Geneva

EUCAS 2017

Sep 19, 2017

Magneto-optical imaging of AC-susceptibility in superconducting thin films

Wilson A. Ortiz

Departamento de Física
Universidade Federal de São Carlos

wortiz@df.ufscar.br

Maycon Motta

José Claudio Corsaletti-Filho

Fabiano Colauto

Tom Henning Johanson

University of Oslo, Norway

Alejandro V. Silhanek

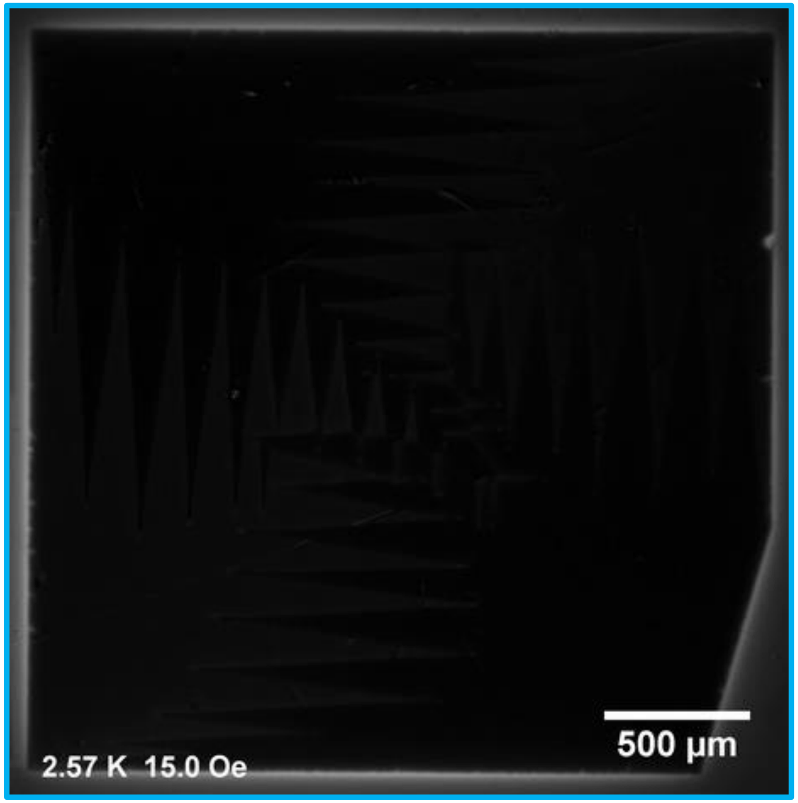
Universitè de Liège, Belgium

Jo Cuppens, Joris Van de Vondel,
Victor V. Moshchalkov

Katholieke Univeersiteit Leuven , Belgium

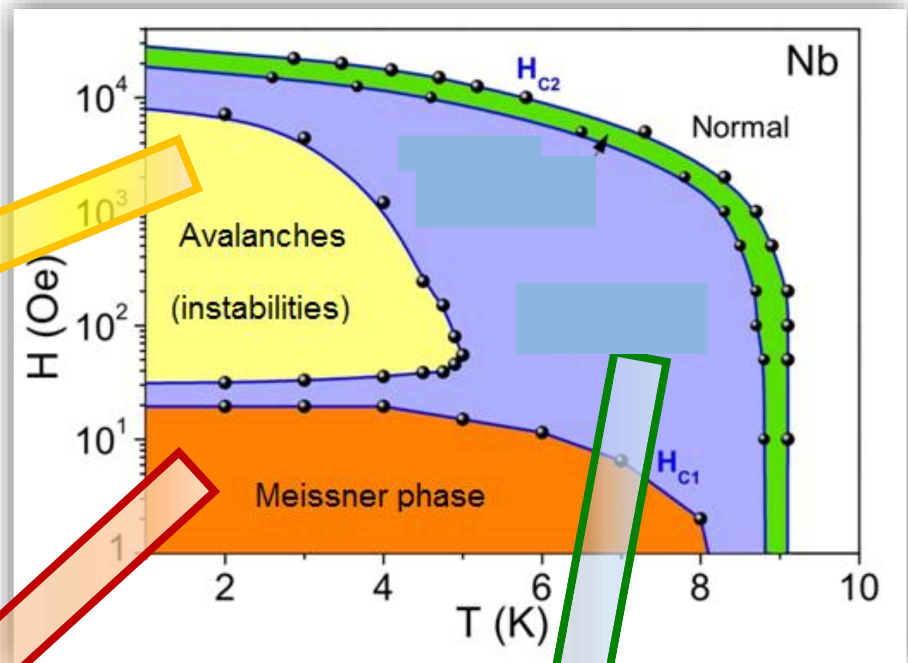
Facts

Under certain conditions of temperature and magnetic field, flux avalanches of dendritic form develop into superconducting films, as a consequence of thermomagnetic instabilities (TMI);

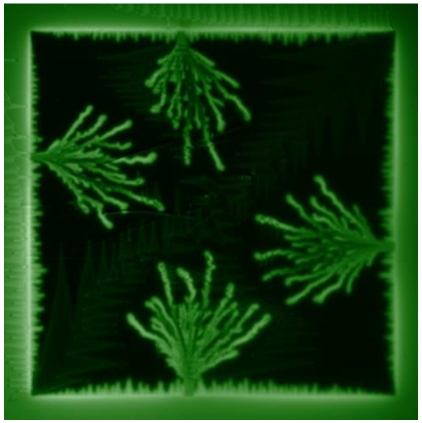


Nb film

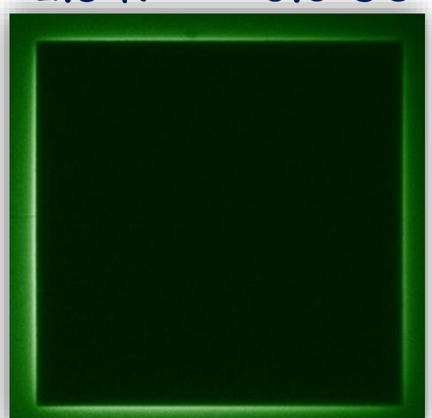
HT-diagram



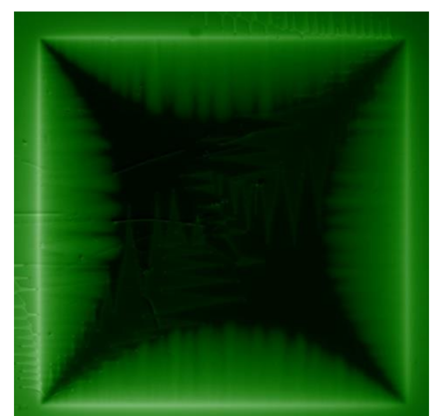
4.0 K 36.5 Oe



2.5 K 3.0 Oe



6.0 K 48.0 Oe



Flux avalanches are detrimental for current transport...

