Experimental characterisation of switching in antiferromagnetic CuMnAs

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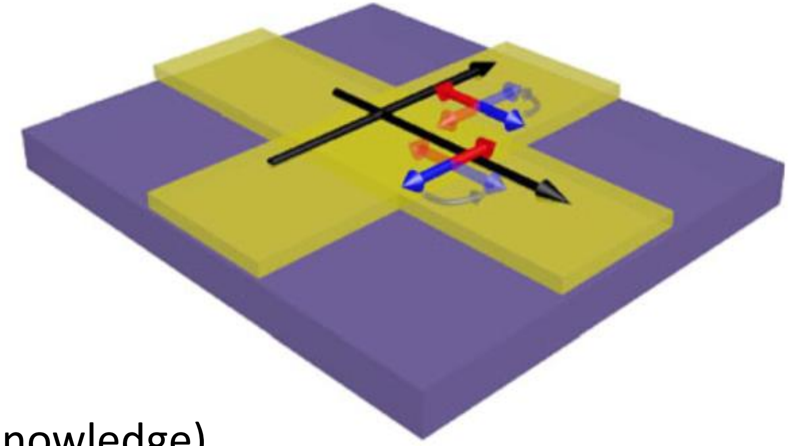
Antiferromagnetic memories



Electrical control of Neél vector

Theory : Železný et al. PRL (2014)

Neel SO writing – 90 degree rotation

AMR readout

Difficulties with AFMs (hard control with field, lack of knowledge)

Advantage of antiferromagnetic memories:

exchange enhanced ultrafast dynamics

no dipolar interactions (high storage density, stability)

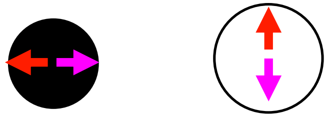
Observed in CuMnAs and Mn_2Au

Wadley et al., Science 2016
Bodnar et al., Nature Commun. 2018
Meinert et al. Phys. Rev. Appl. 2018

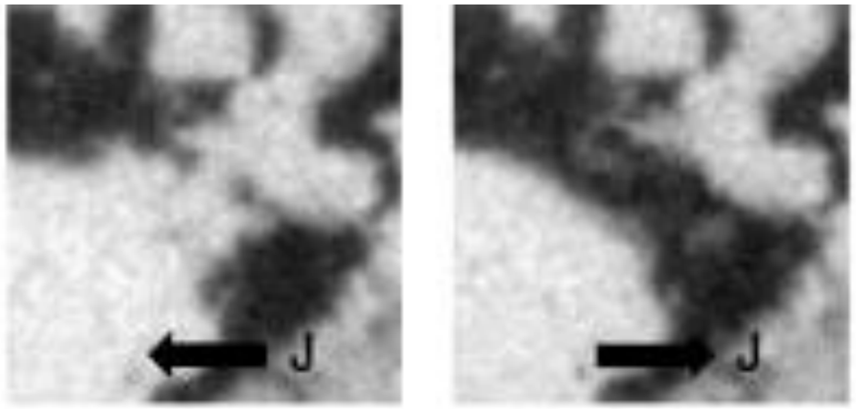
New concept: Nano-texture magnetoresistance
- degree of fragmentation

Electrical control of magnetization direction in AFM observed by XMLD-PEEM

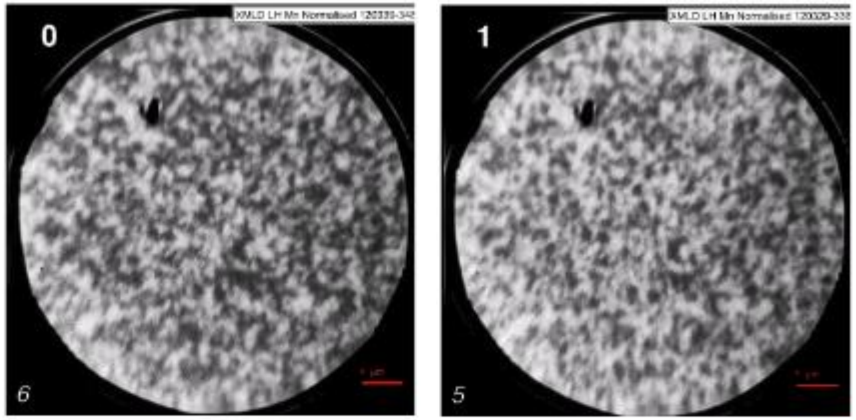
Single domain regime



Multi-domain regime



Wadley et al. Nat. Nano (2018)



Grzybowski et al. PRL 2017

Electrical signals comparable with expected AMR 0.1%

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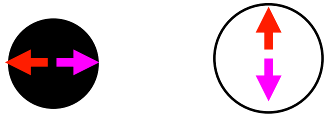

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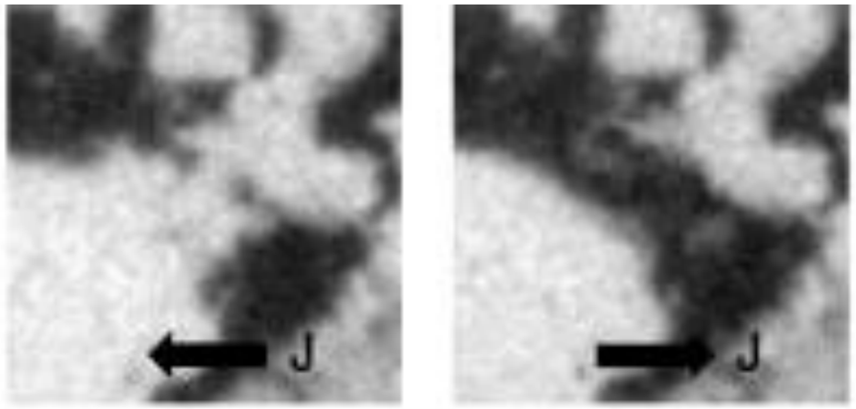

