Ferromagnetic topological crystalline insulator $Sn_{1-x}Mn_xTe$ in an inhomogeneous magnetic field

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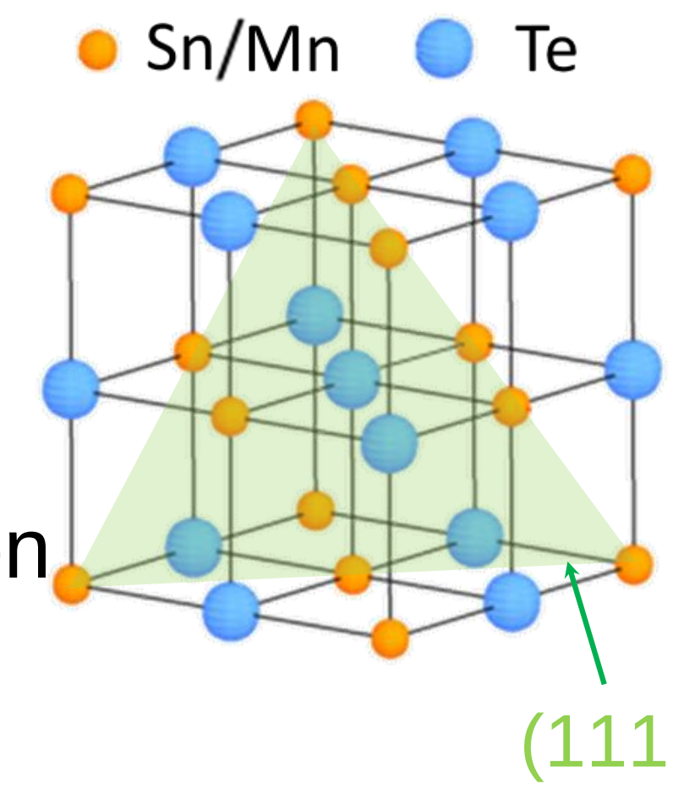
Introduction / Motivation

Topological crystalline insulators:



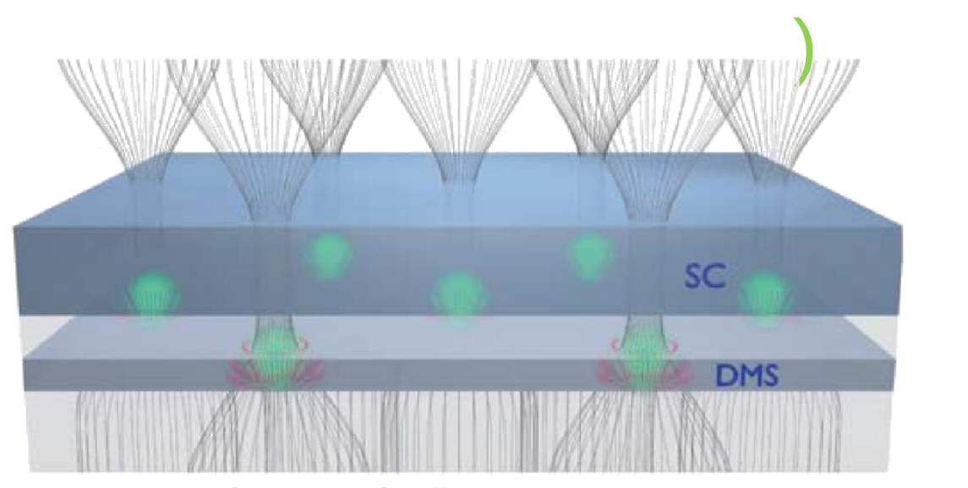
☐ SnTe is an archetypical topological crystalline insulator

☐ Topological surface states (TSS) are protected by the (110) mirror plane symmetry and has linear (Dirac) dispersion

Material: Ternary $Sn_{1-x}Mn_xTe$:

☐ Transition metal Mn-doped SnTe is a ferromagnet

☐ RKKY exchange interaction



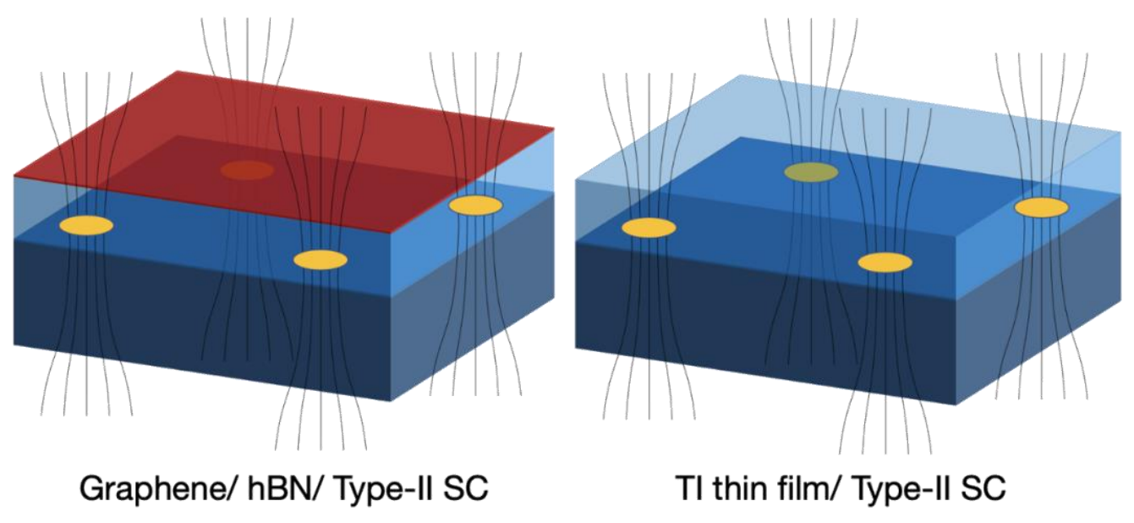
M. Berciu *et al.*, "Manipulating spin and charge in magnetic semiconductor using superconductor vortices" Nature 435,71–75 (2005)

Motivation

☐ Prediction of the novel emergent behavior of electrons in a FM semiconductor or Dirac material in the presence of the periodically modulated magnetic field

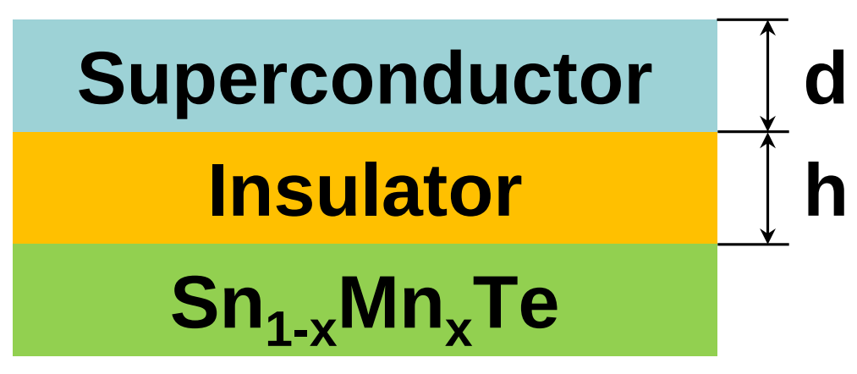
Goal of present work

☐ Study effect of the external field modification on AHE behavior of a FM semiconductor (TCI)



J. Dong *et al.*, "Dirac electron under periodic magnetic field: Platform for fractional Chern insulator and generalized Wigner crystal" arXiv:2208.10516

Modelling



$$B_r(r,z)=\frac{\phi_0}{4\pi\lambda^2}\int_0^\infty kdk\frac{J_1(kr)\exp\left(-kz-\frac{1}{2}\xi^2k^2\right)}{\sqrt{k^2+\lambda^{-2}}\left(k+\sqrt{k^2+\lambda^{-2}}\right)}$$

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T.G. Rappoport et al., PRB 74, 094502 (2006)

Two important length scales in SC:

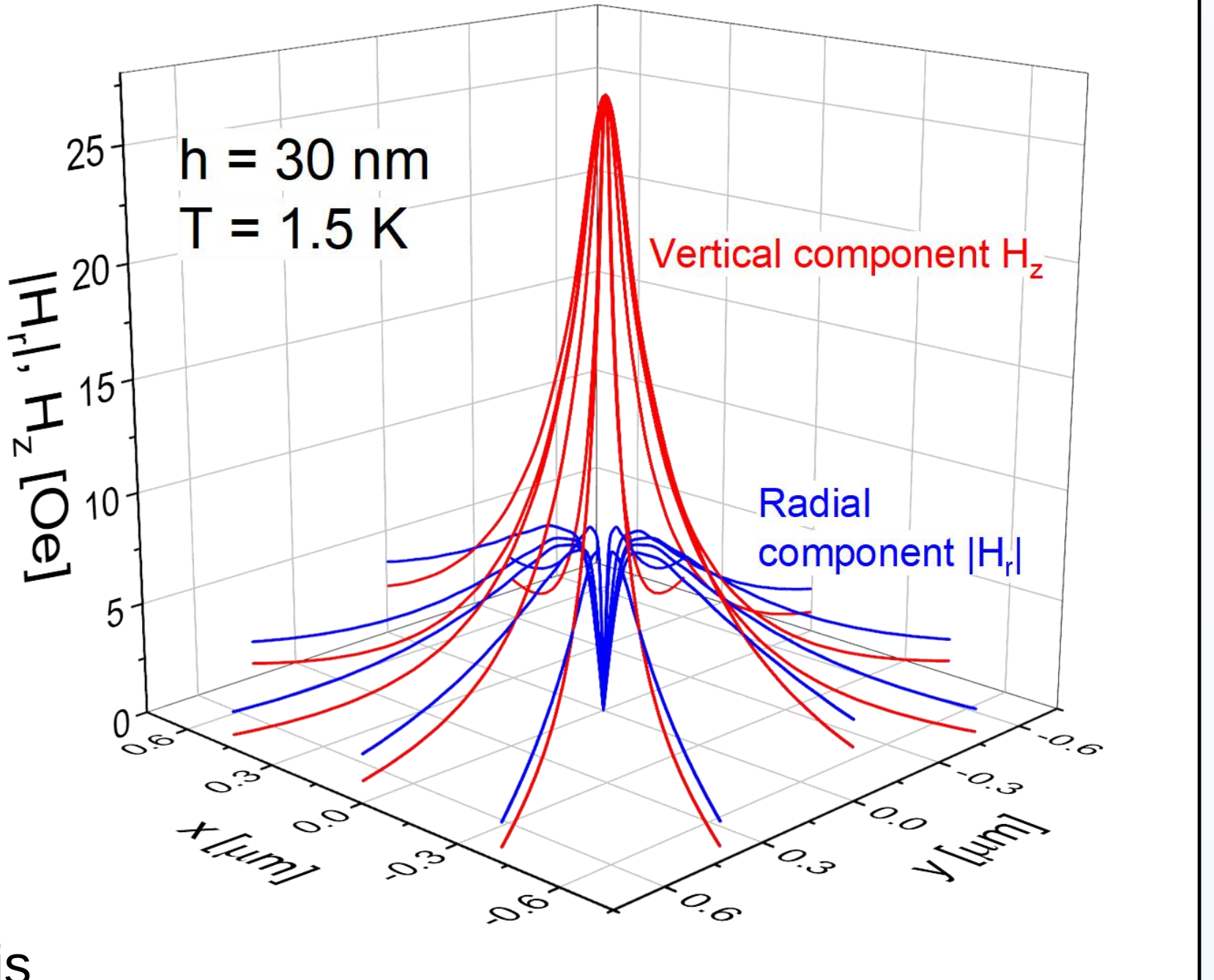
- London penetration depth λ
- Superconducting coherence length ξ