… yet, they are controllable

APPLIED PHYSICS LETTERS **96**, 092512 (2010)

Suppression of flux avalanches in superconducting films by electromagnetic braking

F. Colauto,[1] E. Choi,[2] J. Y. Lee,[2] S. I. Lee,[3] E. J. Patiño,[4,5] M. G. Blamire,[5] T. H. Johansen,[6] and W. A. Ortiz[1,a)]
[1]*Departamento de Física, Universidade Federal de São Carlos, São Carlos, 13565-905 São Paulo, Brazil*
[2]*Department of Physics, Pohang University of Science and Technology, Pohang 790-784, Republic of Korea*
[3]*National Creative Research Initiative Center for Superconductivity and Department of Physics, Sogang University, Seoul 121-742, Republic of Korea*
[4]*Departamento de Física, Universidad de los Andes, Bogota, DC, Colombia*
[5]*Department of Materials Science, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, United Kingdom*
[6]*Department of Physics, University of Oslo, POB 1048, Blindern, 0316 Oslo, Norway*

(Received 9 February 2010; accepted 10 February 2010; published online 4 March 2010)

Magnetic fields perpendicular to superconducting films often trigger vortex avalanches, which always are very harmful for electronic devices and other applications. Such avalanches can be suppressed by a metal layer placed in contact with the superconductor surface, an effect that up to now has been thought to be a consequence of improved heat conduction. Here we show experimentally that the role of the metal layer is not that of a heat-sink, but rather that of an electromagnetic drag due to eddy currents induced in the metal layer during the abrupt onset of the flux avalanches. The effect is demonstrated for films of MgB_2 and Nb. © *2010 American Institute of Physics*. [doi:10.1063/1.3350681]

APPLIED PHYSICS LETTERS **96**, 092512 (2010)

Suppression of flux avalanches in superconducting films by electromagnetic braking

F. Colauto,[1] E. Choi,[2] J. Y. Lee,[2] S. I. Lee,[3] E. J. Patiño,[4,5] M. G. Blamire,[5] T. H. Johansen,[6] and W. A. Ortiz[1,a)]

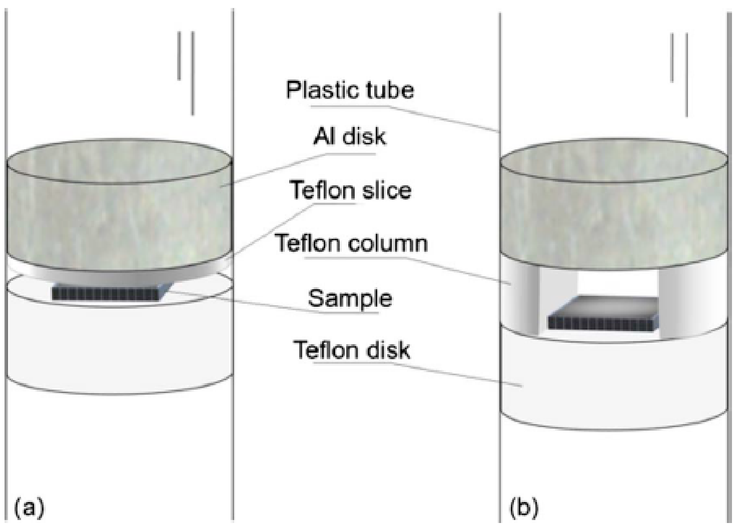


FIG. 1. (Color online) Schematic of the sample mounting with an aluminum disk kept a distance away from the superconducting film sample, which rests on a teflon disk. (a) sheet of teflon is inserted on top of the sample, (b) teflon pillars maintain a gap above the sample.