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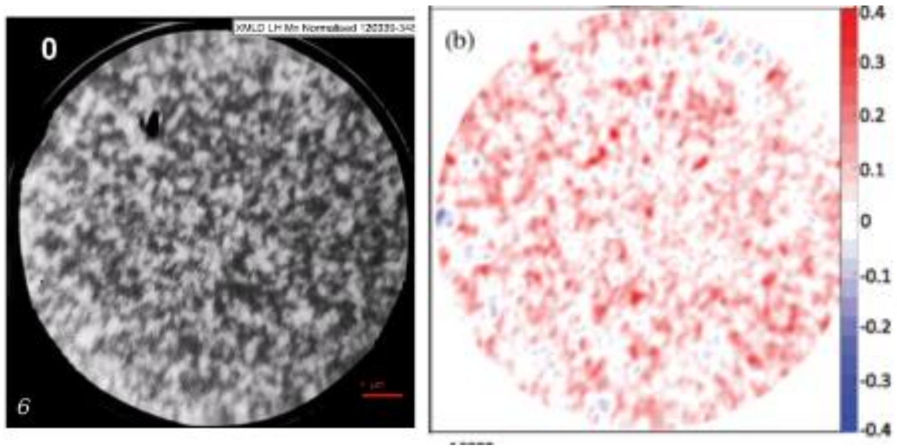

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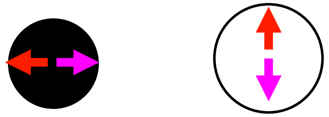

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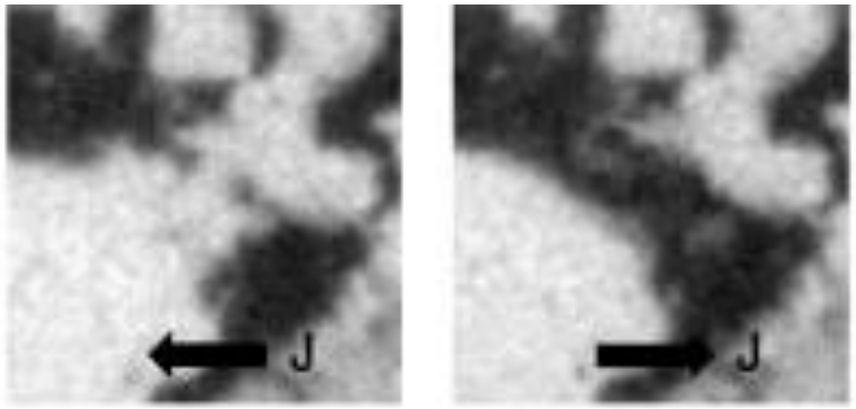

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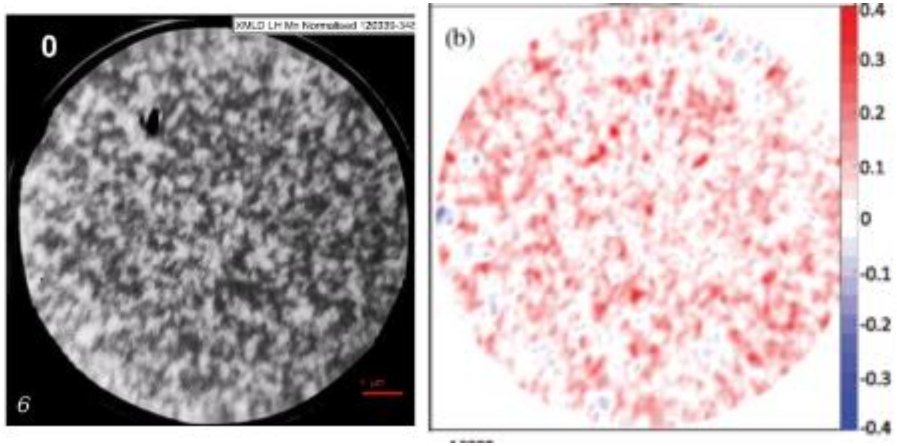


Grzybowski et al. PRL 2017

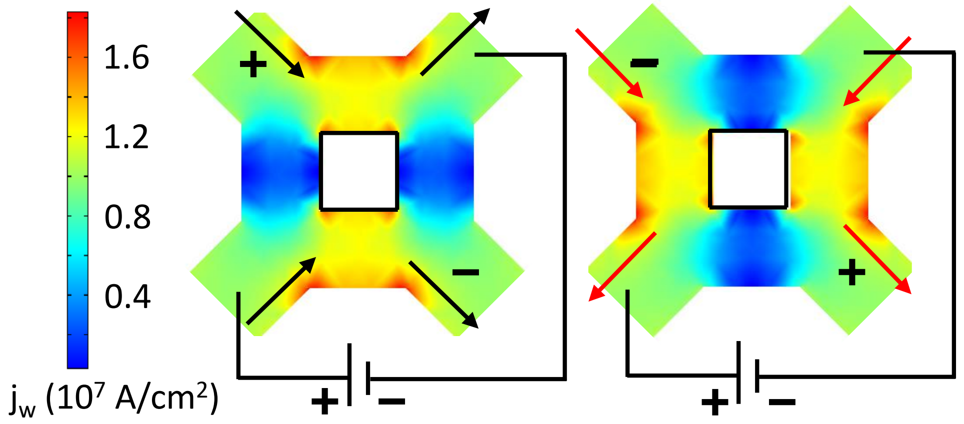
Electrical signals comparable with expected AMR 0.1%

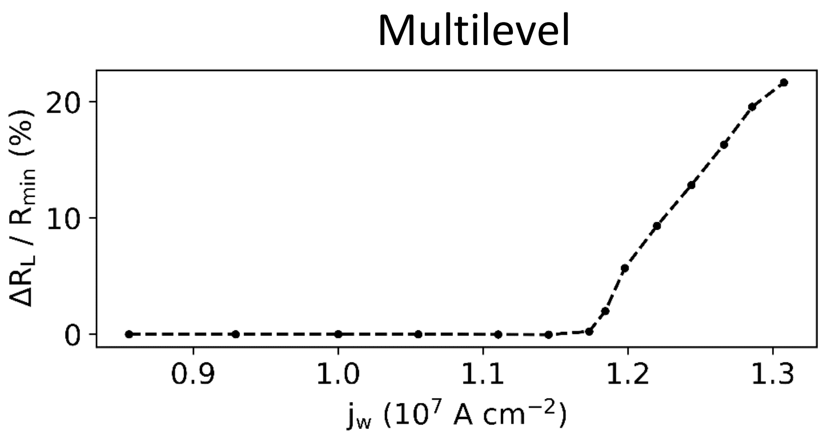
New concept: Nano-texture magnetoresistance degree of fragmentation