2 types of SCs:

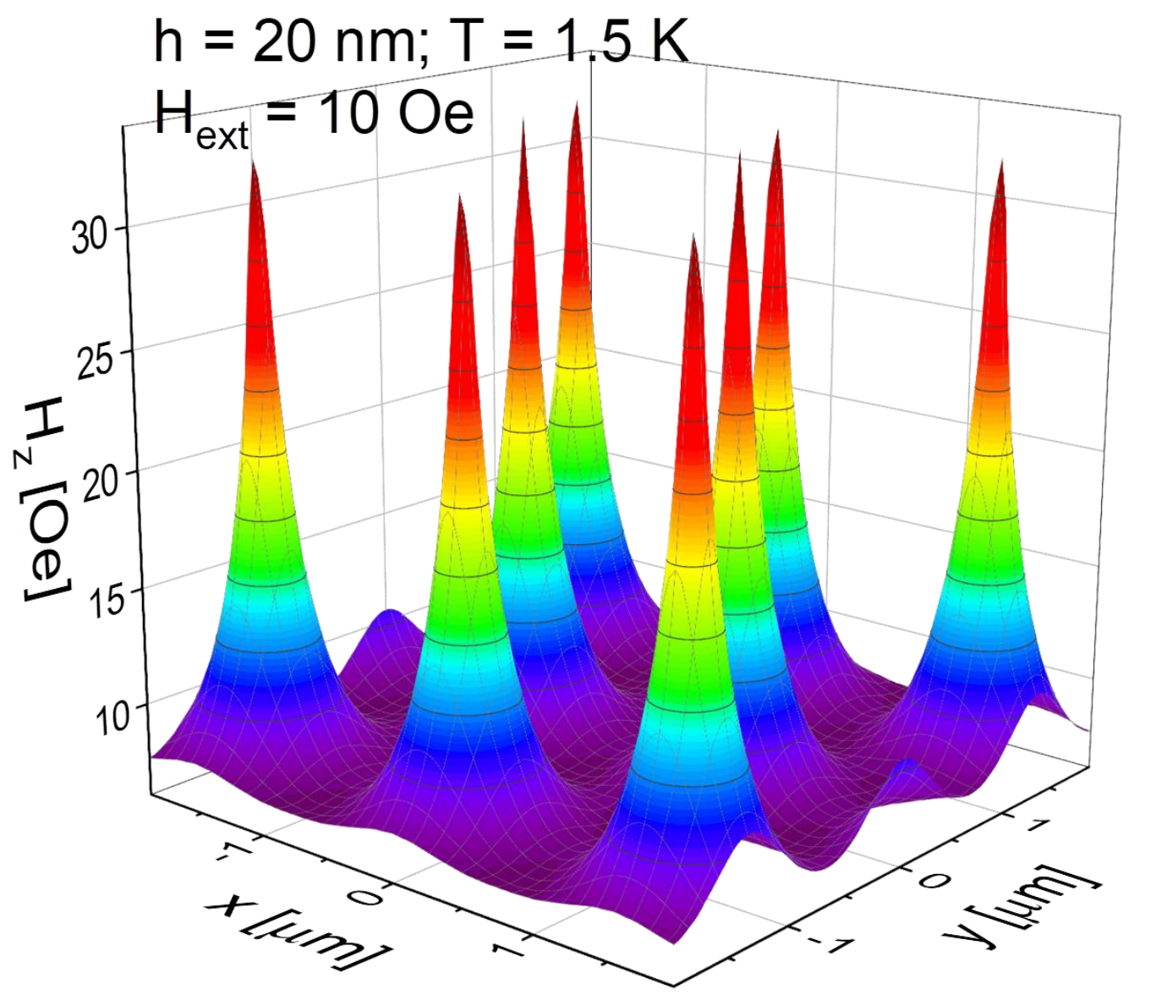
- Type I: $\lambda < \xi/\sqrt{2}$
- Type II: $\lambda > \xi/\sqrt{2}$

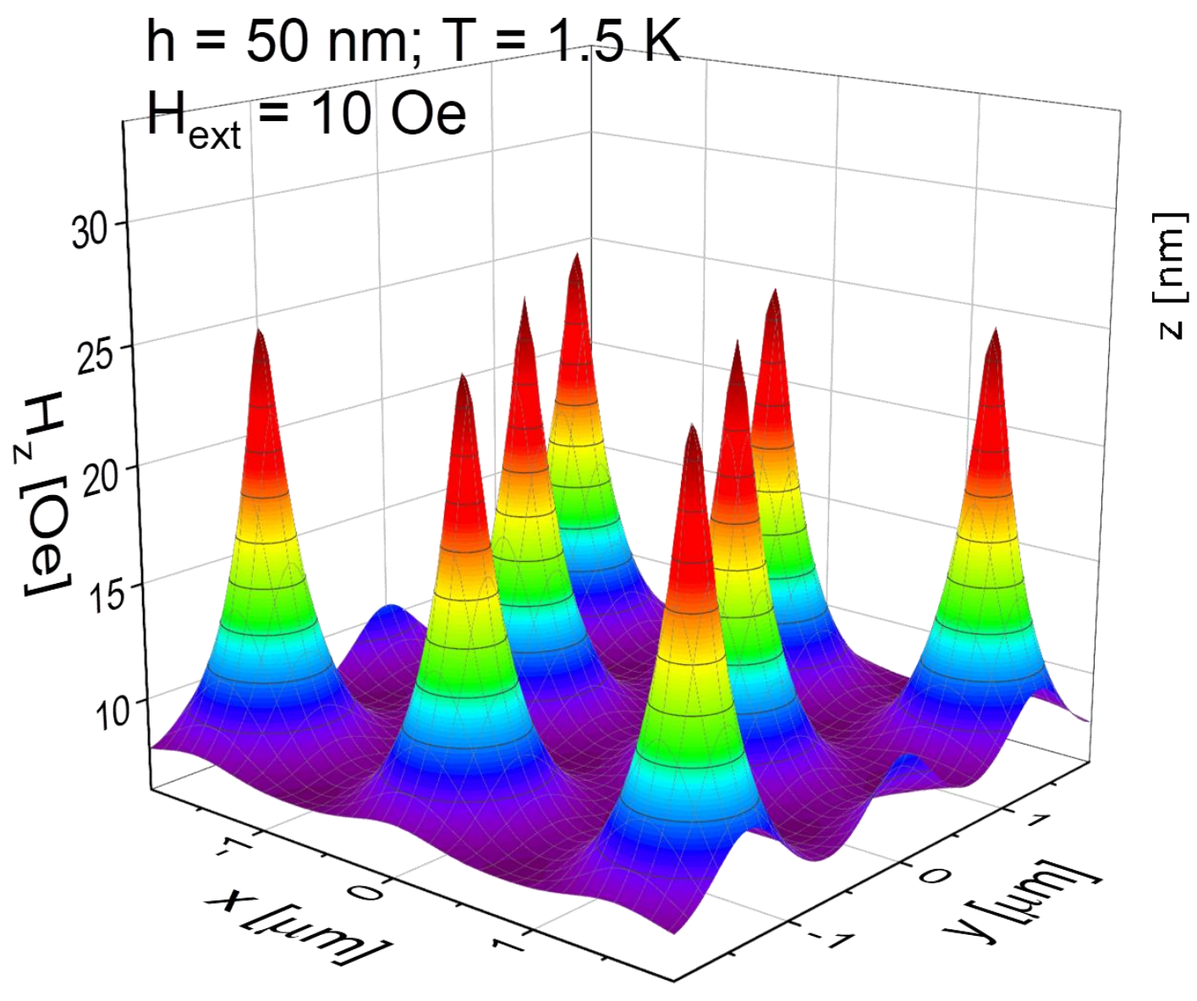
To achieve a significant magnetic field modulation, it is preferable to use type II superconductor with a small penetration depth λ. Optimal choice – Niobium (Nb; $\lambda_0 = 52$ nm, $\xi_0 = 39$ nm)