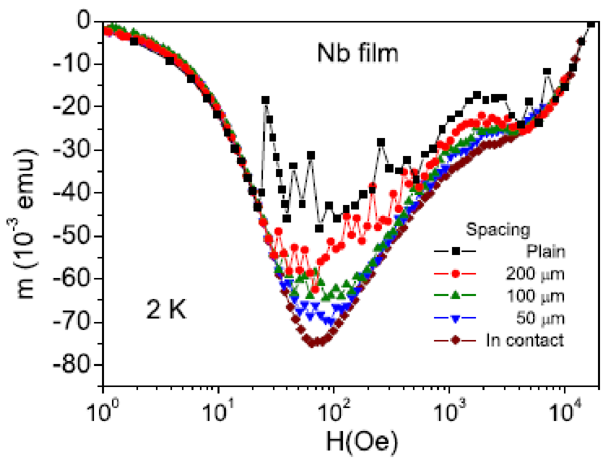
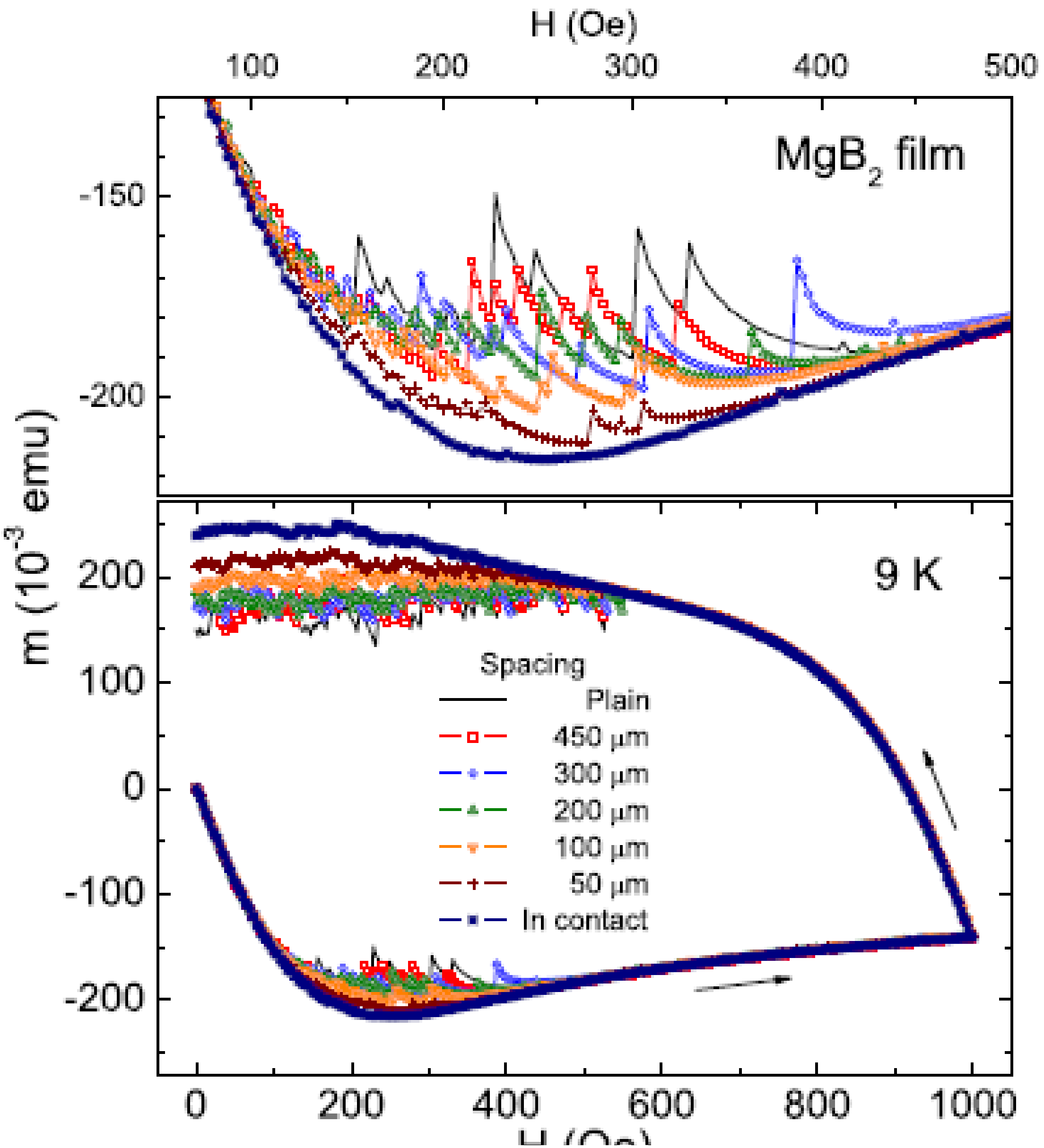


FIG. 3. (Color online) m-H curves for ascending field with the Nb sample and aluminum disk separated by different distances, showing increased suppression of jump activity the smaller their separation becomes.

iting the superconductor depending on the direction of the



Colauto *et al.* Appl. Phys. Lett. **96**, 092512 (2010)

Flux avalanches involve rich vortex physics

➔ although detrimental for applications, one is naturally tempted to unravel this beautiful behavior of Vortex Matter

Flux avalanches are also triggered by AC fields (even in the absence of DC fields)

→ What's the signature?

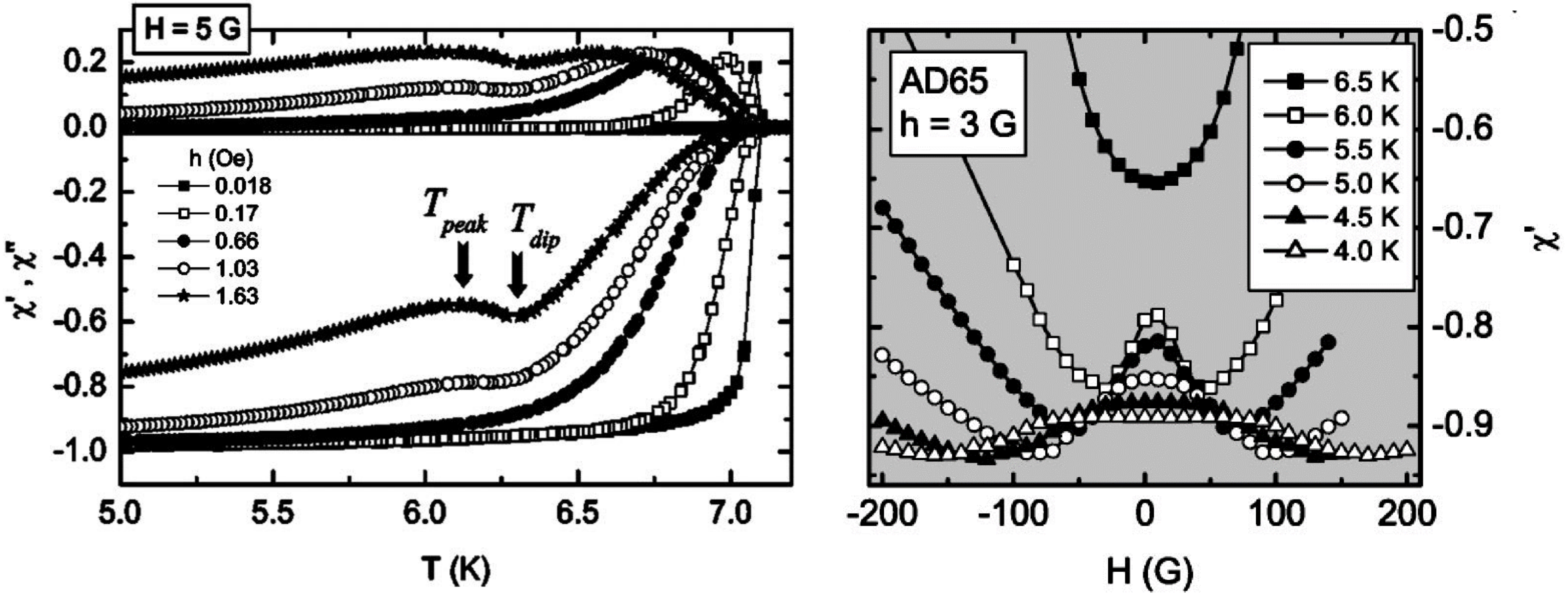
Signature of flux avalanches in χ_{AC} mesaurements

