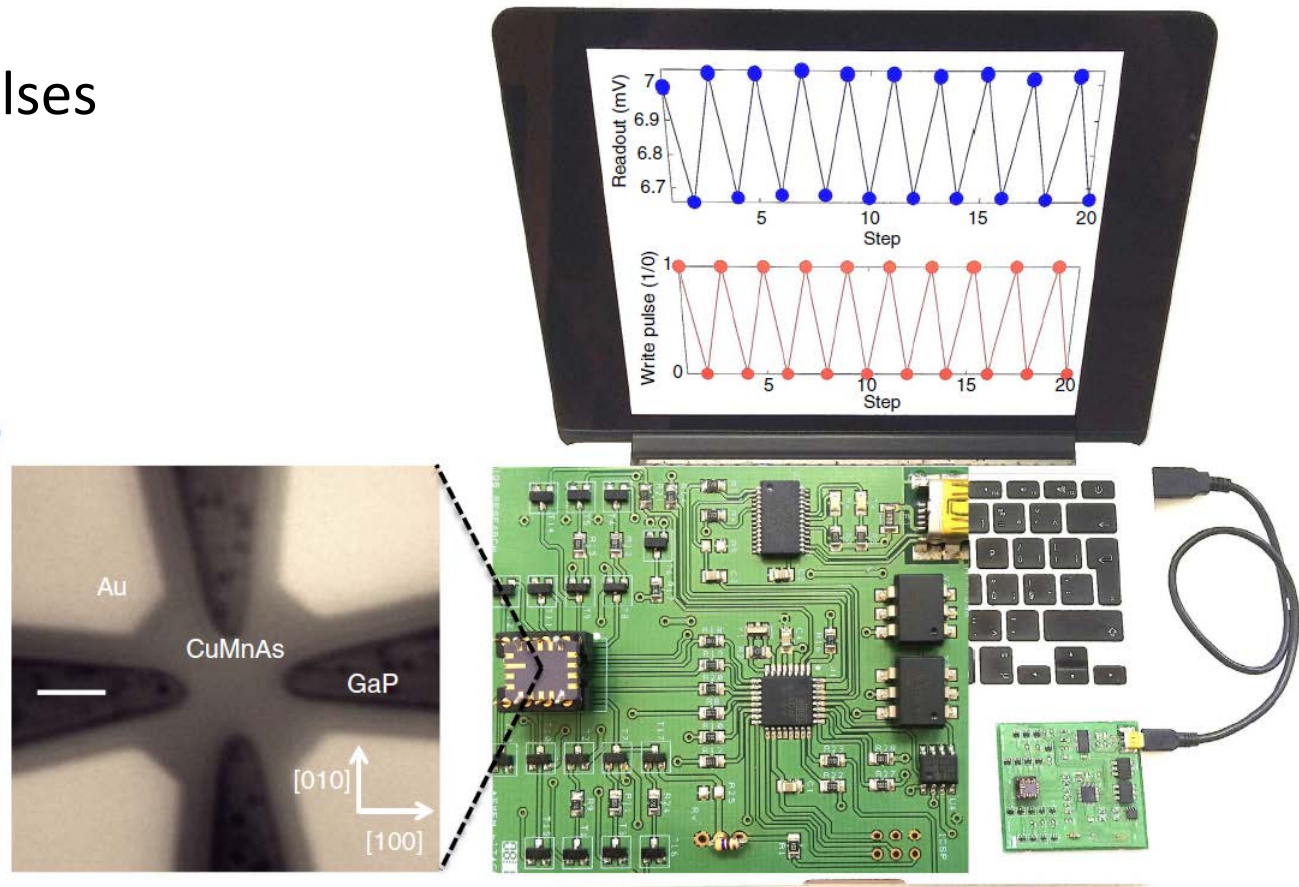
XMLD - PEEM



Summary (before going fast)

“Practical” memory based on AFM CuMnAs

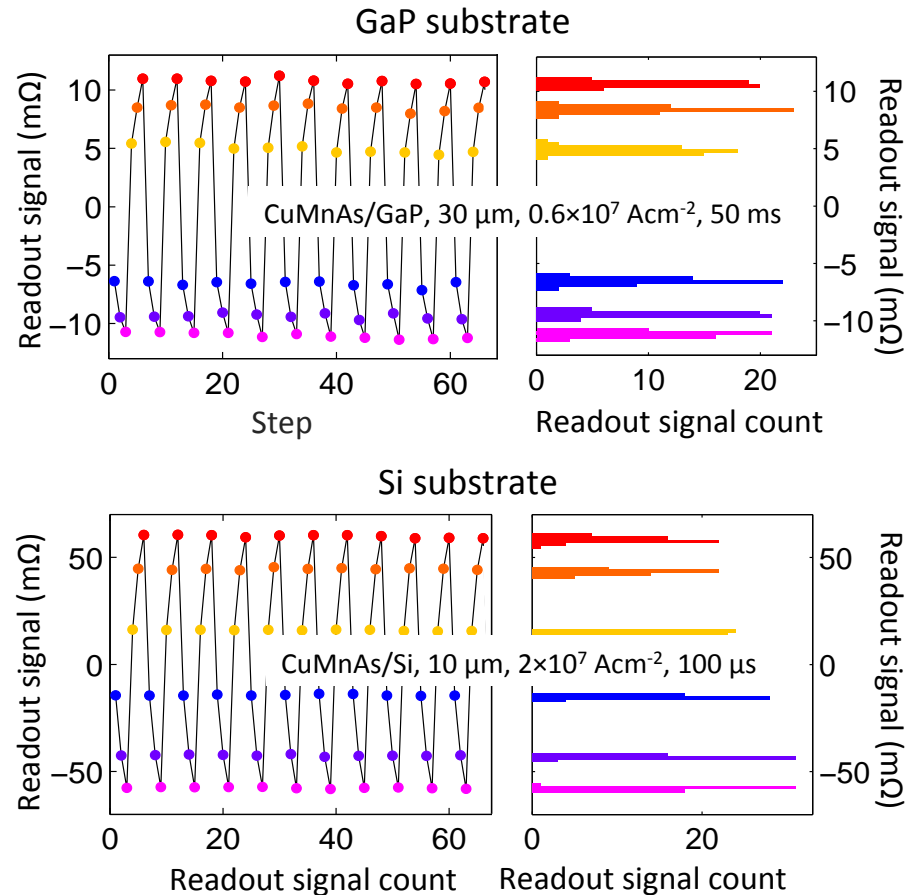
- deterministic switching
- room temperature operation
- practical voltages
 - Writing pulses
 - signal



Summary (before going fast)

“Practical” memory based on AFM CuMnAs

- deterministic switching
- room temperature operation
- practical voltages
 - Writing pulses
 - signal
- **GaAs, GaP, Si substrates**



Summary (before going fast)