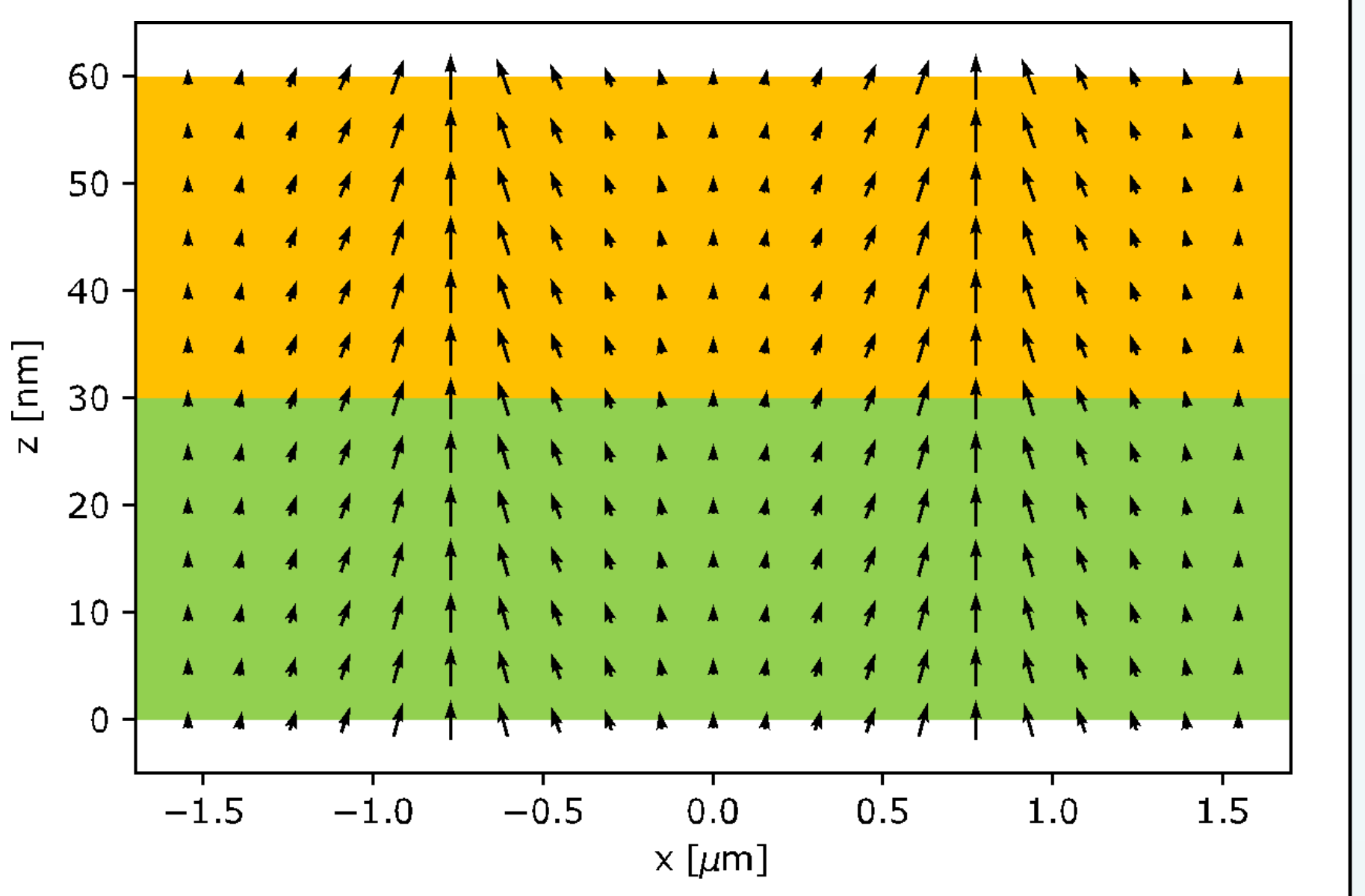
At finite temperatures, $\xi(\mathrm{T}) = \xi_0/\sqrt{1-T/T_C}$ and $\lambda(\mathrm{T}) = \lambda_0/\sqrt{1-(T/T_C)^4}$. Mean free path in a dirty limit l is determined from $\xi(0) = 0.855\sqrt{\xi_0 l}$. For a SC thin film, where $d < \lambda$, penetration depth is replaced with a Pearl depth $\Lambda = \lambda^2/d$.



Field from a single vortex







Periodic vortex lattice creates spin-charge texture in the underlying DMS layer
(Nb; d = 30 nm; h = 30 nm; T = 1.5 K; H_{ext} = 10 Oe)

Experimental results

MBE growth

☐ Veeco GENxplor, SnTe, Mn, Te sources, (111) BaF_2 substrates

☐ $Sn_{1-x}Mn_xTe$ films, $x_{Mn} = 0 \div 0.07$, 20-50 nm thickness

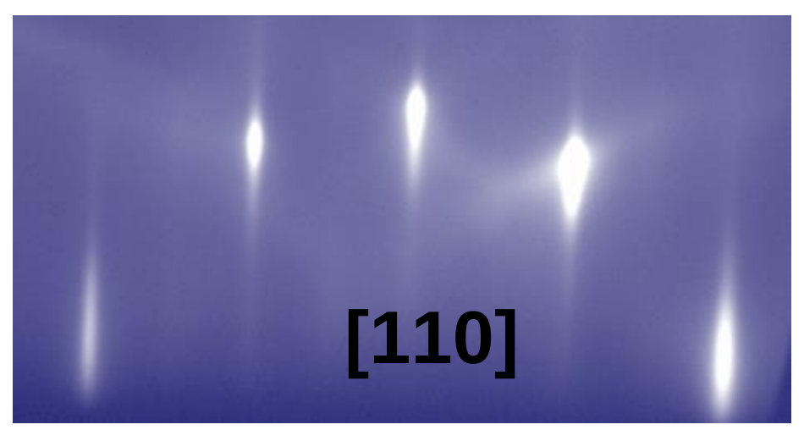
☐ RHEED *in-situ*, shows streaky pattern, smooth surface

☐ AFM confirms atomically smooth surface

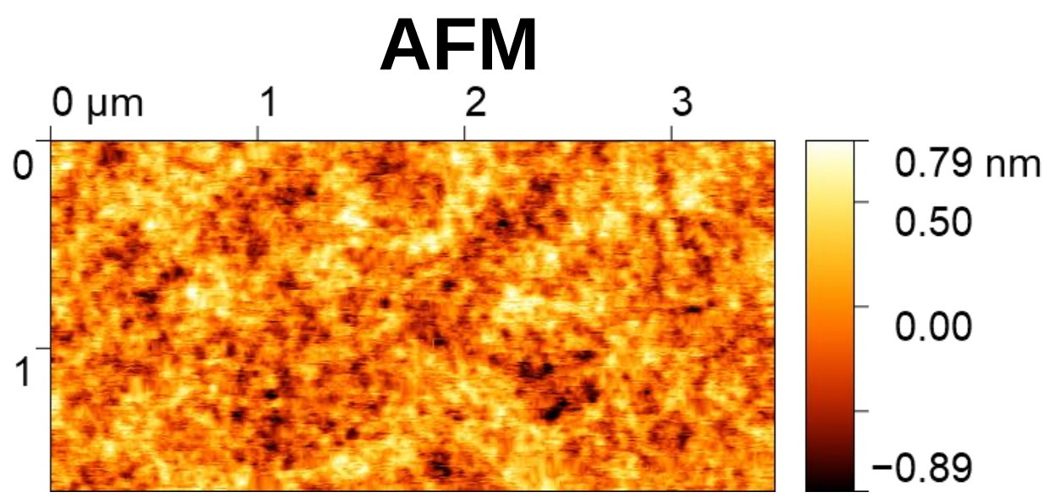
☐ XRD, only (111) orientation, systematic reduction of lattice constant with Mn doping, no strains detected from asymmetric RSM

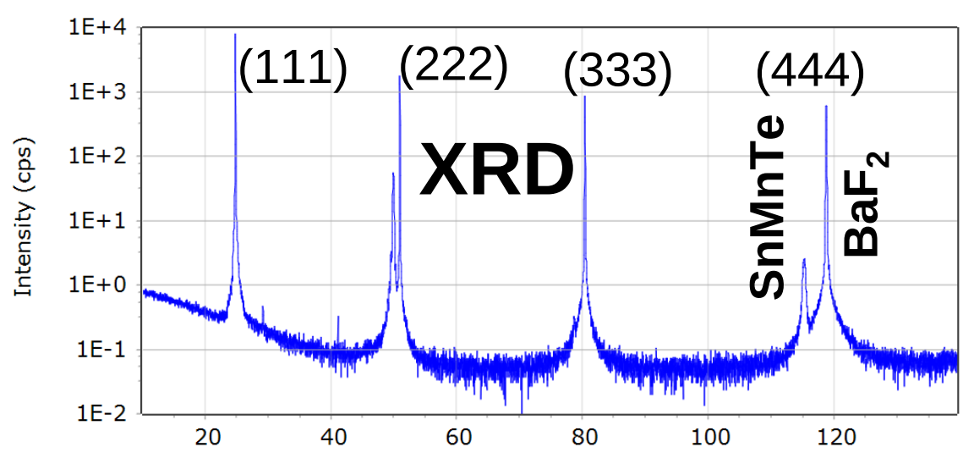
☐ Nonstoichiometric growth with high Te flux drastically increases surface roughness, in-plane compressive strains up to -0.5 % introduced