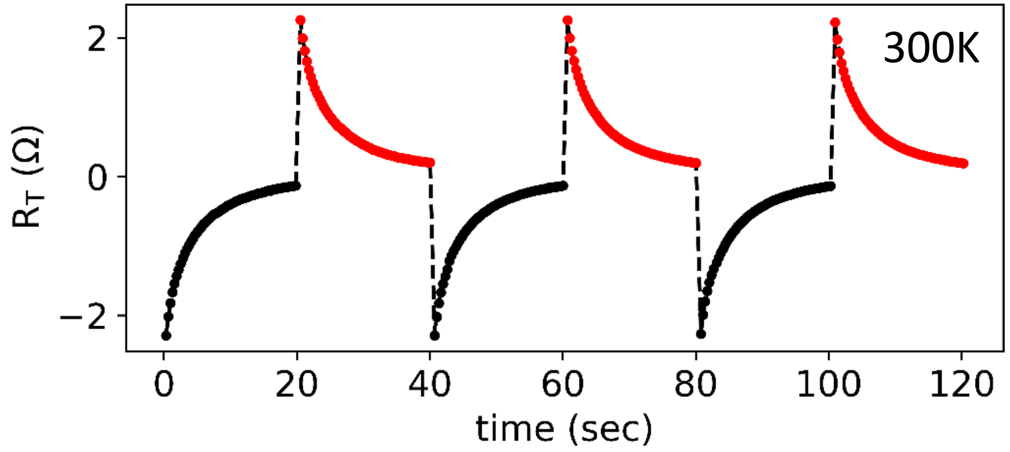
3 talks on imaging (P. Wadley, J. Wunderlich, P. Gambardella)

Large, relaxing signal

Wheatstone bridge geometry – offset free ressitivity measurement



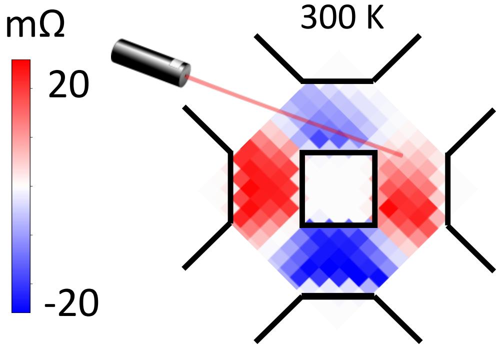


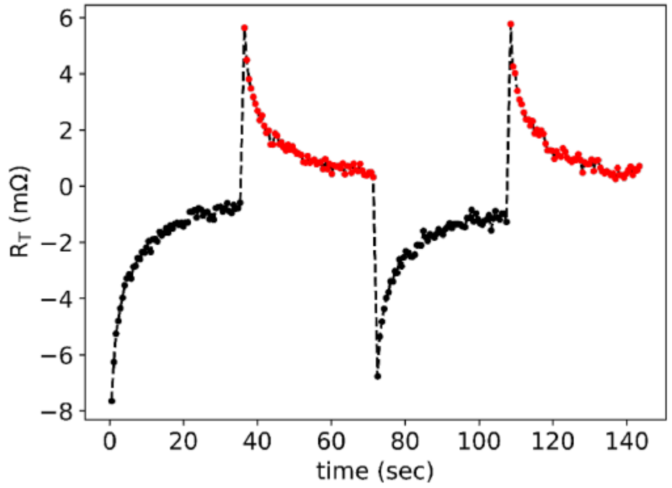


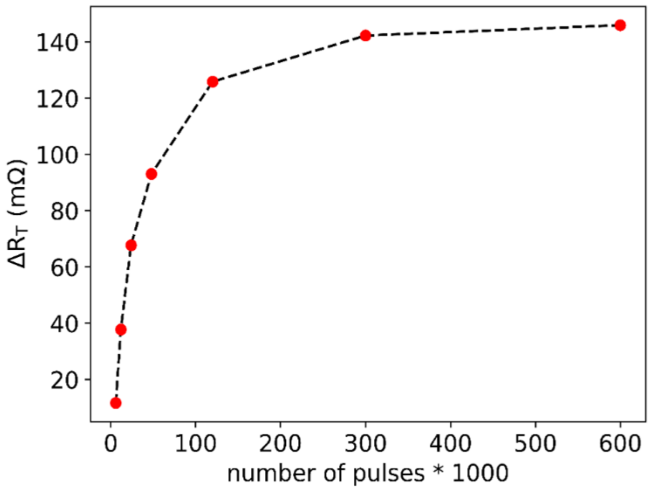
- Pulses 100us – 1ns
- Single 50nm layer (effect seen in range of thicknesses, substrates - for details see poster „Growth and structural characterisation of CuMnAs“ by Filip Křížek)
- Signals up to ~10% at RT - too strong for AMR