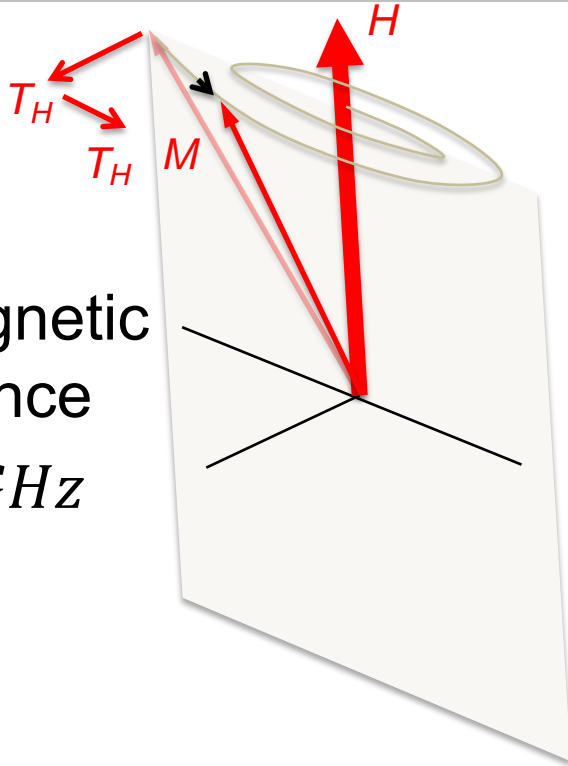
“Practical” memory based on AFM CuMnAs

- deterministic switching
- room temperature operation
- practical voltages
 - Writing pulses
 - signal
- GaAs, GaP, Si substrates

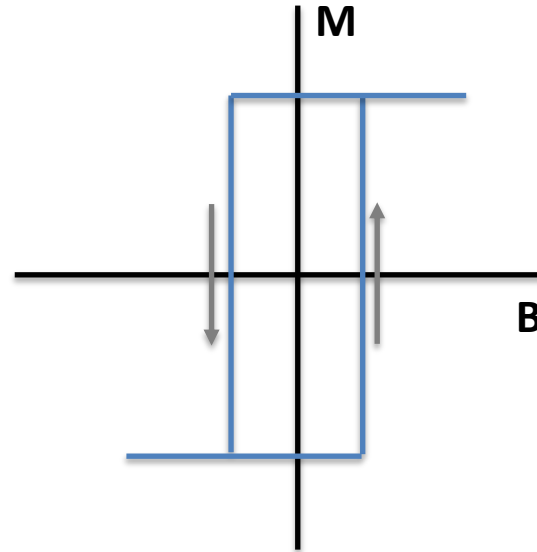
Advantages of AFM:

- **multistate (neuromorphic applications)**
- **no stray fields (high integration density, robust)**
- **SPEED !!!**

From GHz FM to THz AFM spintronics



Ferromagnetic
resonance
 $f_{FMR} \sim GHz$



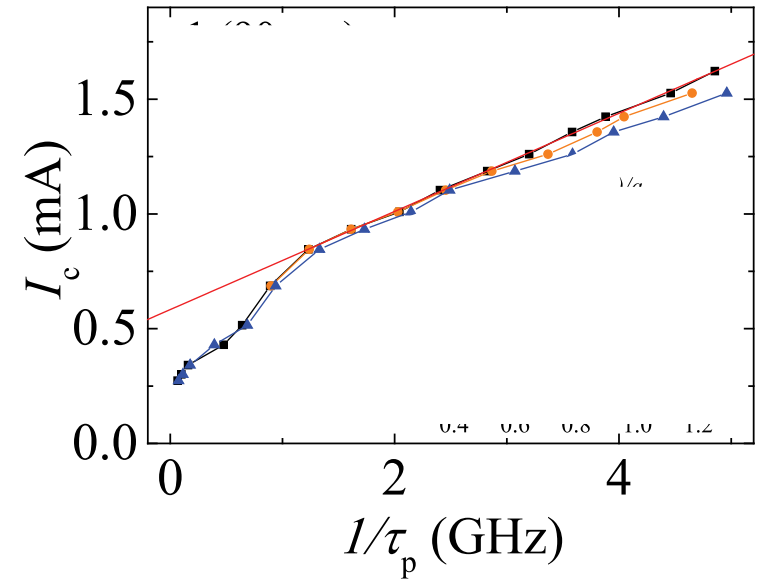
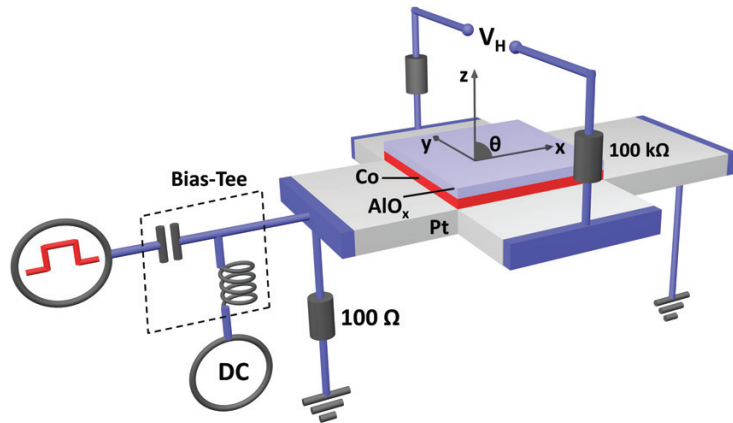
LLG equation

$$\frac{dM}{dt} = -\gamma \left(M \times B_{eff} - \eta \frac{dM}{dt} \times M \right)$$

Relaxation (switching) to energy minimum direction controlled by precession speed

Ferromagnets : GHz threshold in writing current

FM spin-orbit torque MRAM



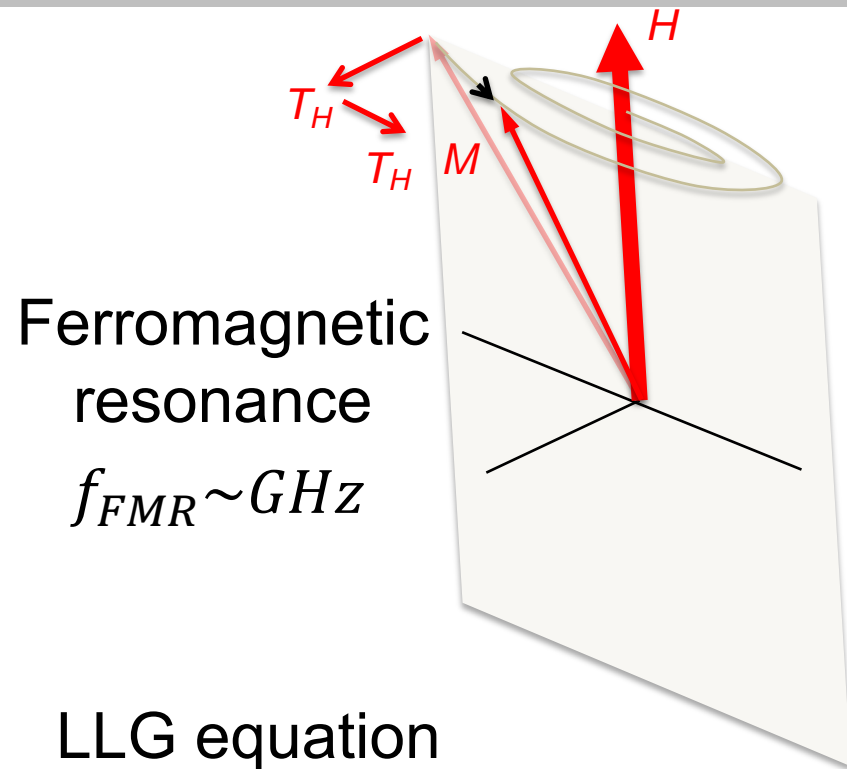
Garello et al., APL (2014)