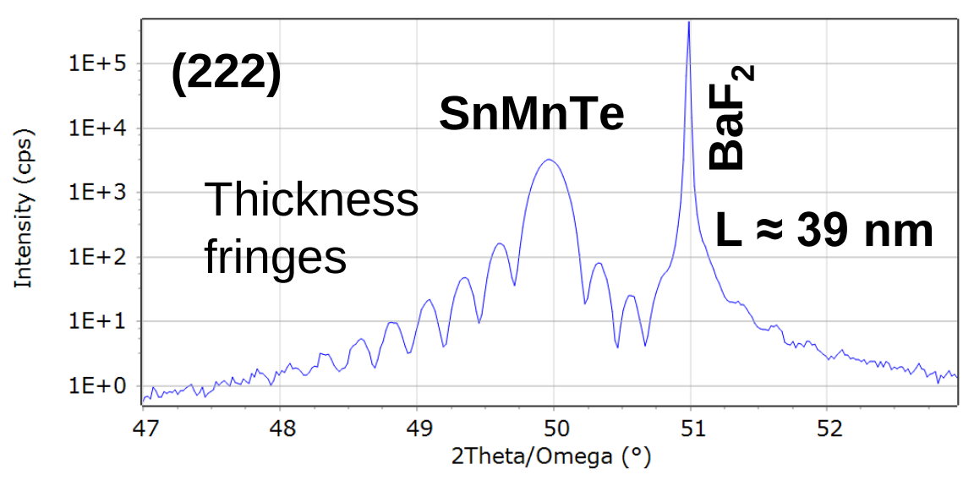
RHEED

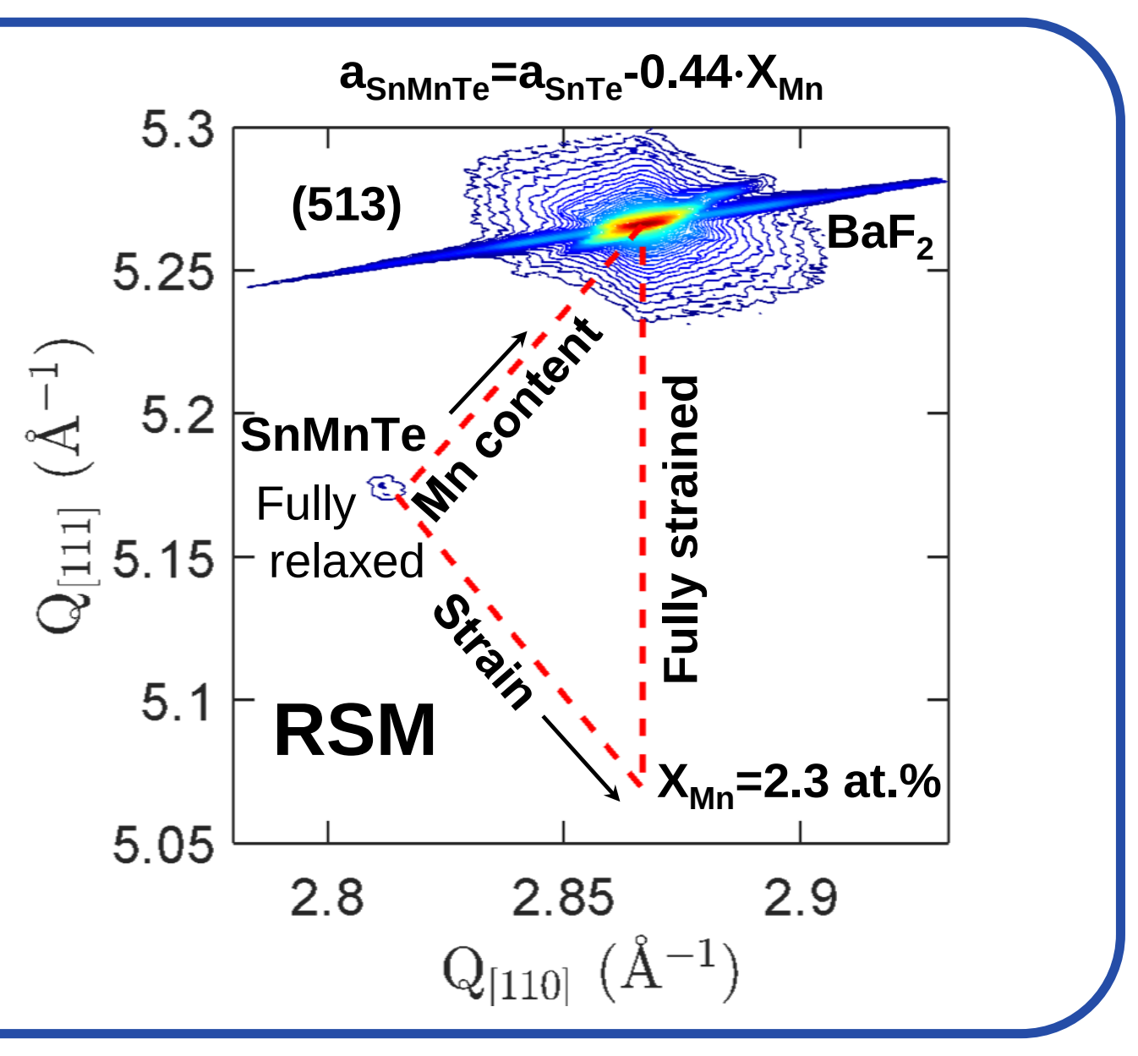


AFM

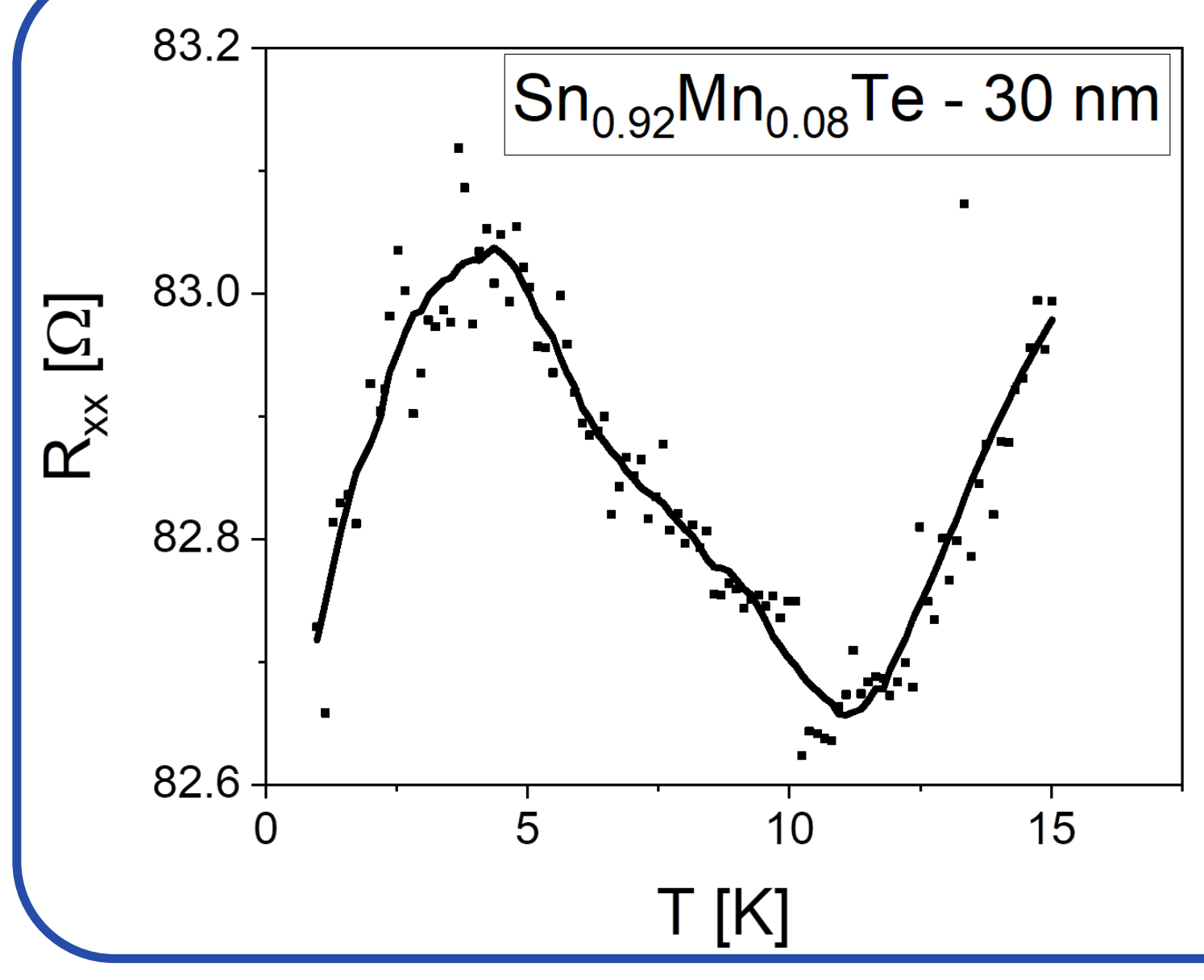


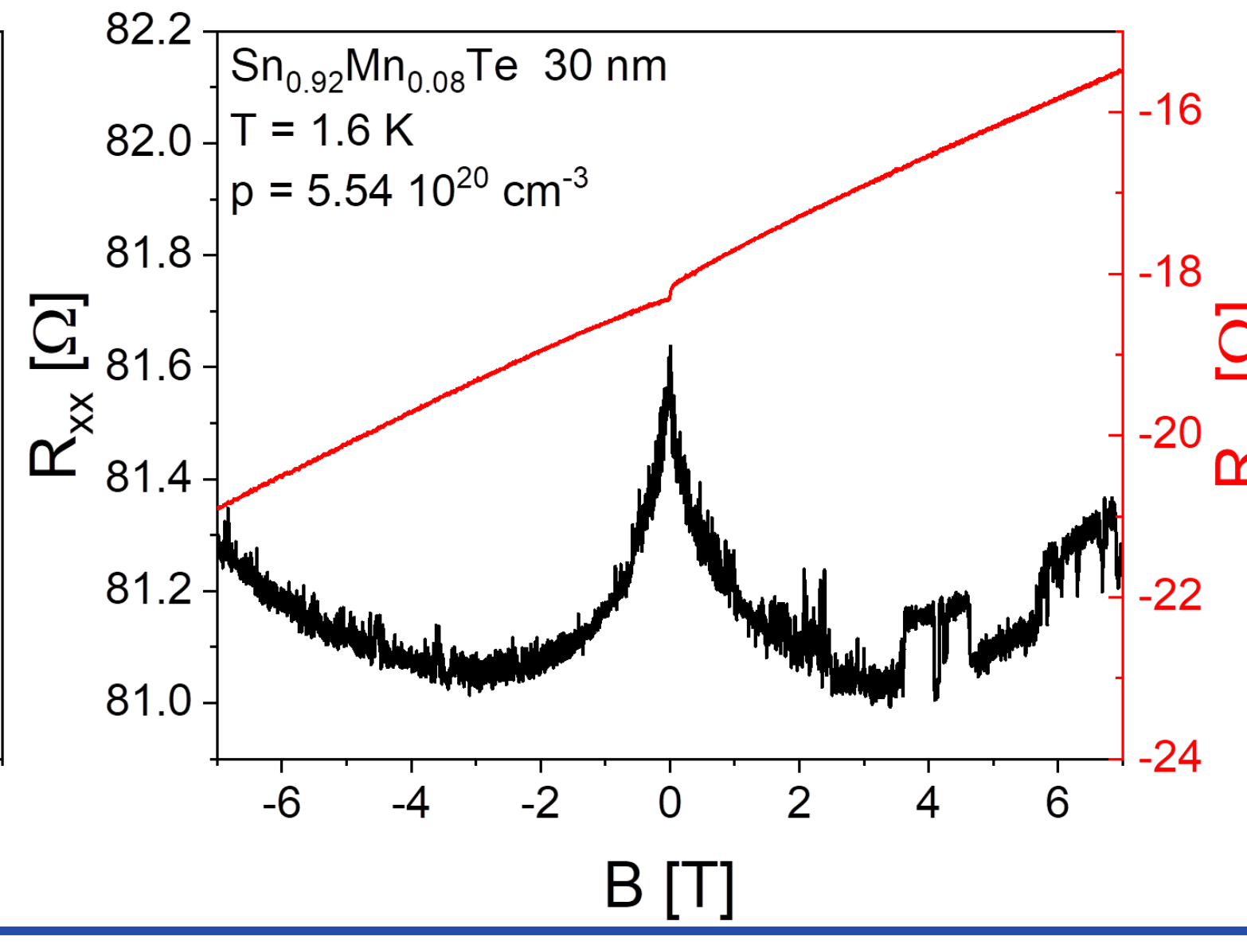


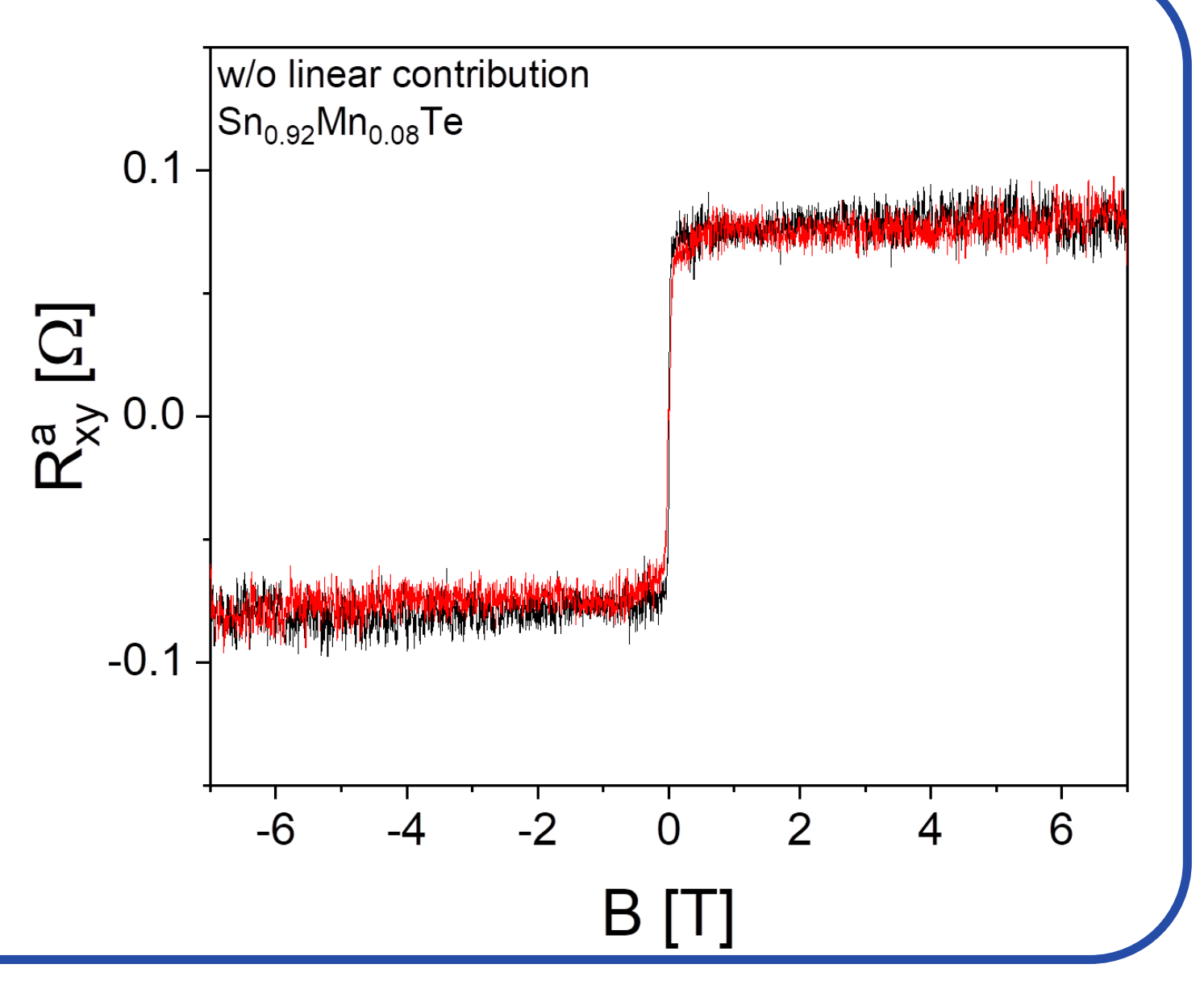




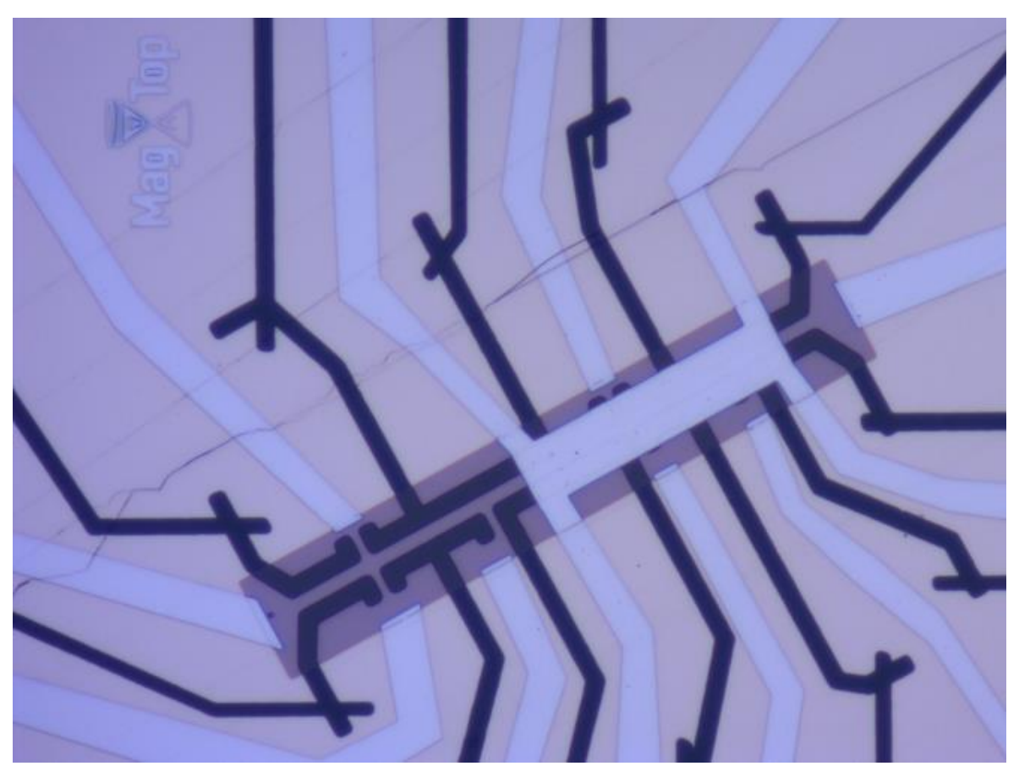