Optical writing

Single pulse 100 femtosecond pulse, 1 nJ, 800 nm







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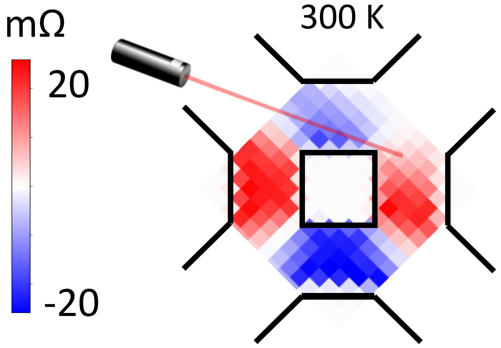
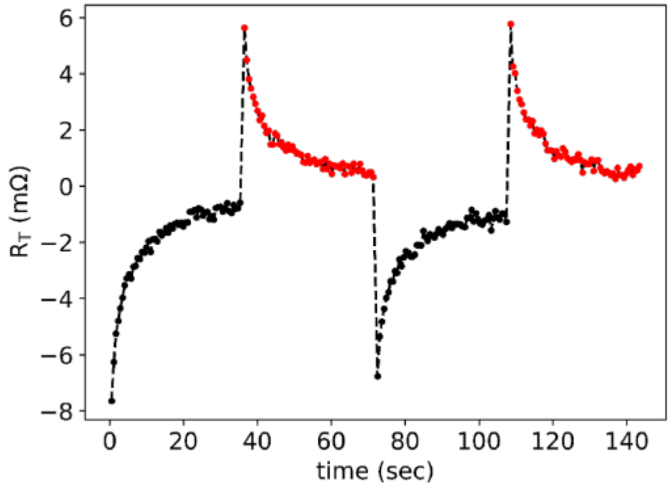
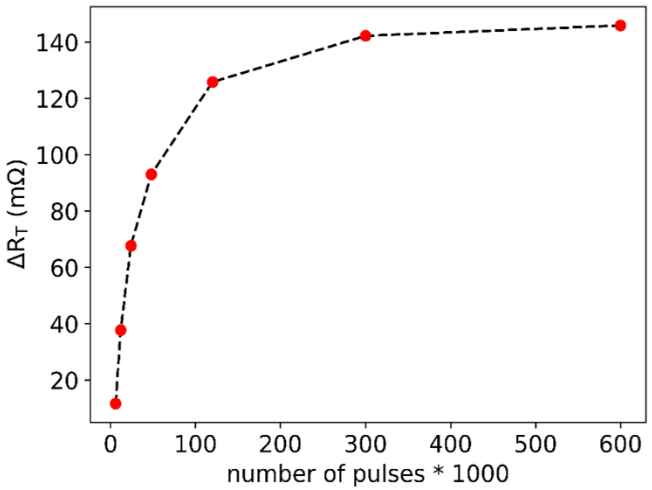
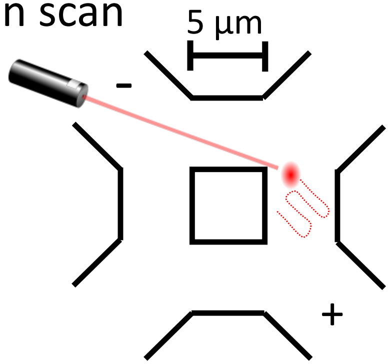


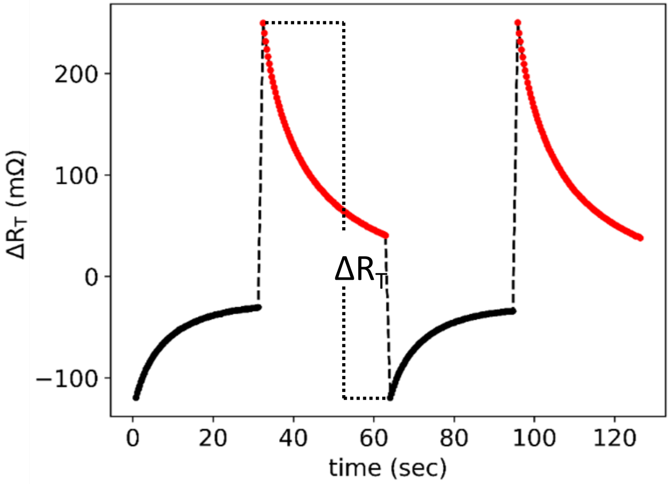




Area exposed by scanning beam

pulse train scan





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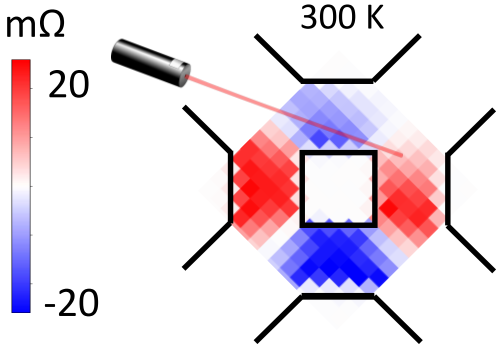