Above $\sim \text{GHz}$

Writing current: $I \sim 1/\tau_p \sim \text{speed}$

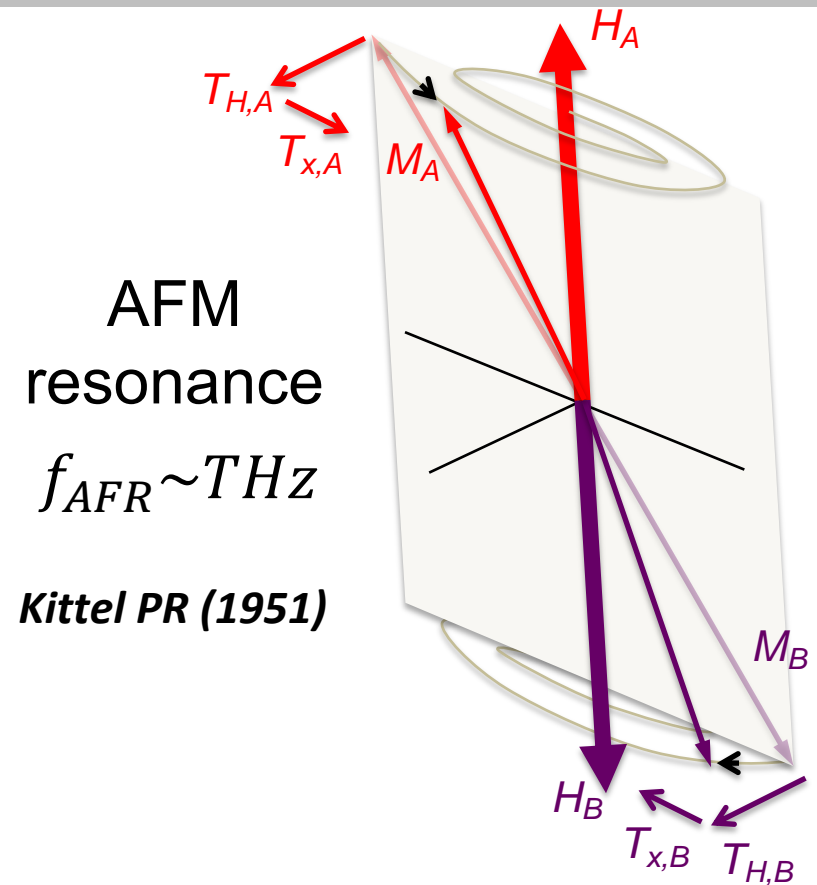
Writing energy: $E \sim I^2 \tau_p \sim 1/\tau_p \sim \text{speed}$

Prospect of THz writing speed in antiferromagnets



LLG equation

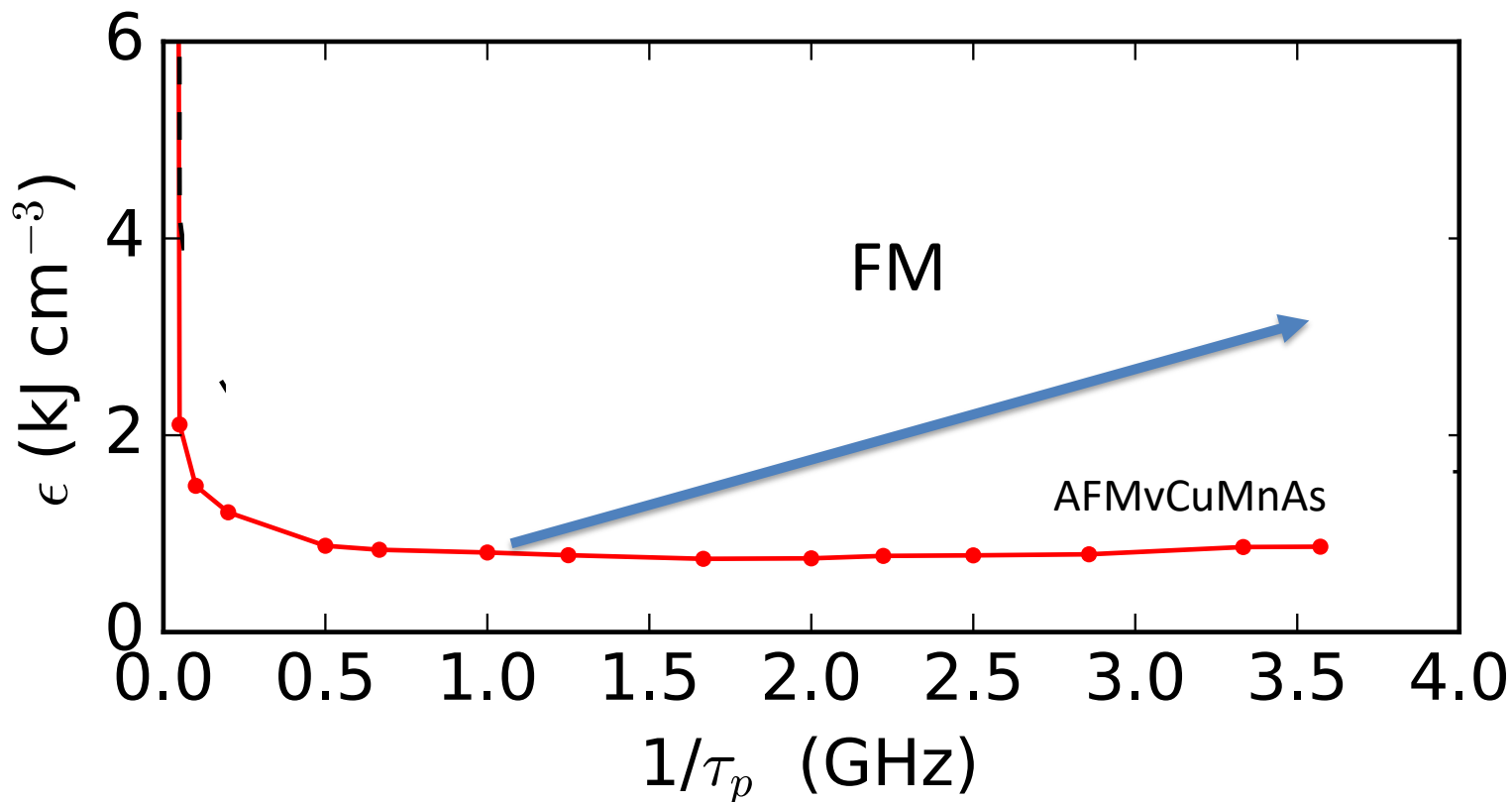
$$\frac{d\mathbf{M}}{dt} = -\gamma \left(\mathbf{M} \times (\mathbf{B}_{ext} + \mathbf{B}_{anis}) - \eta \frac{d\mathbf{M}}{dt} \times \mathbf{M} \right)$$



$$\frac{d\mathbf{M}_1}{dt} = -\gamma \left(\mathbf{M}_1 \times (\mathbf{B}_{ext} + \mathbf{B}_{anis} + J_{ex} \mathbf{M}_2) - \eta \frac{d\mathbf{M}_1}{dt} \times \mathbf{M}_1 \right)$$

Relaxation (switching) to energy minimum direction controlled by precession speed

GHz switching in CuMnAs



Energy constant in sub-nanosecond range

- thermally assisted switching
- shorter pulses could work !!!