Characterization of the material before the processing







Processing (EBL):

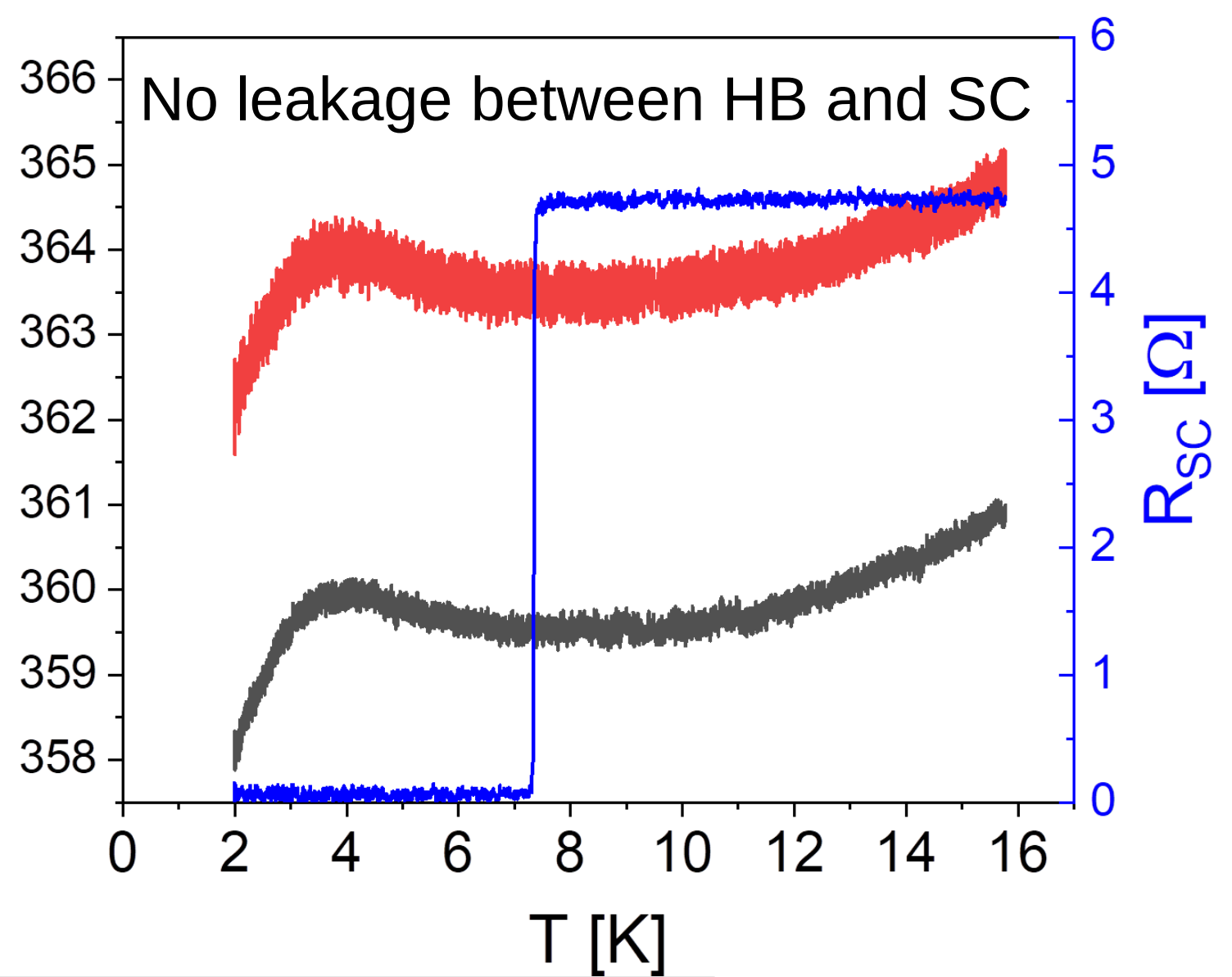


2 sections in a Hallbar allow comparison between AHE affected by the presence of a SC and undisturbed AHE