Reentrance in χ(T) and χ(H) curves

Pb plain films

Pb with ADs

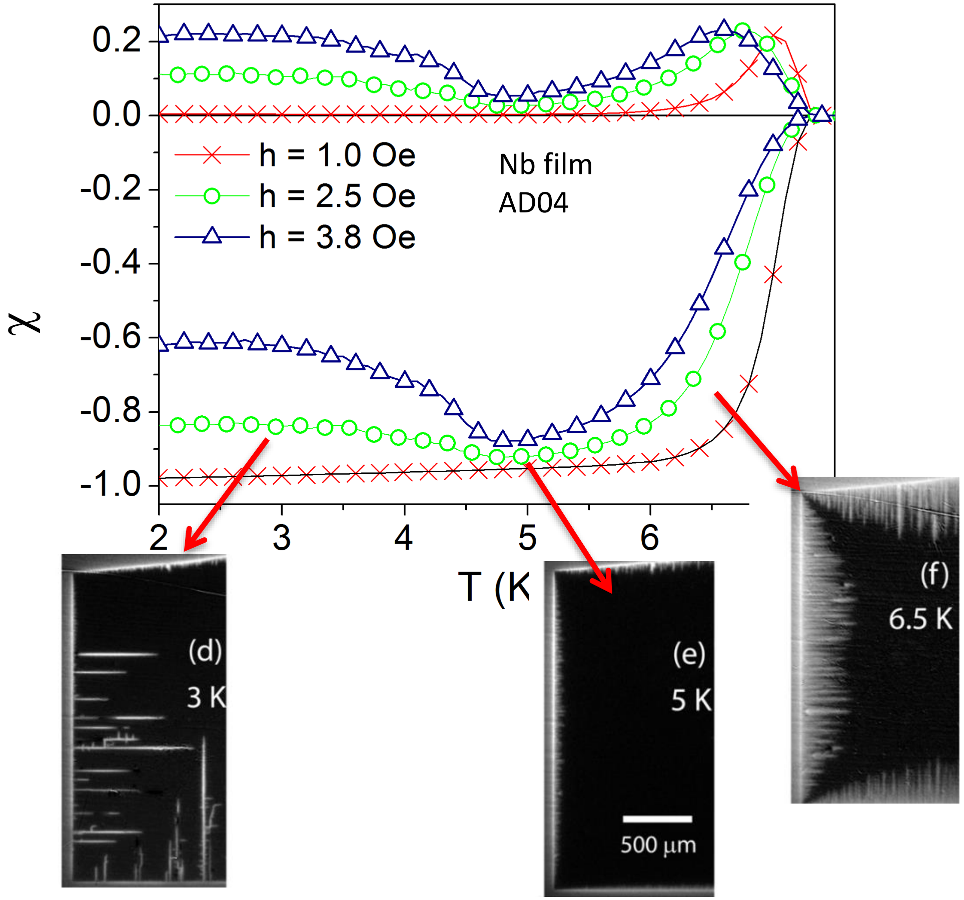
Lattice = 1.5 μm – AD size = 0.8 μm



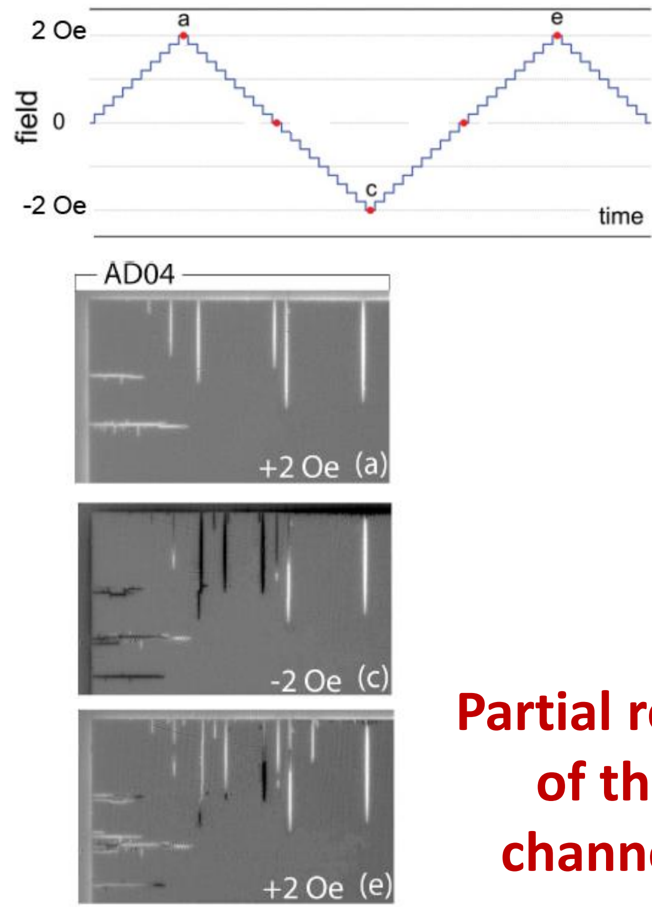
A. V. Silhanek, S. Raedts, and V. V. Moshchalkov, Phys. Rev. B 70, 144504 (2004).