1 ps pulses

Terahertz Physics Group (Berlin)

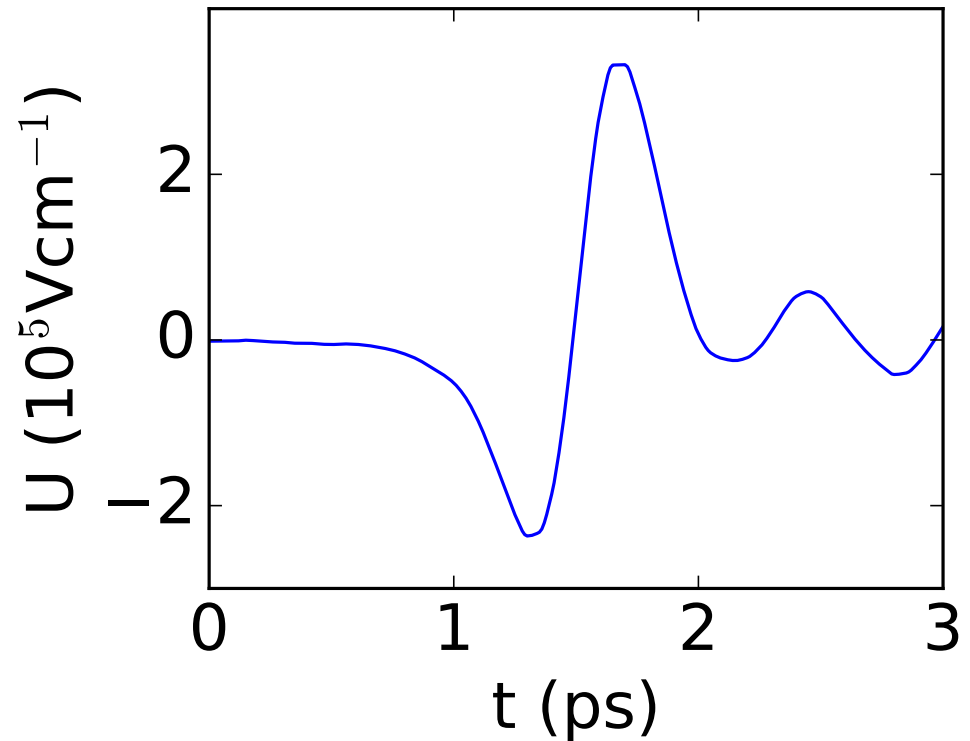


Tobias Kampfrath



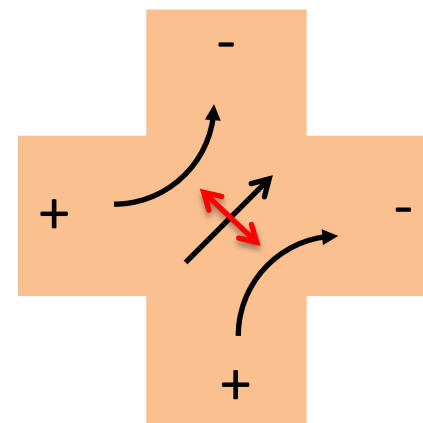
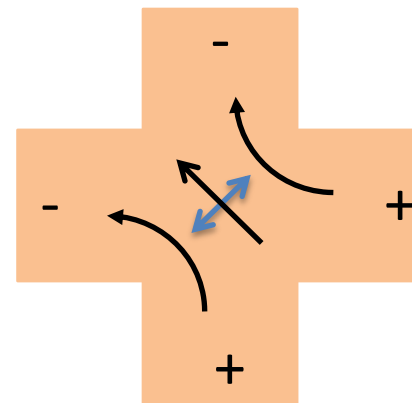
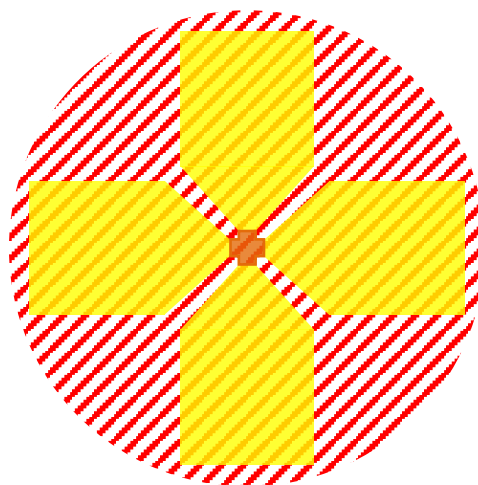
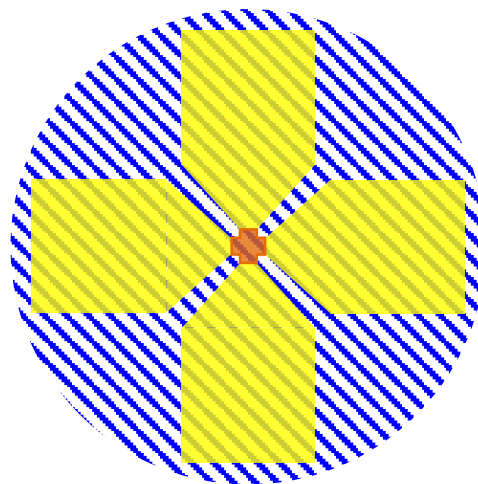
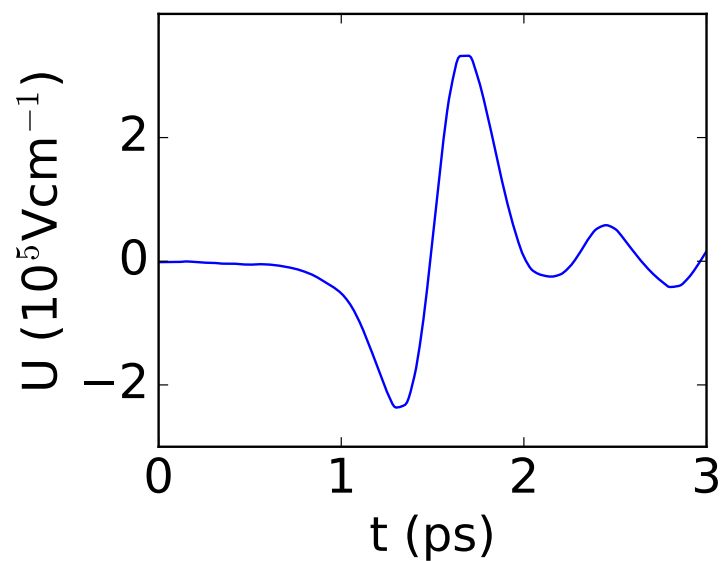
Tom Seifert

THz radiation :