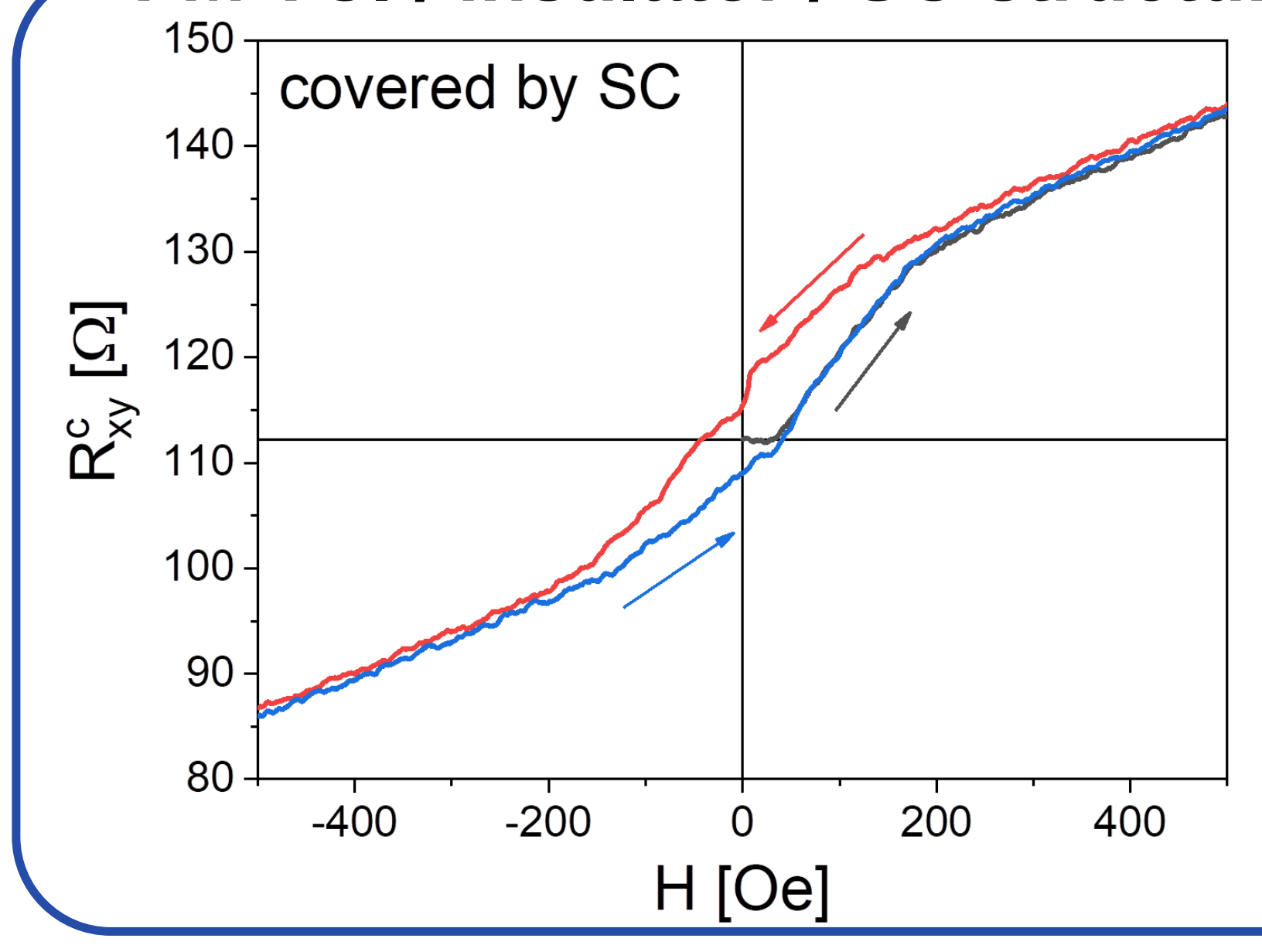
5-step device processing:

1. Position marks
2. Mesa etching (wet etching)
3. SiON insulator growth
4. Nb deposition
5. Outer mesa etch

Resulting structure:
30/30/50 nm SnMnTe/SiON/Nb



FM TCI / insulator / SC structure



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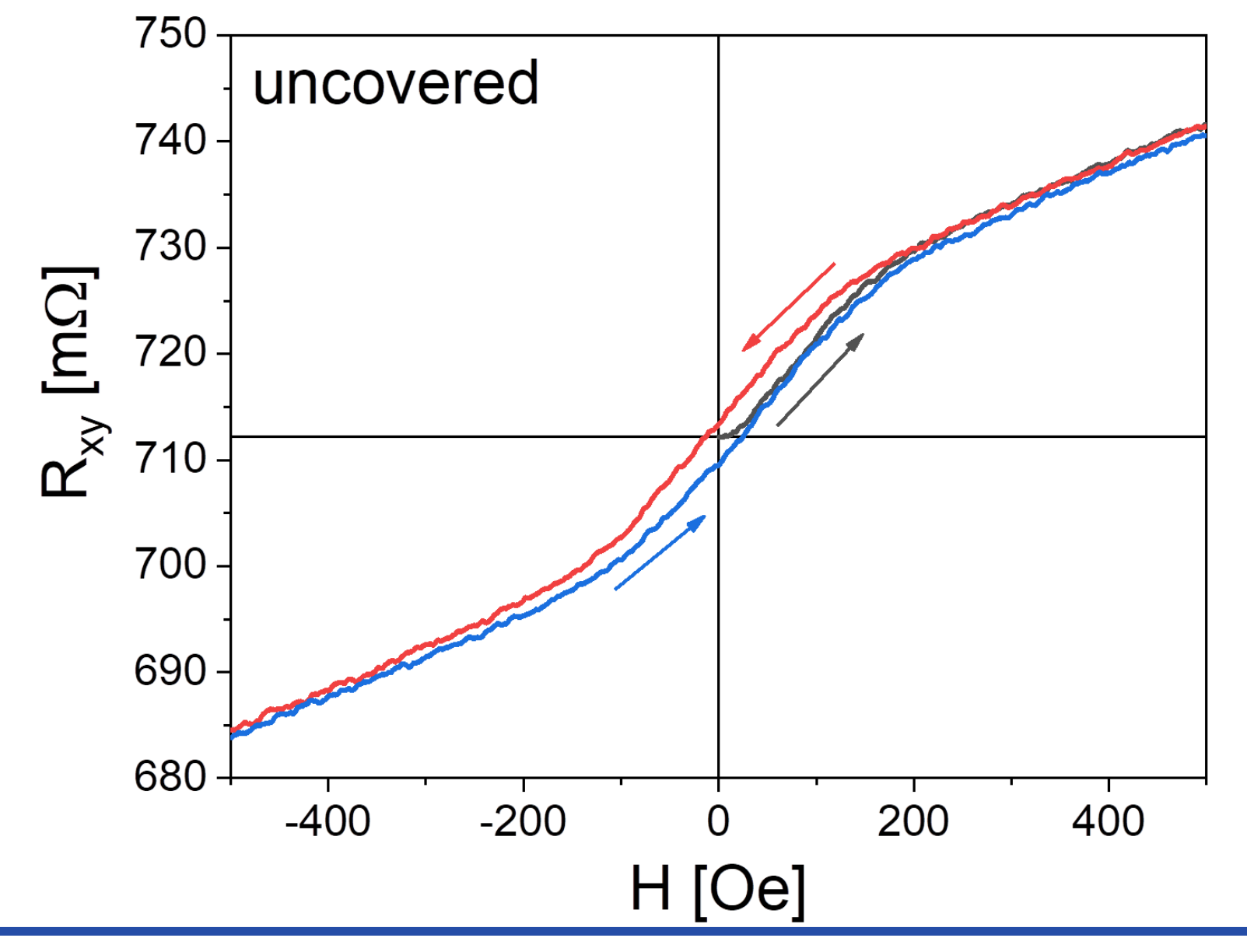