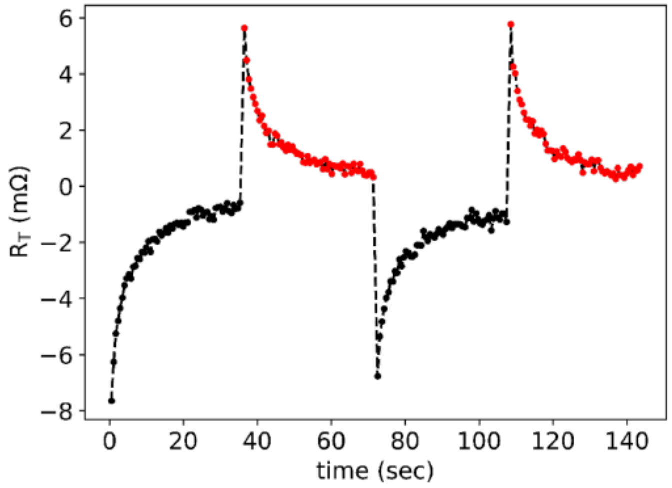

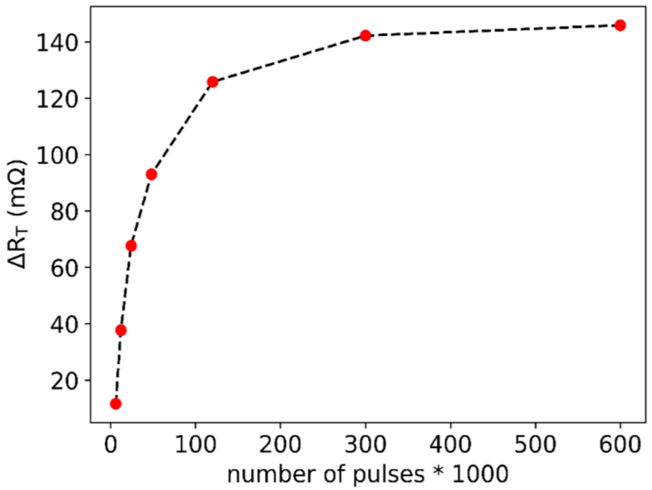

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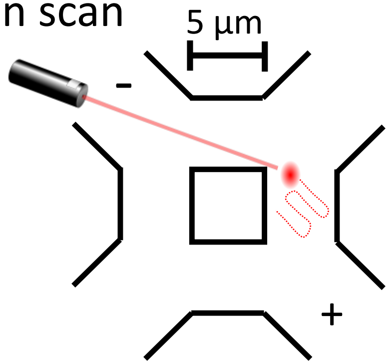
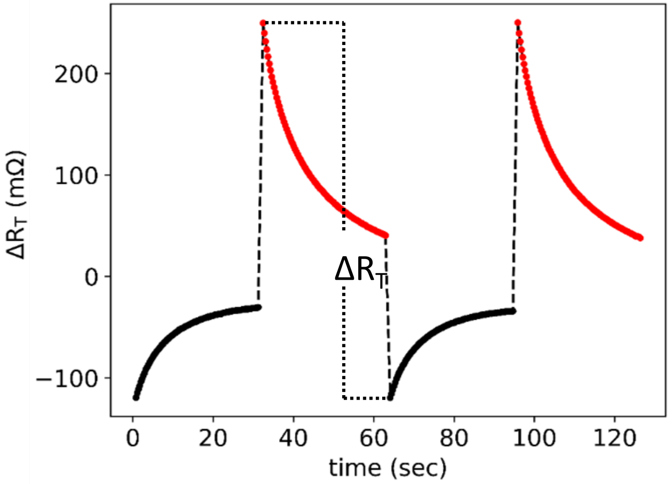
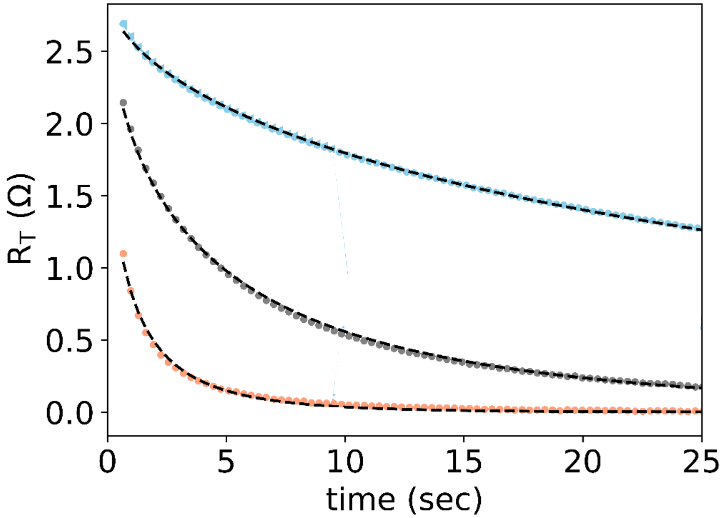




Orientation of moments is not important

Relaxation – stretched exponentials

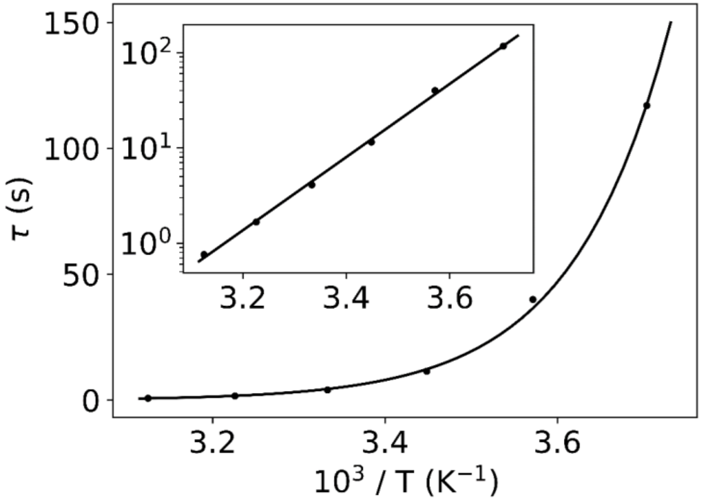


Relaxation well characterised with stretched exponential function :

$$R(t) = Rinit \cdot e^{-\left(\frac{t}{\tau}\right)^{3/5}}$$

Phillips J. Non-cryst. Sol. ,2006

Exponent 3 / 5 -> complex interactions in 3D system



Exponential temperature dependence of relaxation time τ

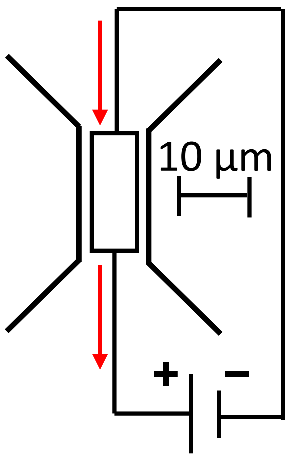
Fit :