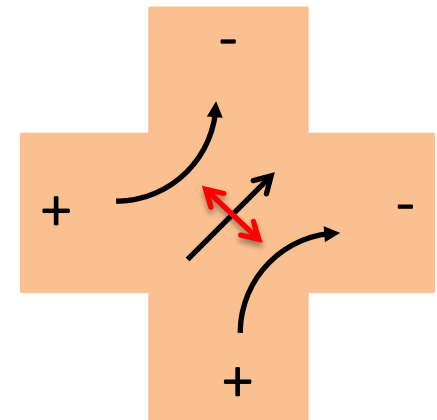
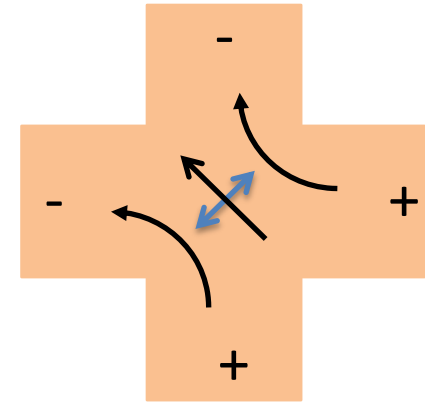
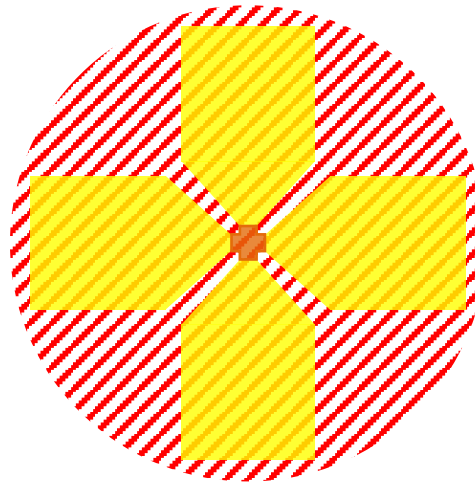
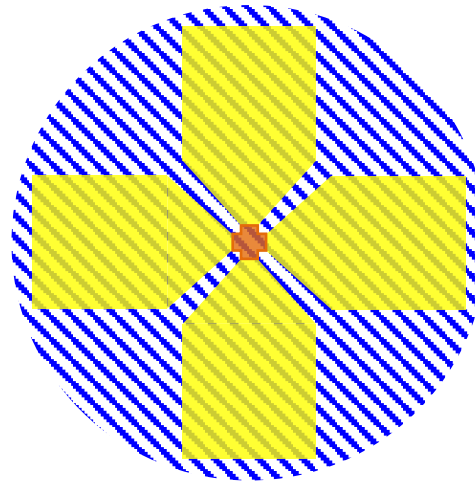
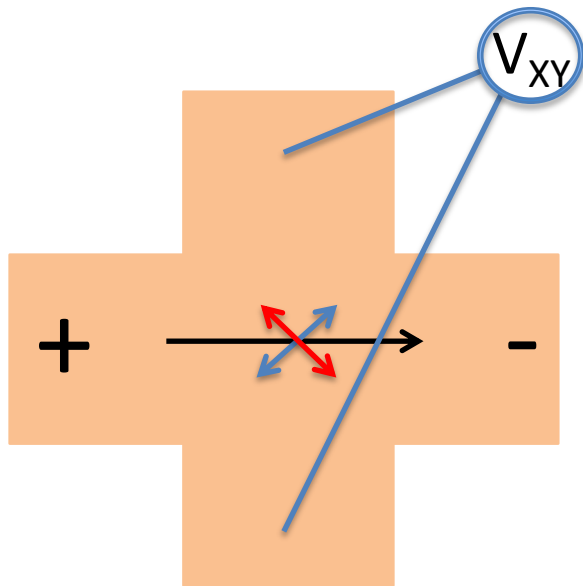
THz switching