Flux avalanches signature

Paramagnetic reentrance



AC field emulated by DC field



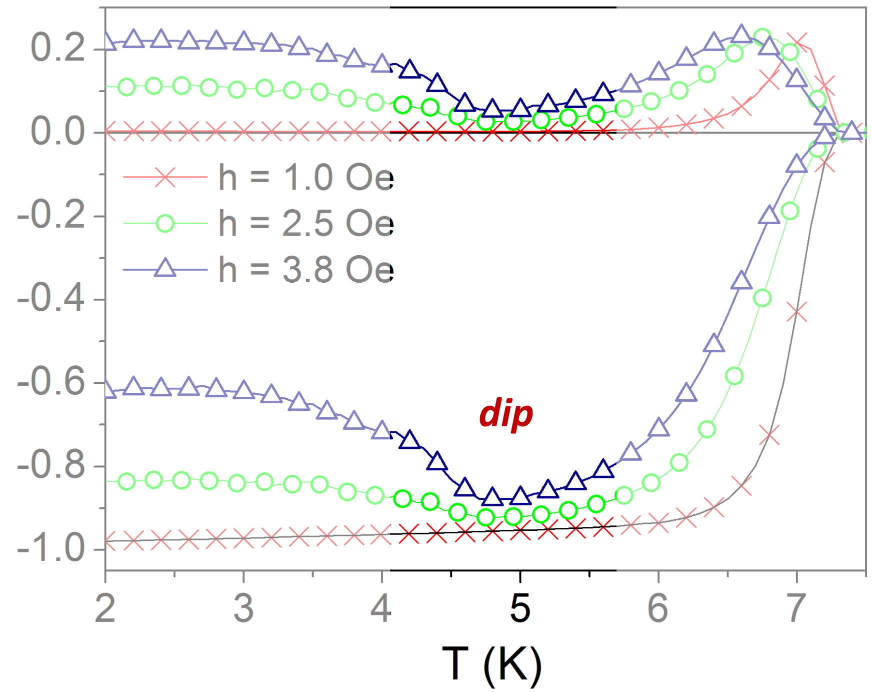
Partial reuse of the channels

The reentrance is intimately associated with the occurrence

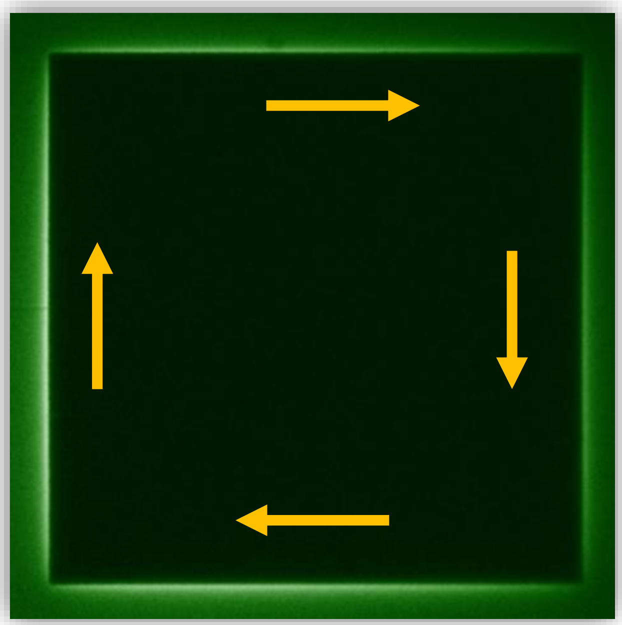
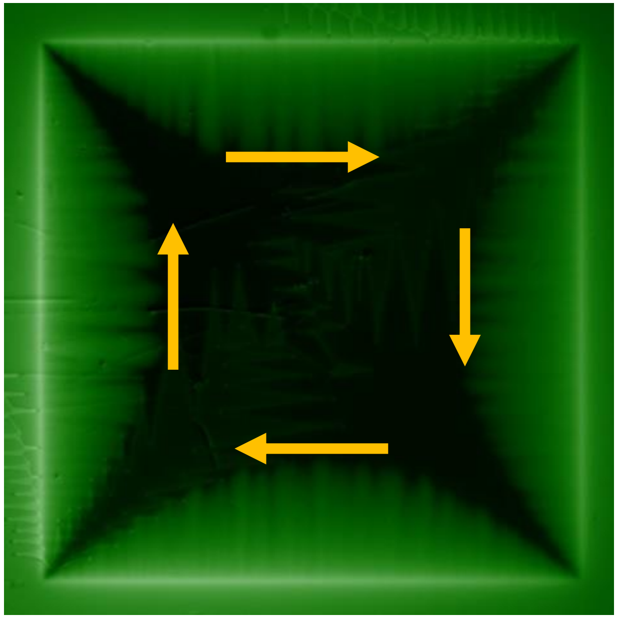
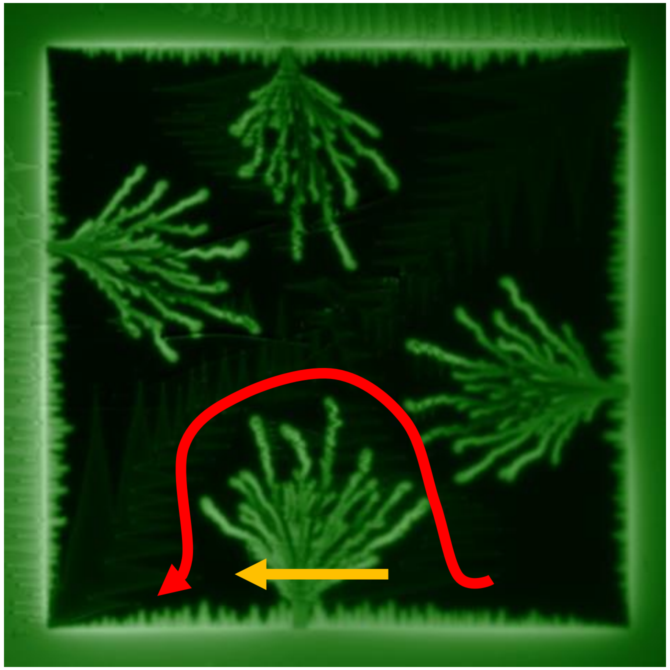
M. Motta, F. Colauto, R. Zadorosny, T.H. Johansen, R.B. Dinner, M.G. Blamire, G.W. Ataklti, V.V. Moshchalkov, A.V. Silhanek, W.A. Ortiz, Phys. Rev. B 84 (2011) 214529.

Motivation

Why is there an increase in $|\chi'|$ while χ'' decreases around T_{dip}?



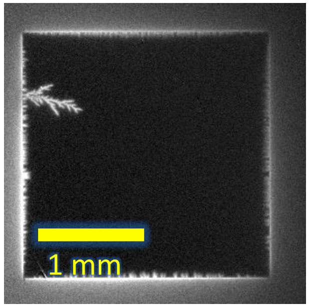
Why are the AC susceptibility versus temperature curves independent of the magnetic history?

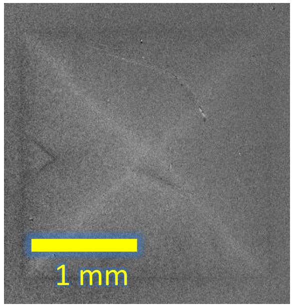
Sample details and methods

Samples:

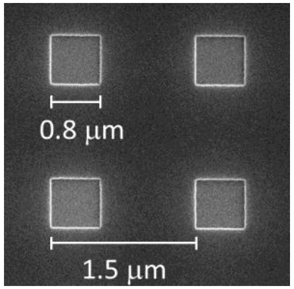
- Amorphous plain MoSi film (t = 100 nm):
  - 2.5 x 2.5 mm^2;
  - T_c = 7.2 K;
  - T* ≈ 3.9 K.
- a-MoGe film (t = 25 nm) decorated with a square lattice with 1.5 µm of square ADs of 0.8 µm (AD08):
  - 5 x 5 mm^2;
  - T_c = 6.6 K;
  - T* ≈ 5.0 K.