$$\tau = \tau_0 \cdot e^{\frac{E_A}{k_B T}}$$

1/ τ_0 = 1.6 THz -> antiferromagnetic dynamics

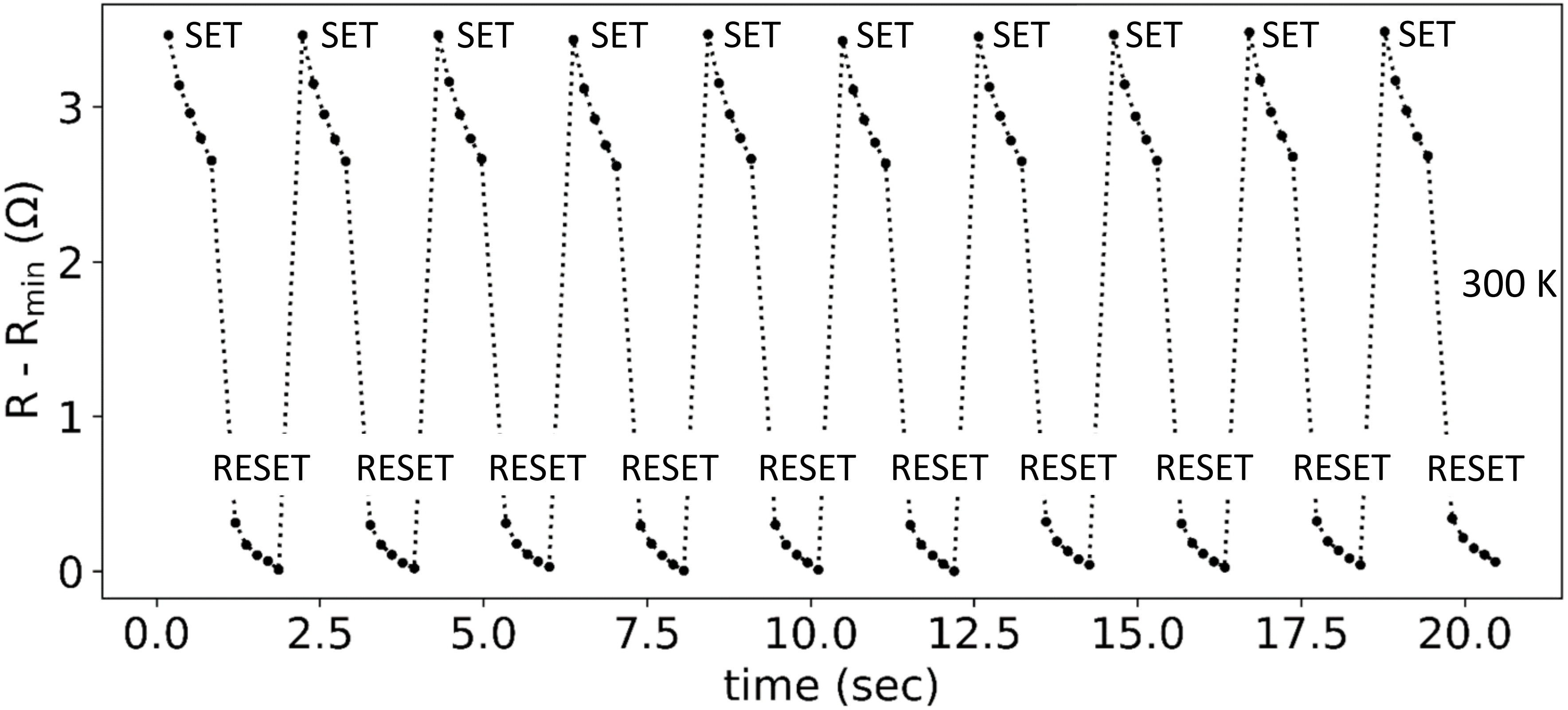
Unipolar device

Two-point resistor



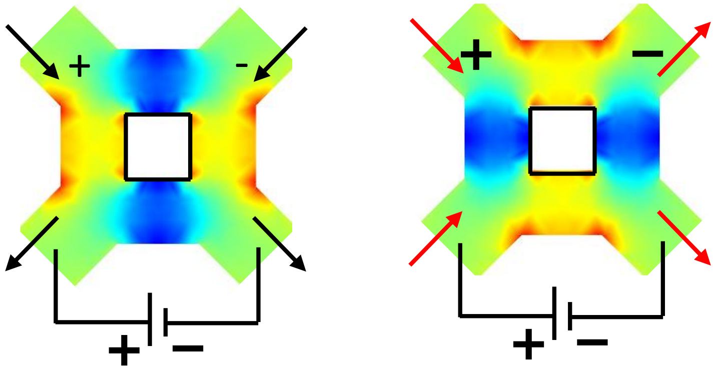
SET: 1 x 10^7 A/cm^2

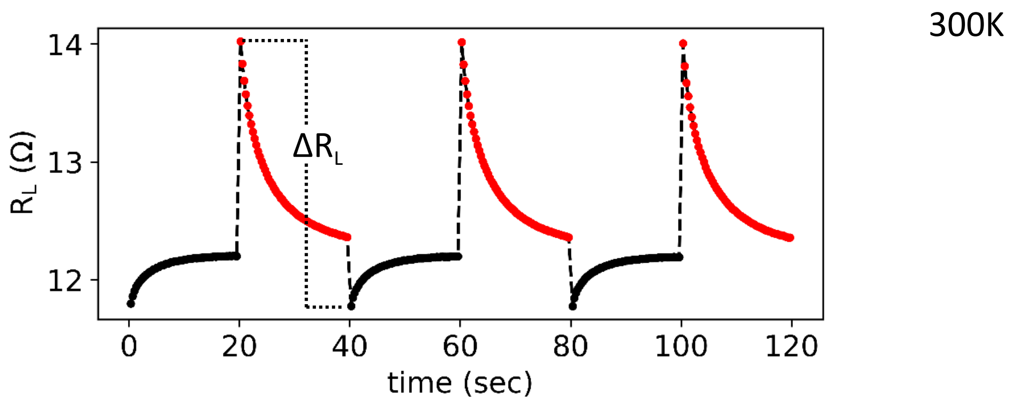
RESET: 0.9 x 10^7 A/cm^2

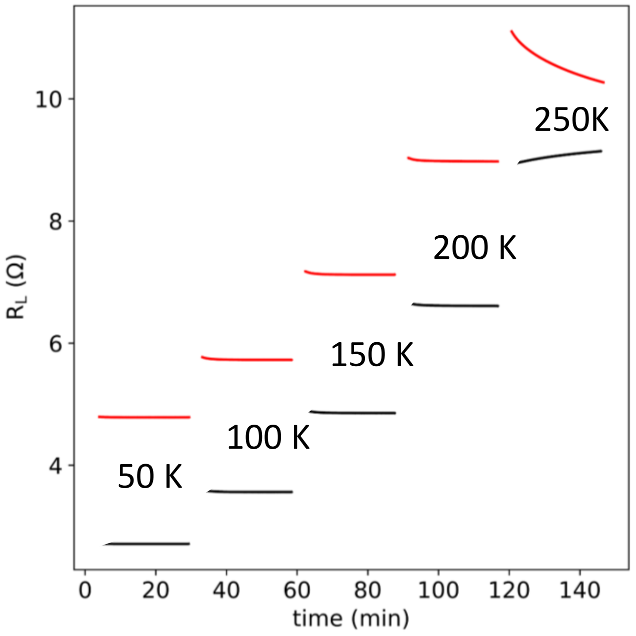


Unipolar set/reset controlled by current amplitude

Temperature dependency of the switching signal







Low T: ΔR comparable with residual resistivity

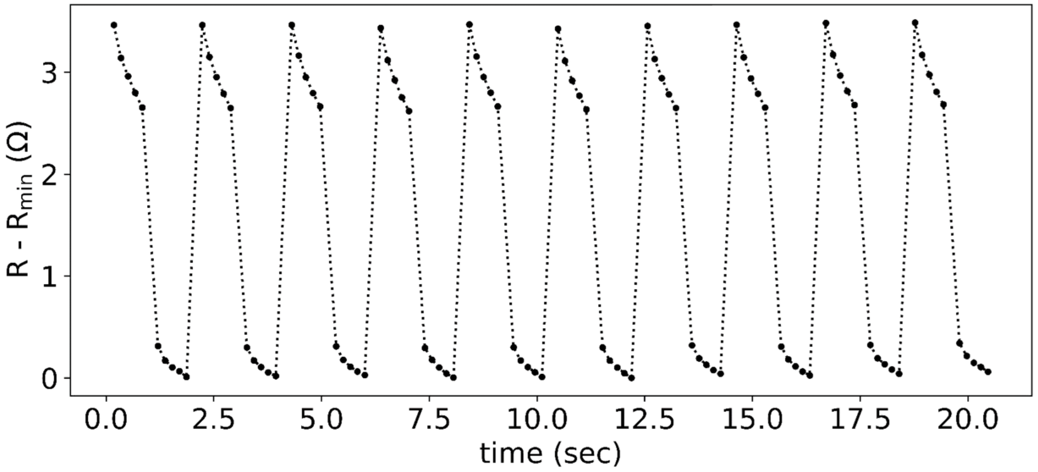