Linearly polarized
THz radiation pulses



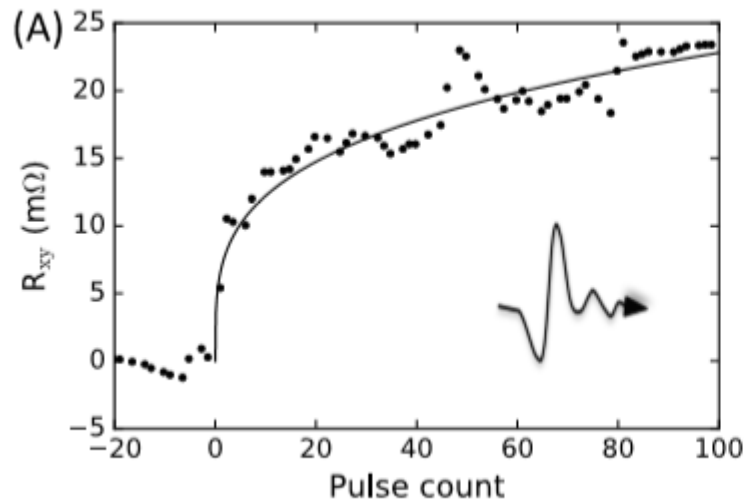
THz switching

DC AMR readout

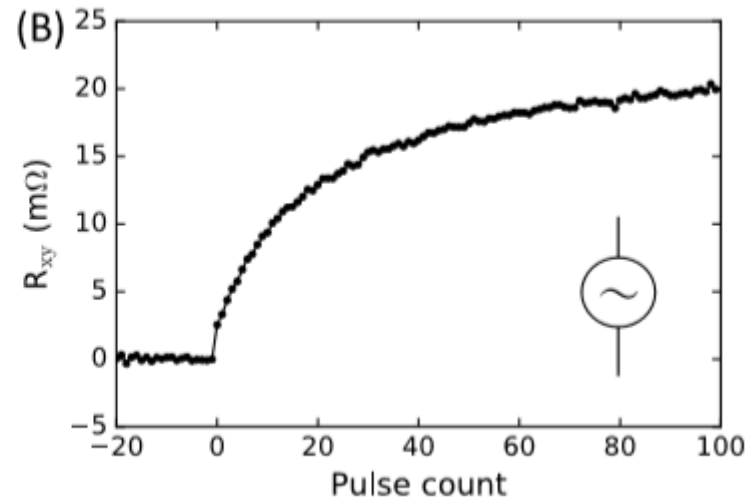


THz switching – individual pulses

1ps pulses

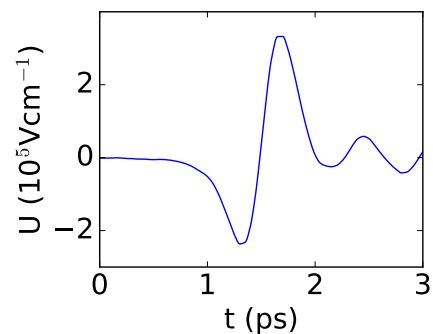
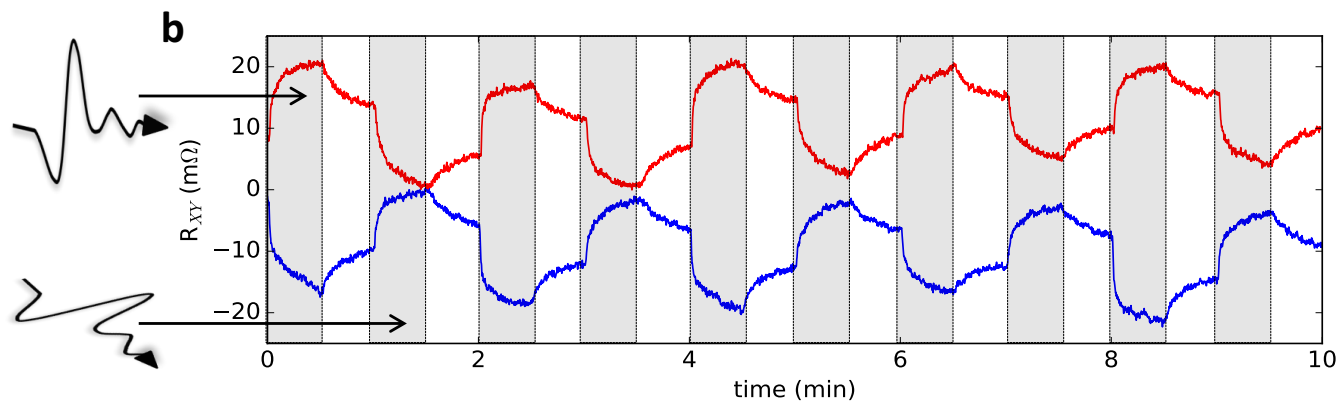
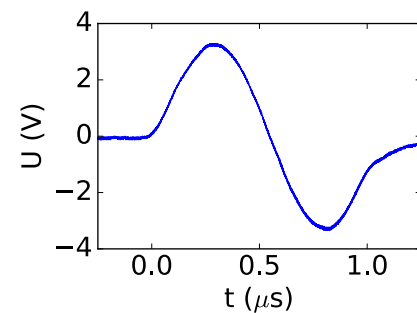
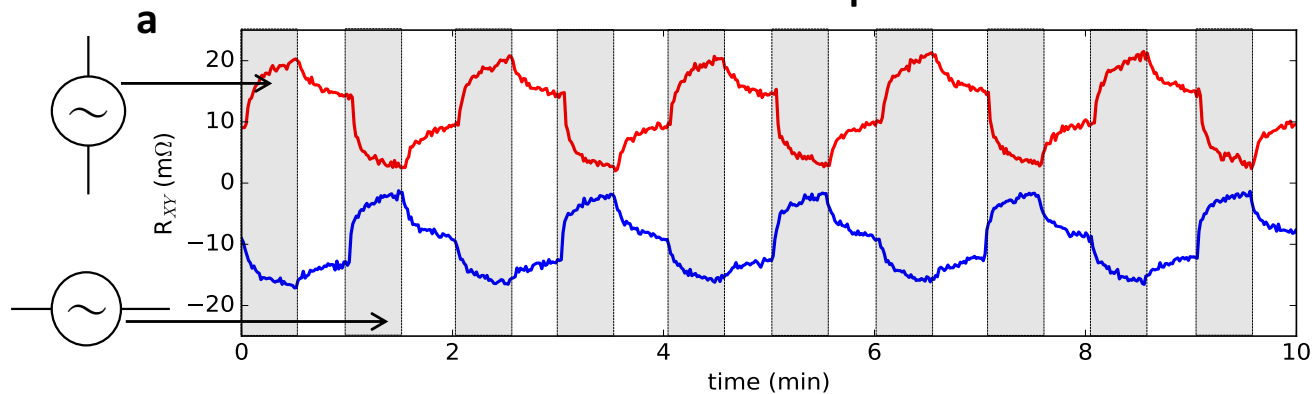


1 μ s pulses



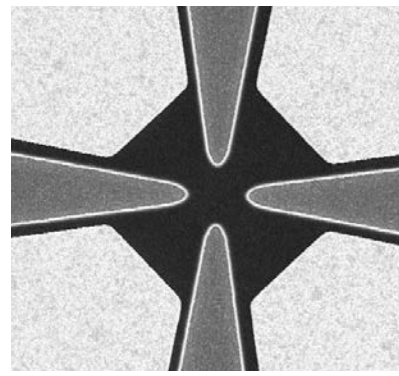
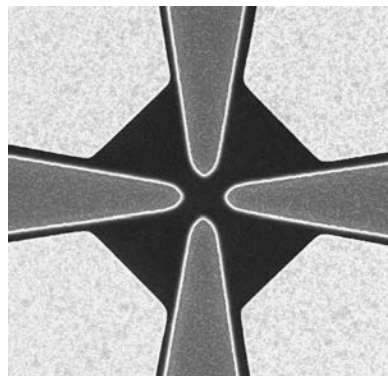
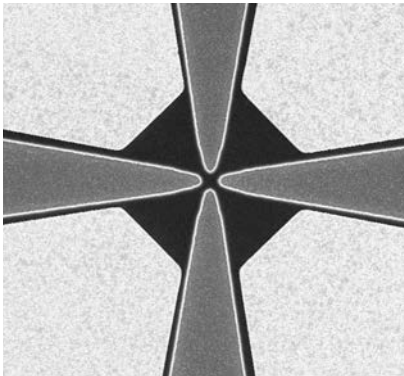
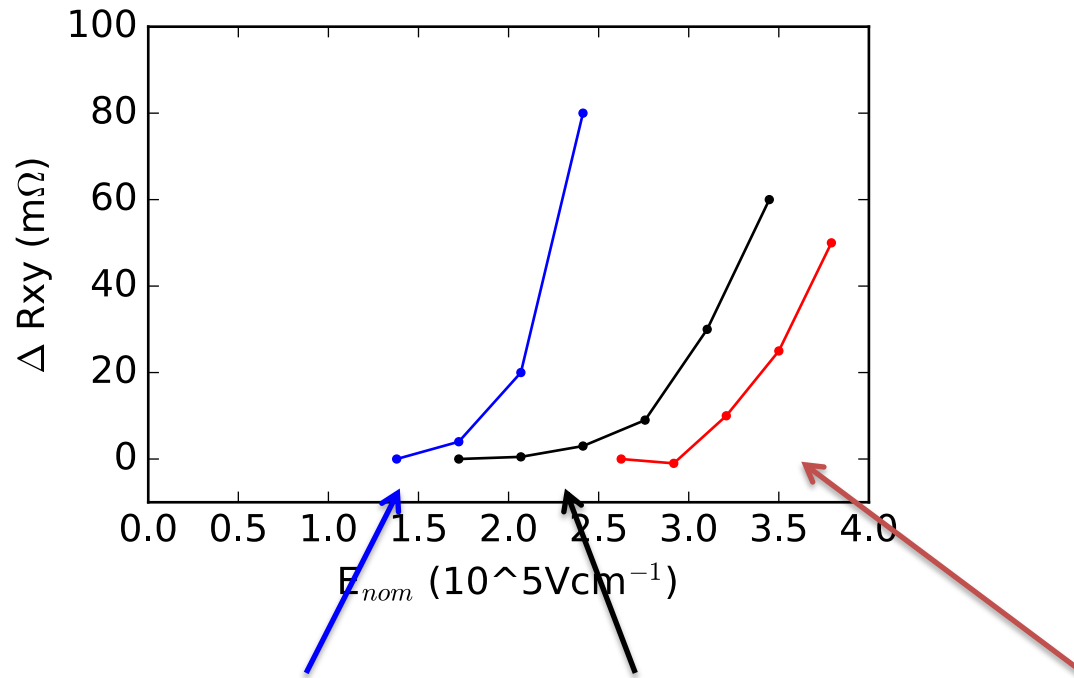
THz switching