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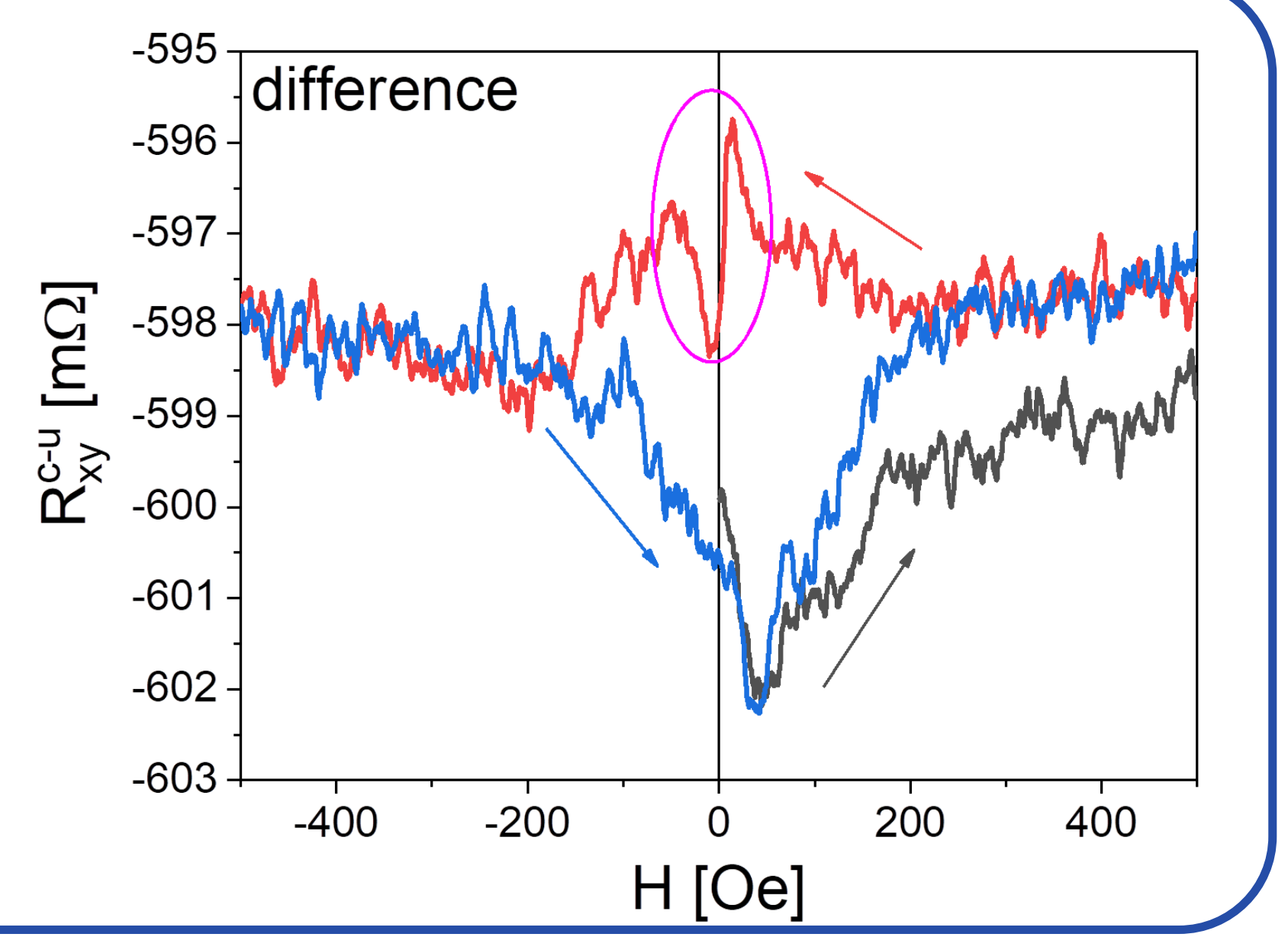
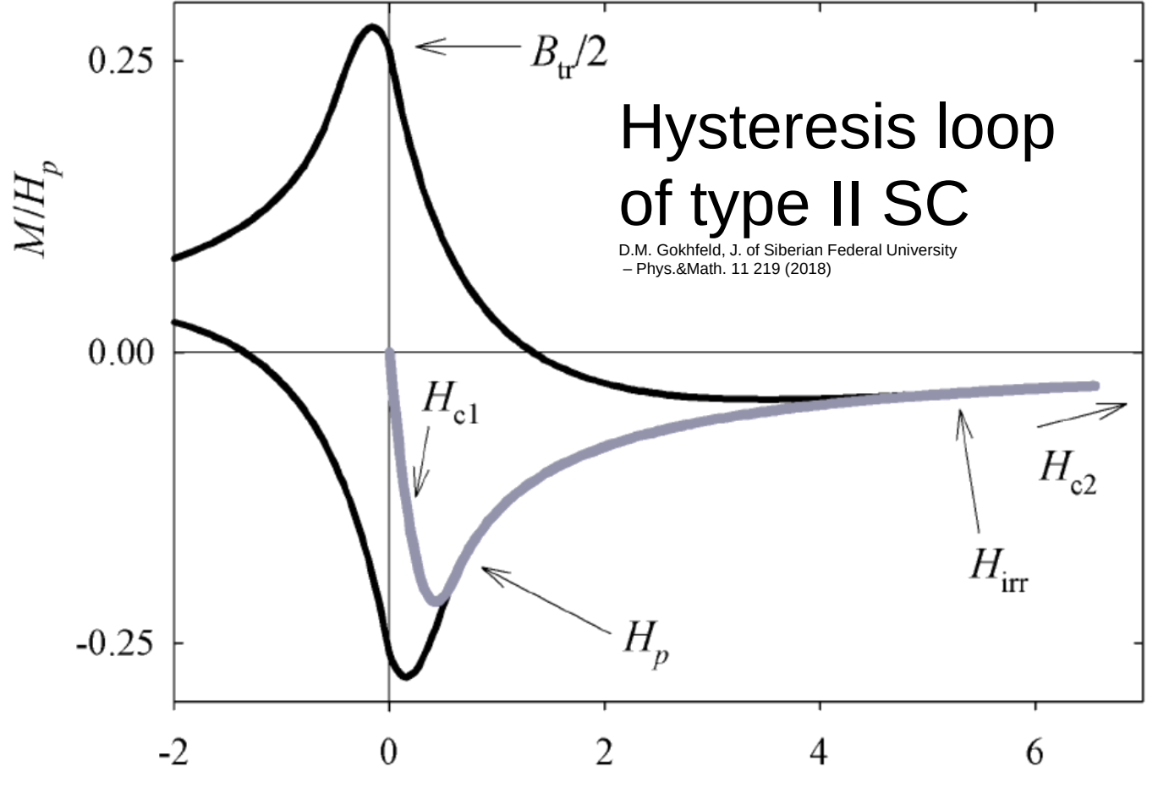