Ab initio calculations of conductivity in CuMnAs:
factor of 3 difference of AFM vs. frozen paramagnetic state

F. Máca, et al., Physical Review B 96, 094406 (2017)

Summary

Nano-texture magnetoresistance:

Kašpar et al. **arXiv:1909.09071**

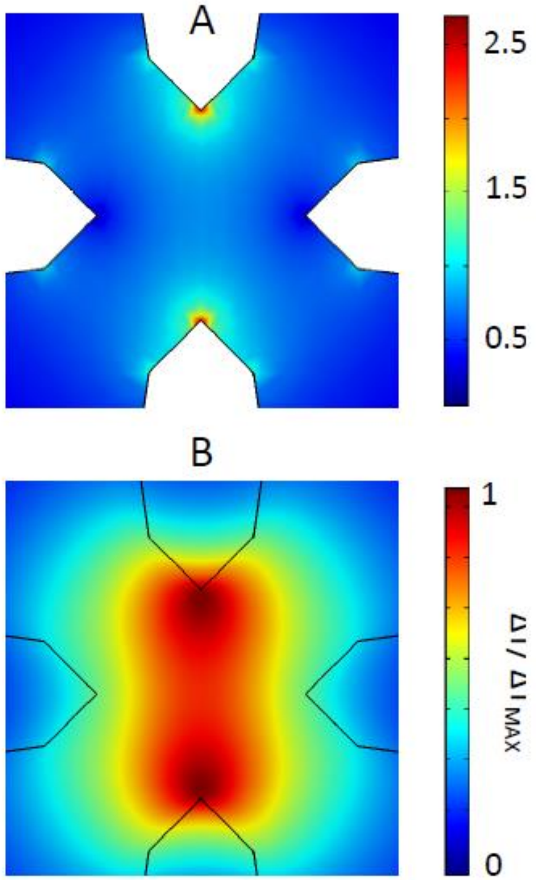


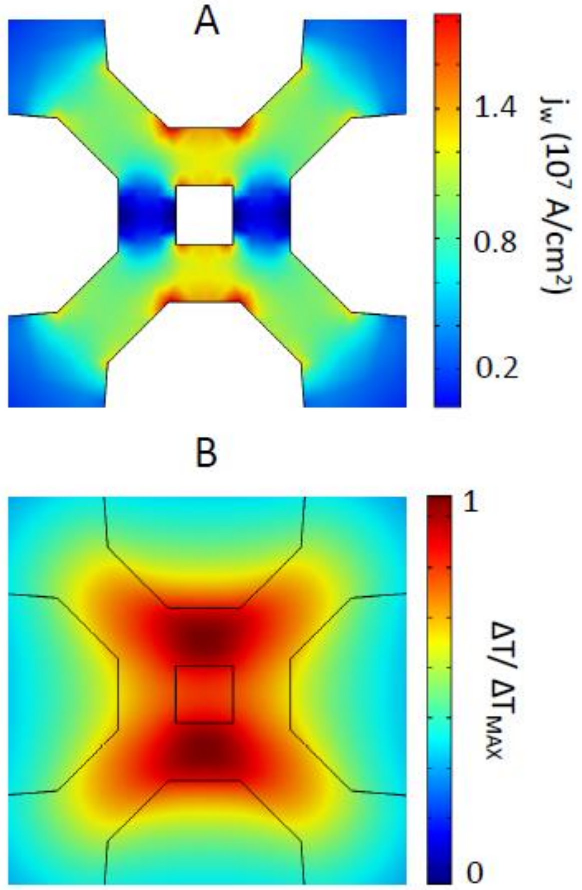
- Large resistance change ~10% at RT
- Possibly universal for conductive AFMs
  (no requirements on crystal properties)
- Single layer
- Simplest 2 point configuration
- Writing and resetting with unipolar el. pulses
- Multilevel
- Regular relaxation at RT