electrical 1 μ s pulses

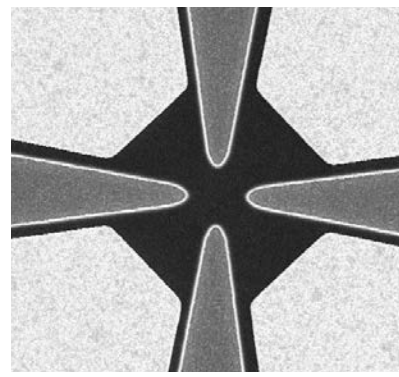
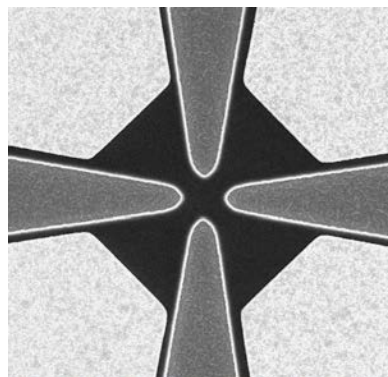
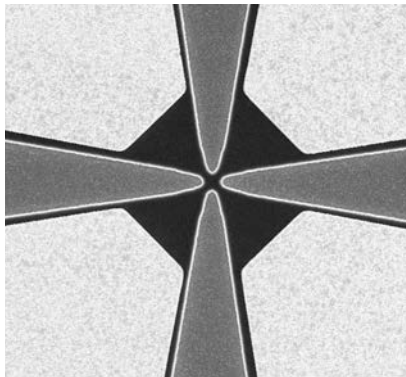
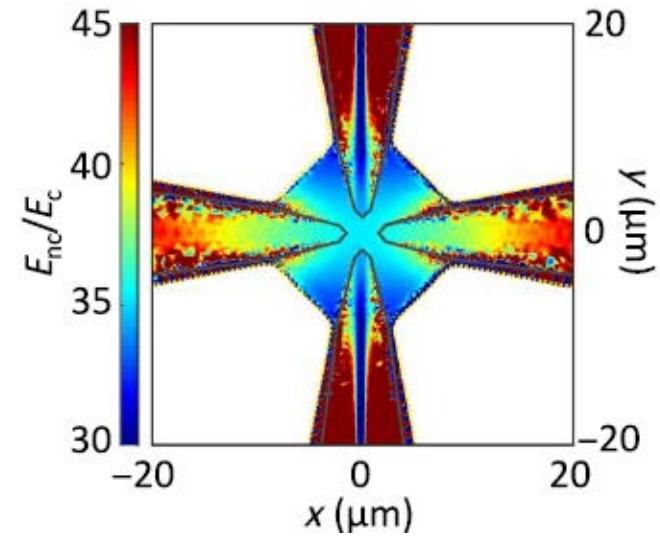
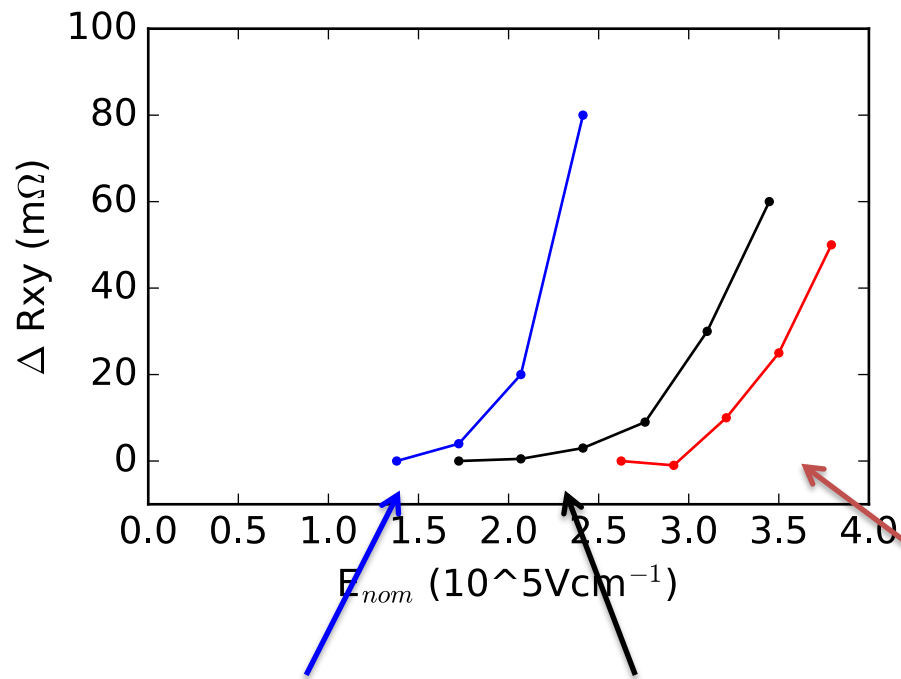


THz pulses

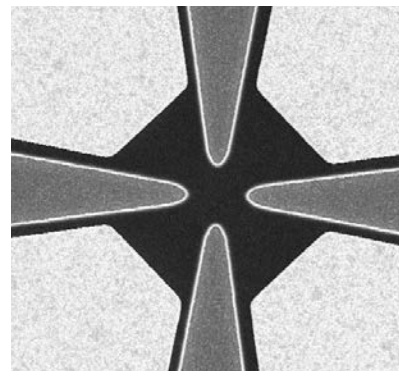
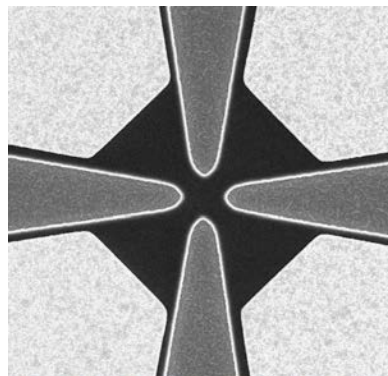
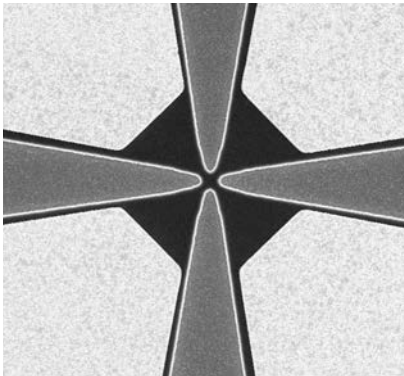
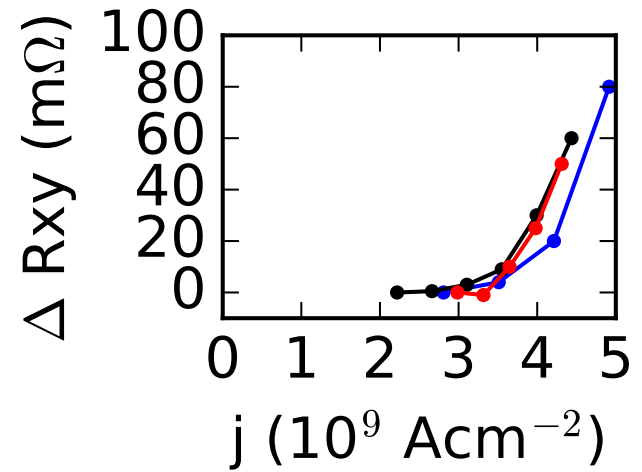
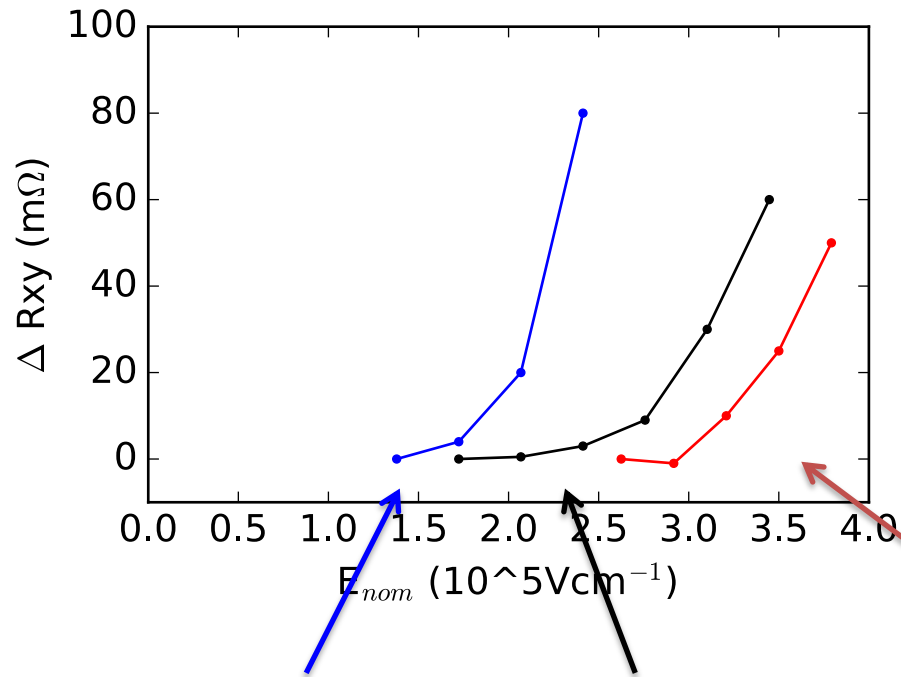
THz switching – antenna effect