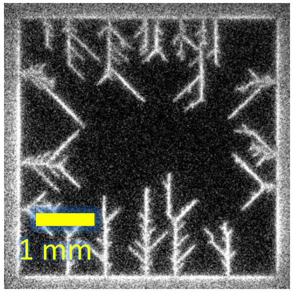
T = 2.7 K, H = 2.0 Oe



T = 6.5 K, H = 0.2 Oe (after 2.4 Oe)



Optical image: AD lattice



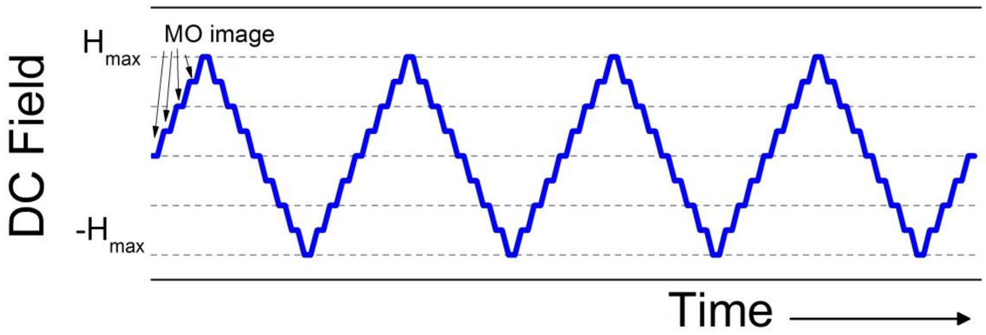
T = 2.5 K, H = 0.7 Oe

Measurements:

- SQUID MPMS-5S (Quantum Design)
- Magneto-optical Imaging (MOI) based on the Faraday effect;

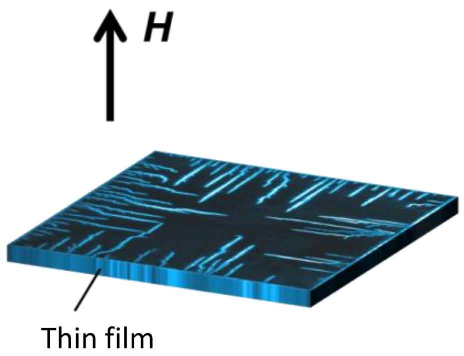
Sample details and methods

Emulating an AC field in the MOI setup:

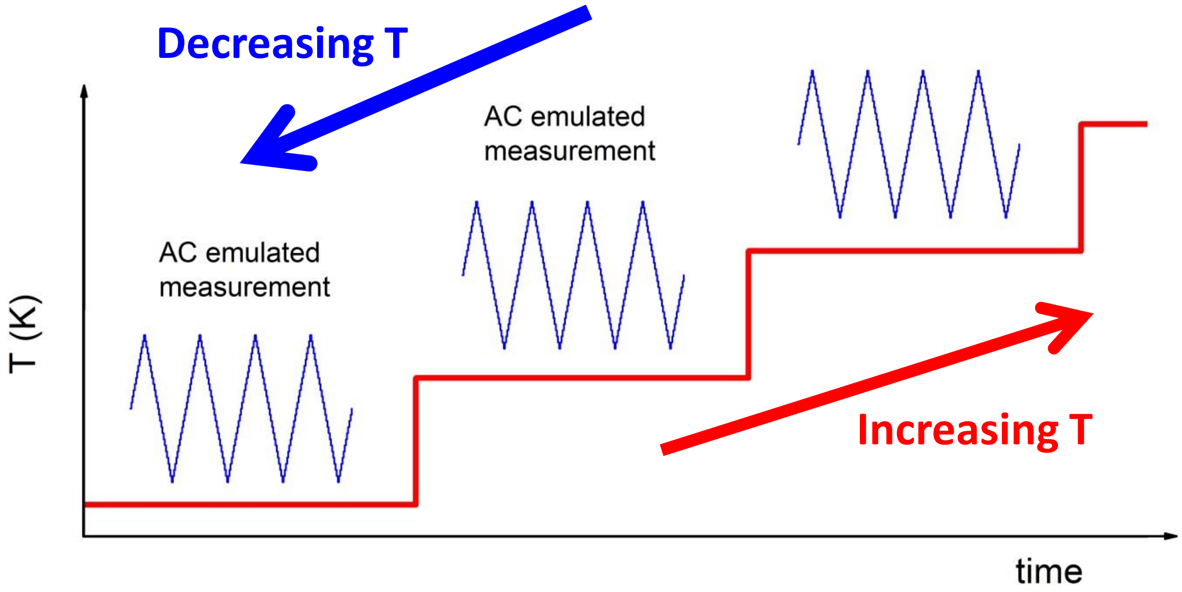


Frequency ≈ 0.05 Hz
Exposure times ≈ 0.2 s

50 steps/period



Measurements in MOI setup:

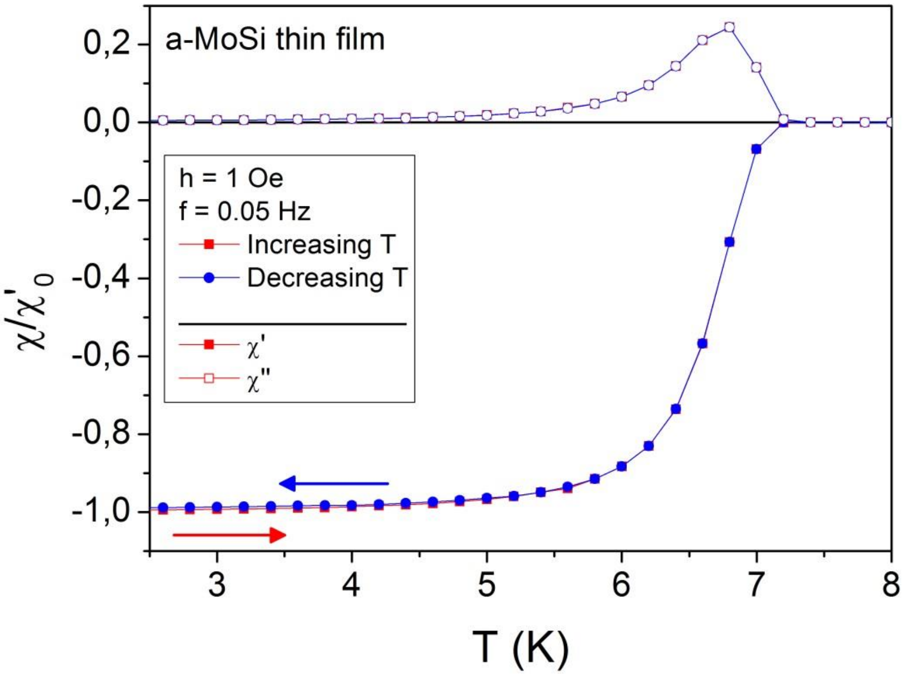


Temperatures:

2.7 K, 3 K, 3.5 K, 4.0 K, 5.0 K, 5.5 K, 6.0 K, 6.5 K.

AC Susceptibility measurements – no avalanches

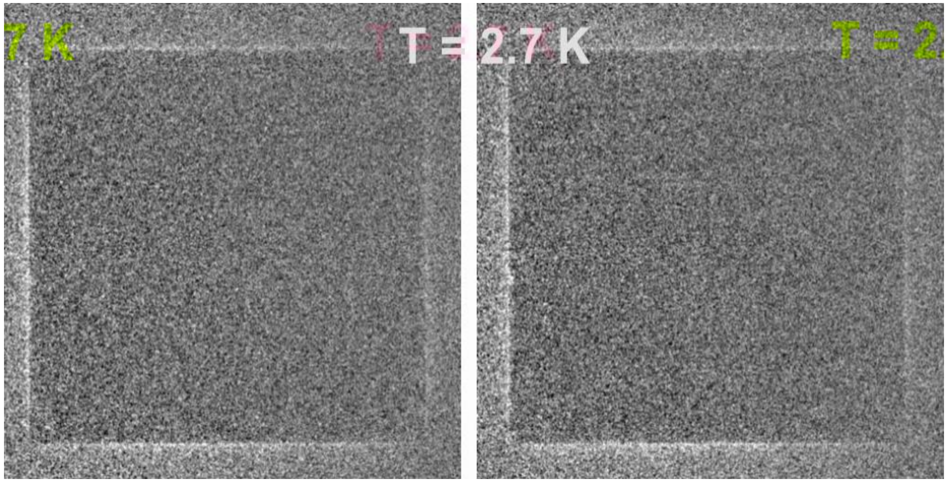
SQUID (h = 1 Oe, 4 cycles/measurement)



MOI (4 cycles)

Increasing temperature

Decreasing temperature



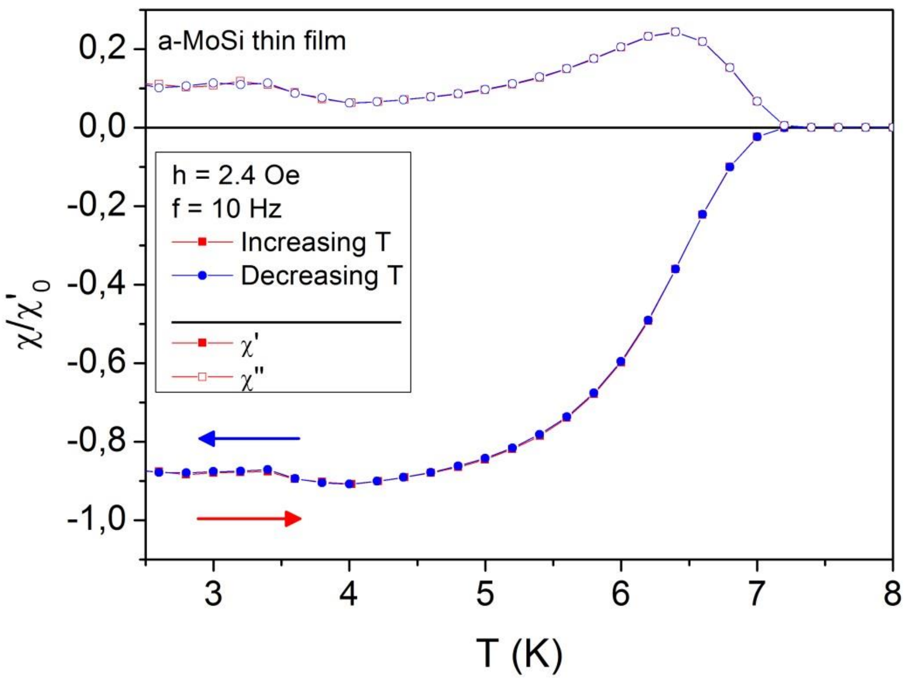
Differential Image
Img(x+1) – Img(x)

Differential Image
Img(x+1) – Img(x)

Although the magnetic history is different, the differential images are so equal that one cannot tell if T was approached from above or below

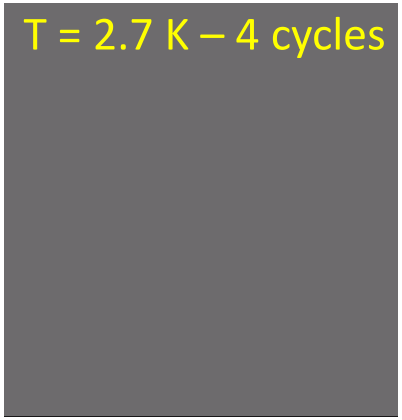
Flux avalanches: reusing channels

SQUID measurements (h = 2.4 Oe):