- promising for neuromorphic computation applications … next talk by Xavi Marti

Thank you for your attention

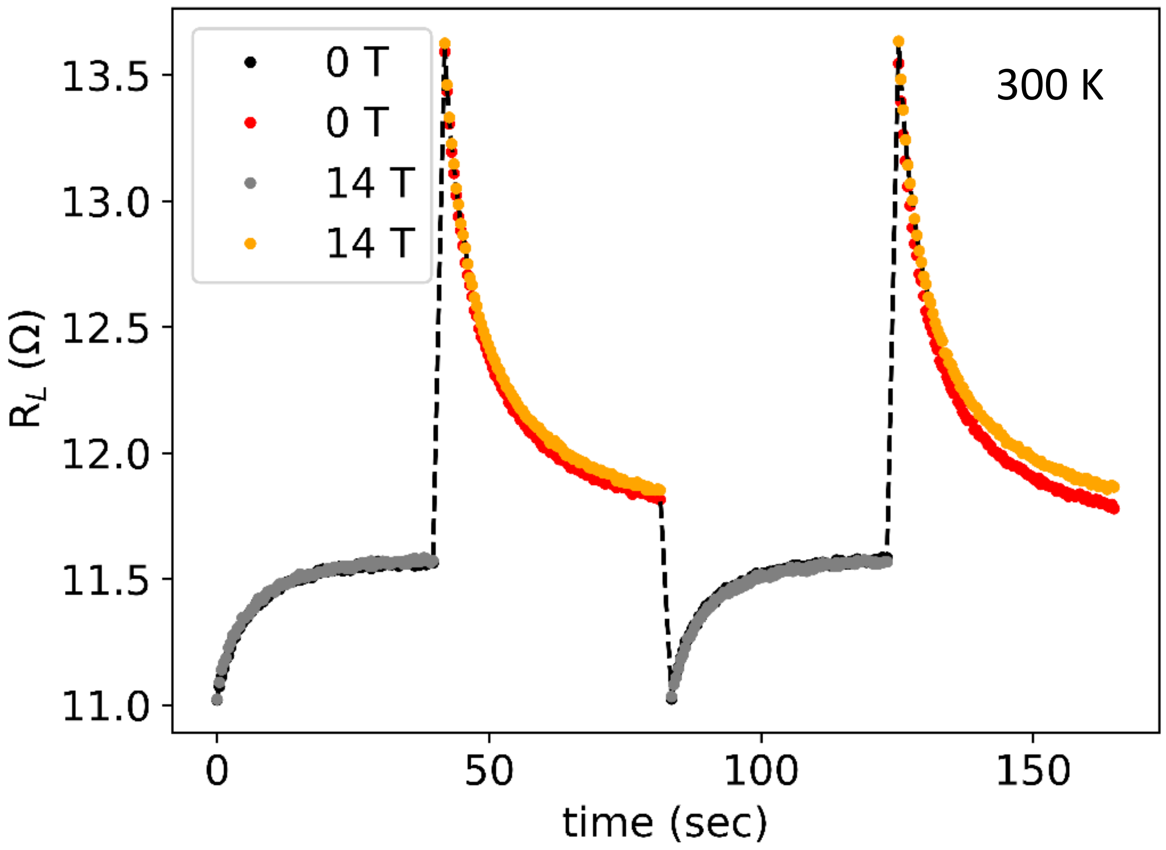
Temperature during pulse - simulations





Wheatstone bridge structure

Insensitivity to magnetic field



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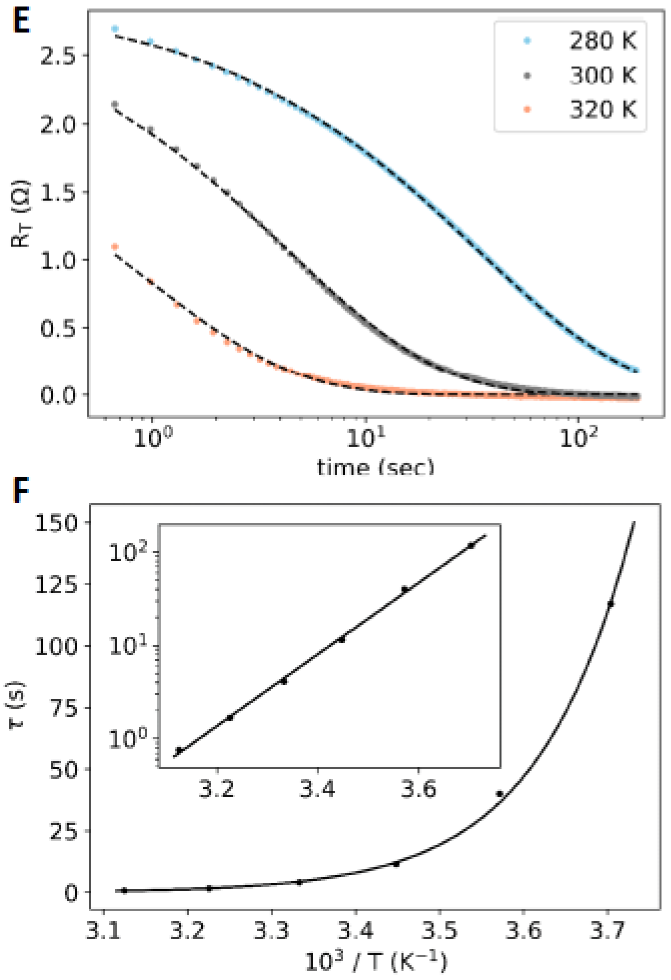

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