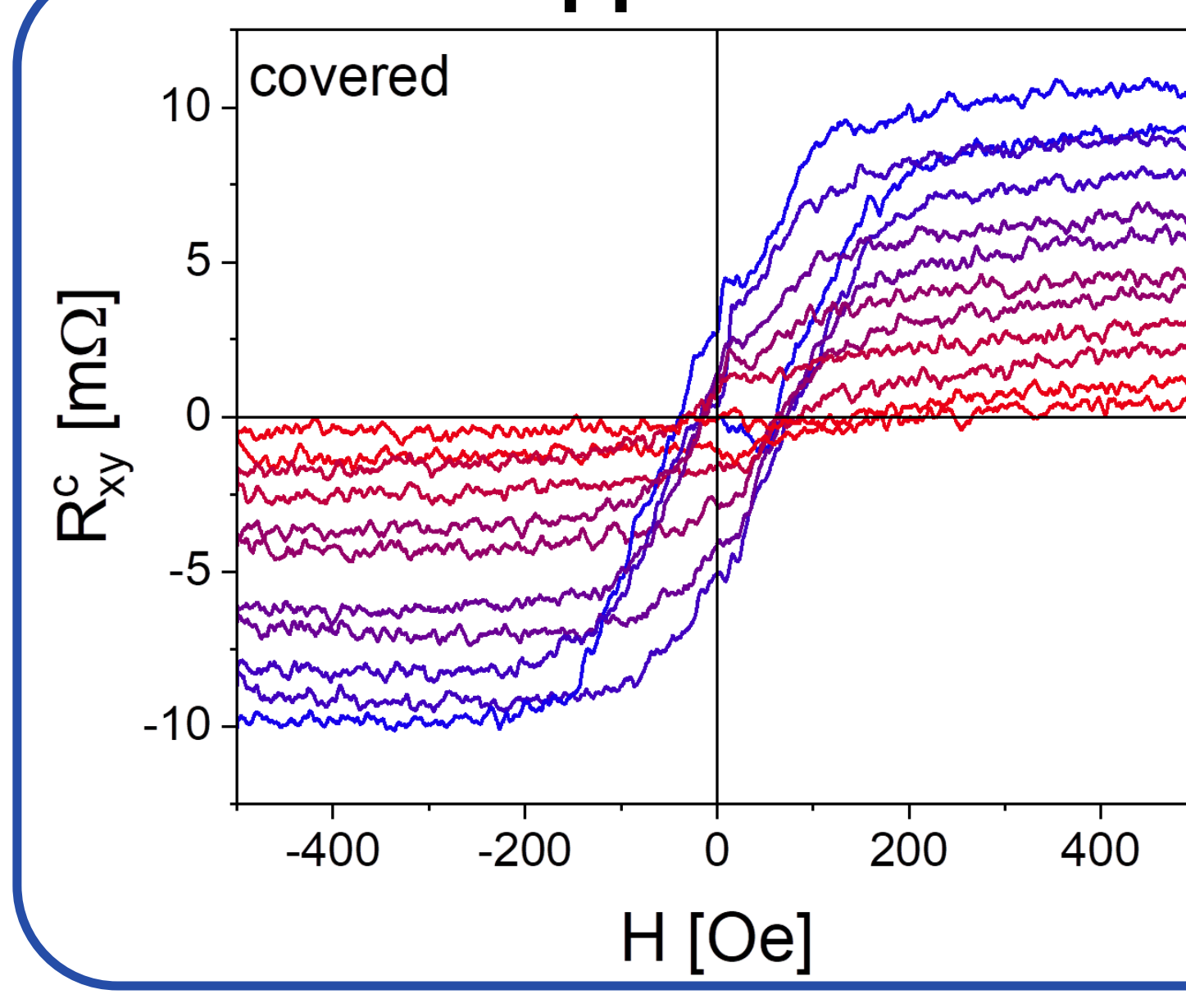


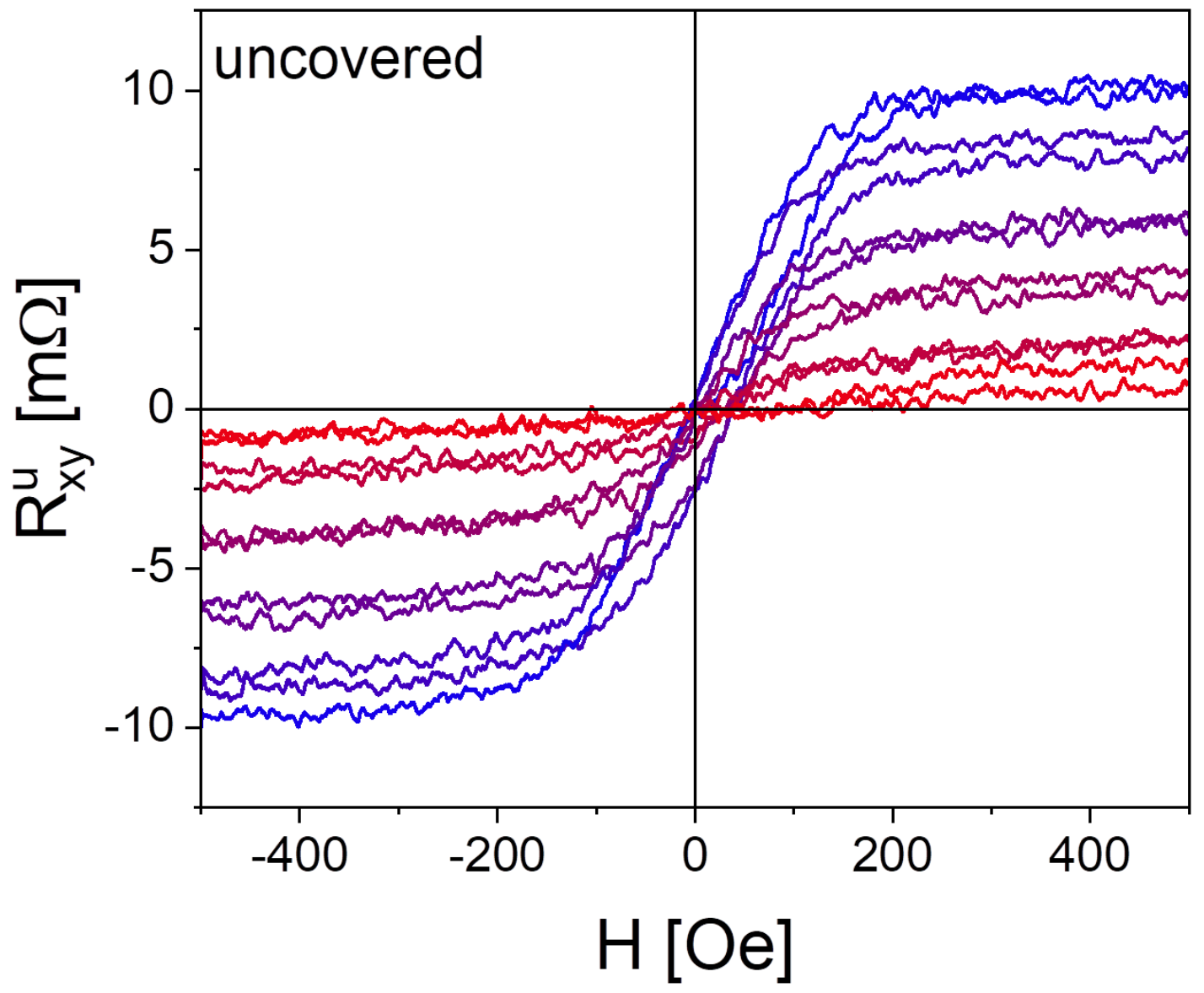
Hysteresis loop of type II SC

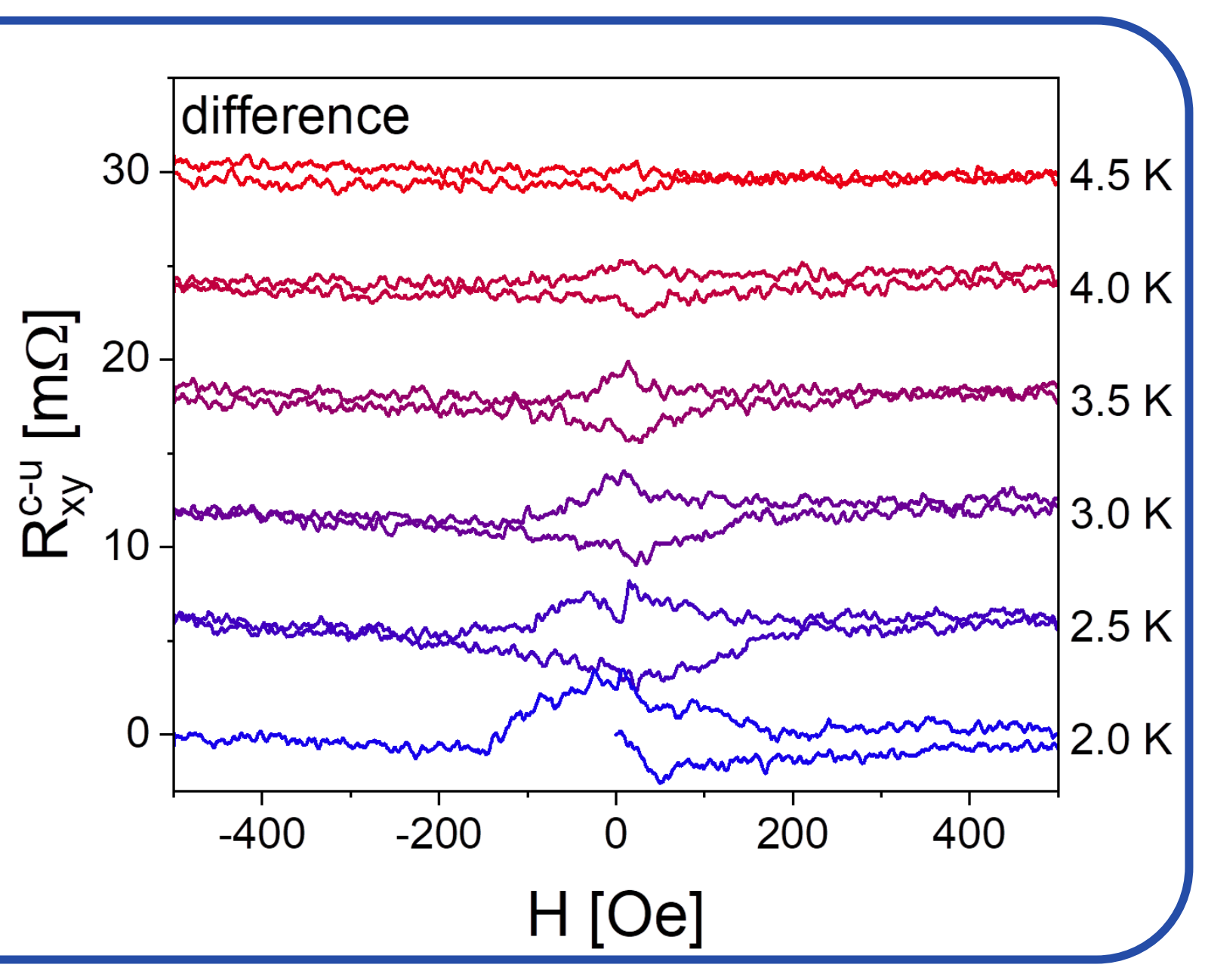
D.M. Gokhfeld, J. of Siberian Federal University – Phys.&Math. 11 219 (2018)

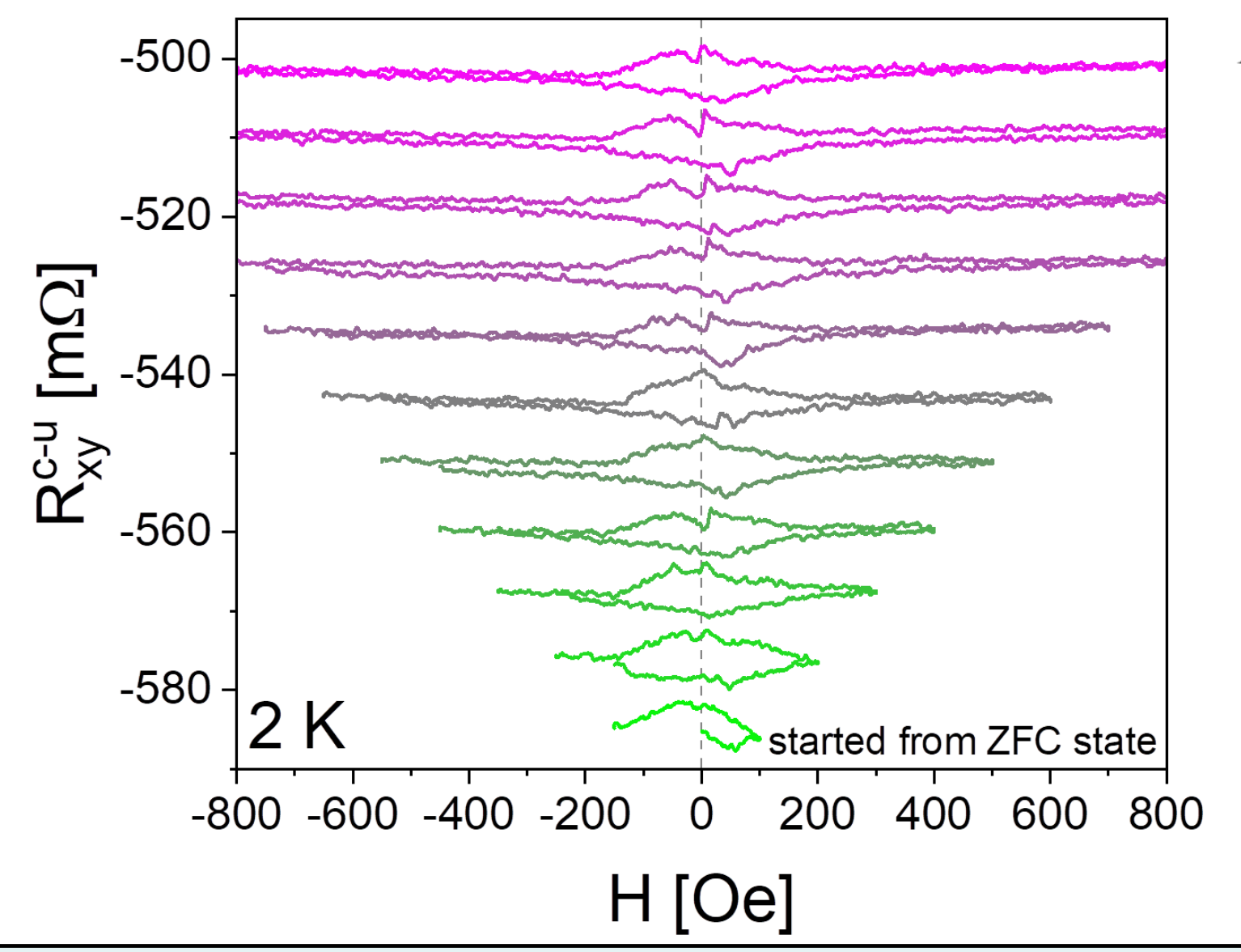
Meissner effect causes wider AHE hysteresis

Effect disappears with FM T_C









History dependence

Sometimes we see dips/peaks near 0 Oe, sometimes not. Possible mechanism – THE due to formation of non-uniform magnetization, similar to skyrmionic systems

Main results

☐ First attempt to study electron transport in DMS under periodic field modulation created by a SC

☐ Clear effect of the Meissner state on AHE behavior in the DMS layer

☐ Signatures of the vortex lattice effect on the AHE behavior in the DMS layer

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