THz switching – antenna effect

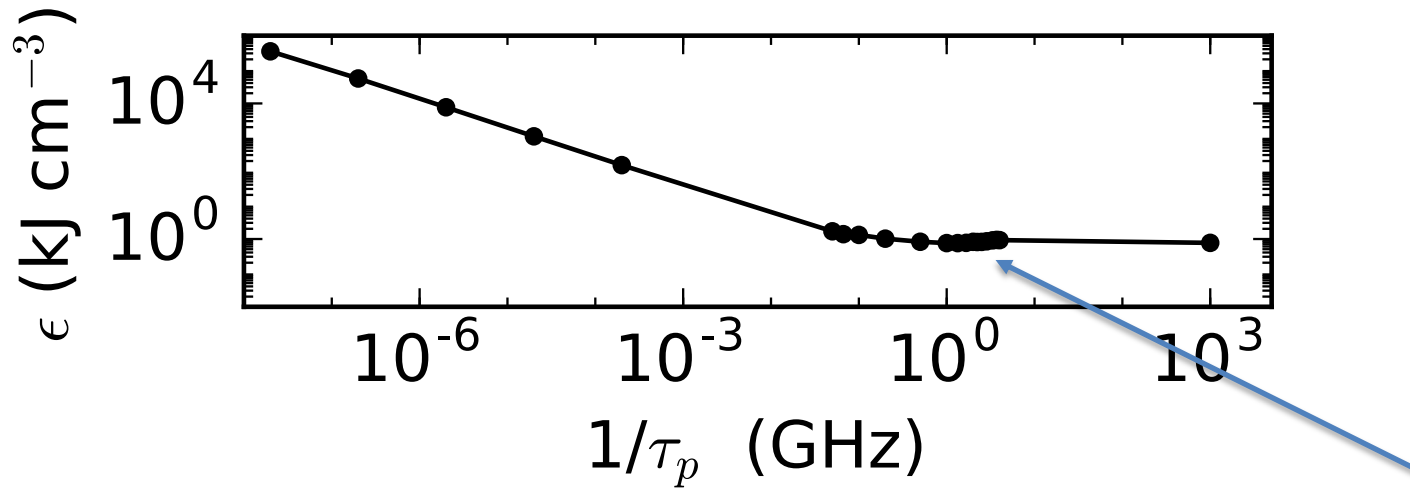


THz switching – antenna effect



THz writing – Energy of pulses

Energy density of pulse writing 1m Ω signal



Constant energy below 1 ns

Energy constant in sub-nanosecond range
- thermally assisted switching

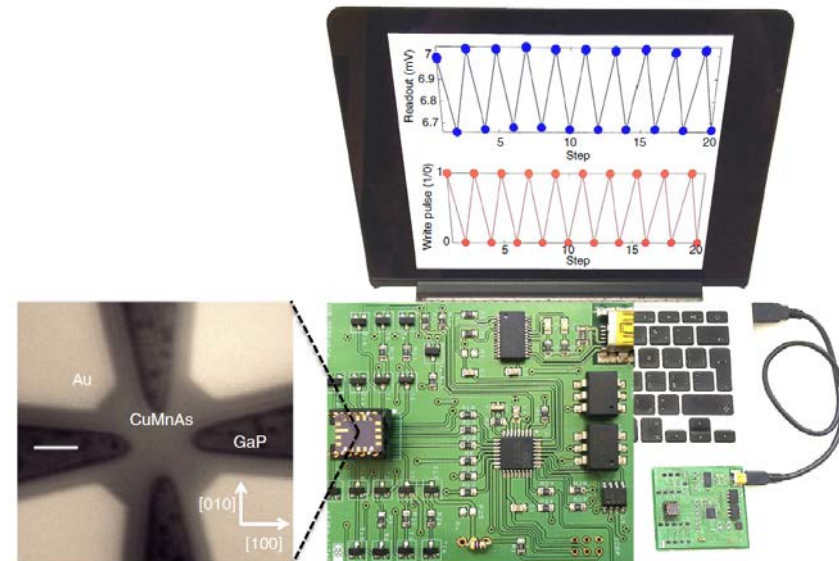
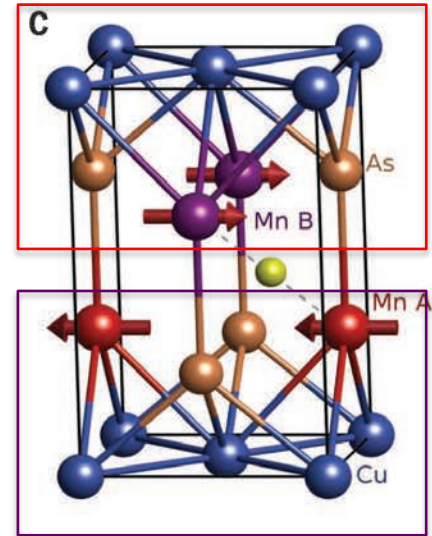
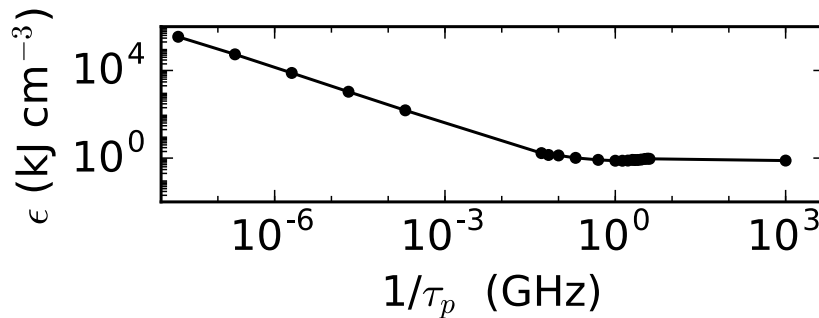
Conclusions

CuMnAs AFM memory devices

- Deterministic switching using Néel SO fields
- Multilevel character
- Ultrashort (1 ps) writing pulses

Remains

- Time resolved experiments



Thank you for your attention