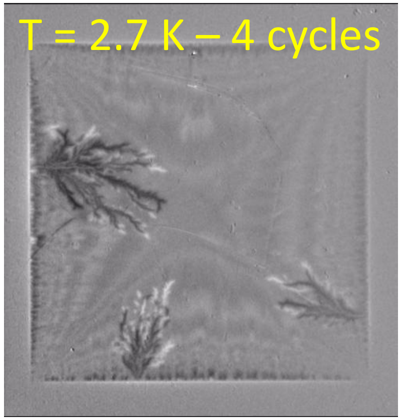
Virtually all channels are reused

Increasing temperature

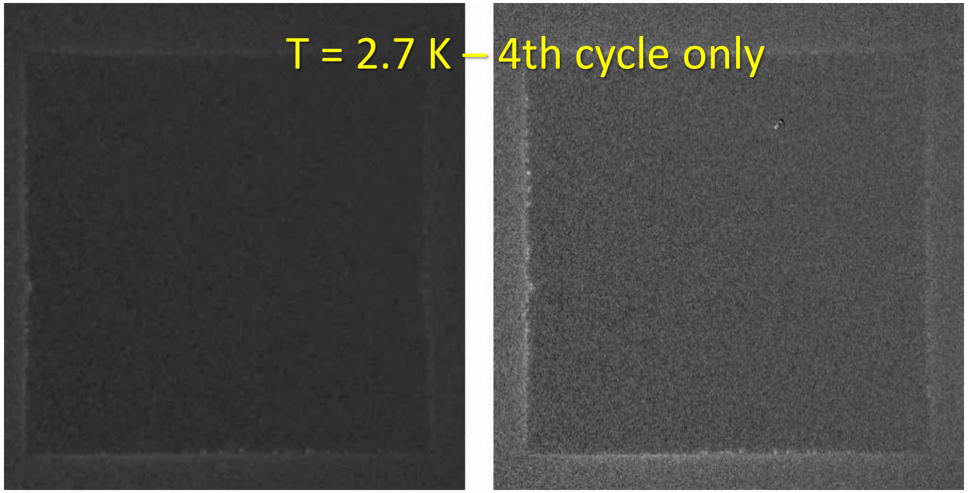


Img(x) – Background_Garnet

Decreasing temperature



Img(x) – Background_Garnet



Differential Image

Differential Image

MOI and AC Susceptibility: quantitative

Considering:

$$\frac{\partial \boldsymbol{B}}{\partial \boldsymbol{H}} = \mu_0(1+\chi)$$

Approximation:

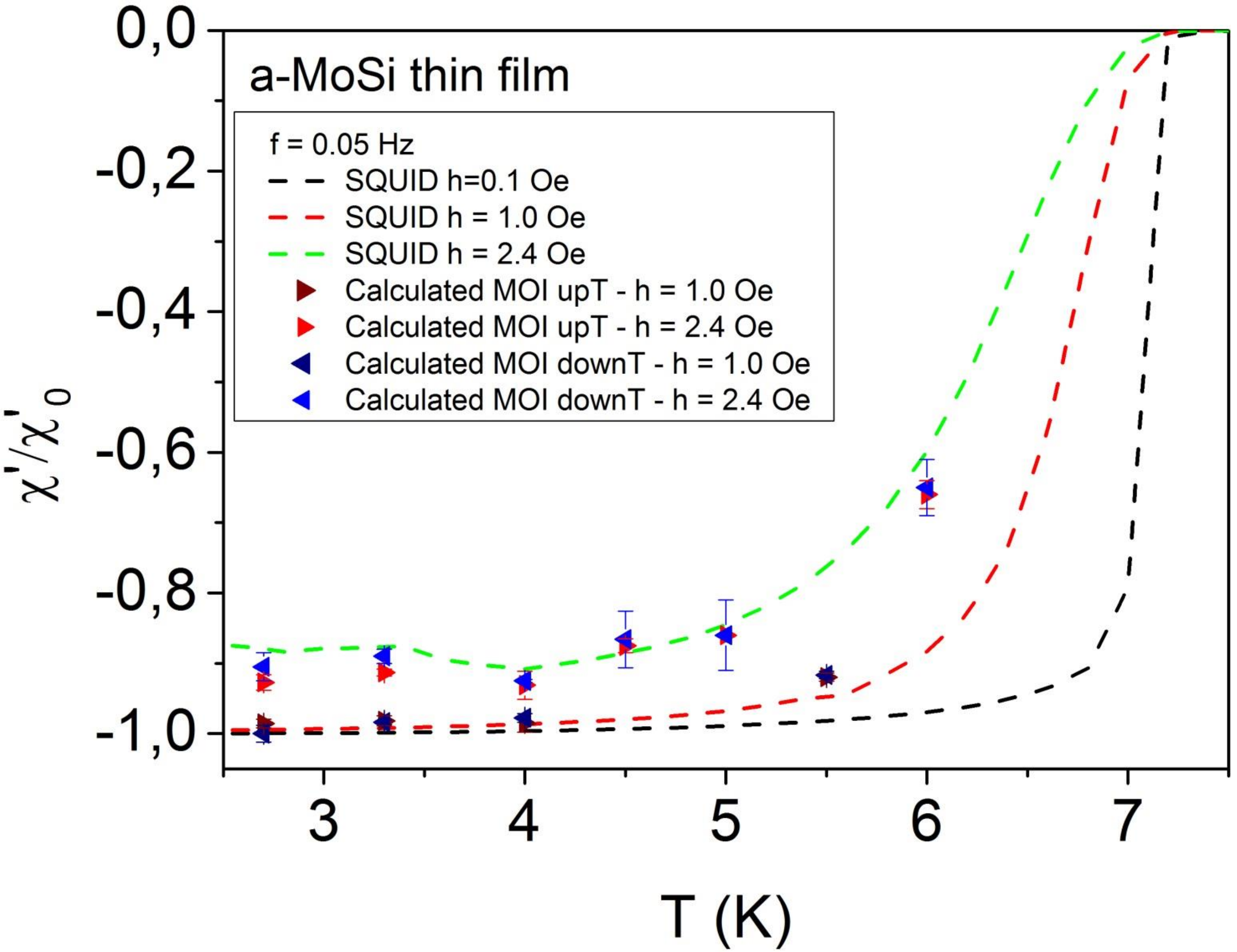
$$\frac{\partial \boldsymbol{B}}{\partial \boldsymbol{H}} \approx \frac{\Delta B}{\Delta H} \approx \mu_0 C \frac{\Delta I}{\Delta H}$$

$\Delta I \rightarrow$ light intensity (differential) in grayscale, averaged over the sample during 4 cycles

Thus:

$$\chi' = C\frac{\Delta I}{\Delta H} - 1$$

C calibrated at the Meissner phase



Final Remarks

- AC susceptibility measurements were emulated and visualized by using of Differential MOI (*d-MOI*);
- *d-MOI* shows that most of the channels are reused ➔ the screening currents reorient themselves at every cancellation, and the effect of flux avalanches on the AC-susceptibility is virtually the same for T approached from above or below;
- The features studied here for plain films are also manifested in samples with arrays of ADs;
- The in-phase component of the *AC* susceptibility was calculated from Differential MOI, showing good agreement with the results coming from SQUID measurements.