Classical analogy for the deflection of flux avalanches by a metallic layer

Alejandro V. Silhanek

Experimental physics of nanostructured materials
Physics Department, University of Liège
BELGIUM
Collaborators

J Brisbois, O-A Adami, J. Avila, B Vanderheyden, N D Nguyen *Université de Liège, BE*

F Colauto, M Motta, W A Ortiz, *Universidade Federal de Saõ Carlos, BR*

J Van de Vondel, V V Moshchalkov, *KULeuven, BE*
Magnetic flux avalanches

Adiabatic conditions, $\Delta T = Q/C(T)$

$v > 10 \text{ km/s} > \text{sound velocity 3 km/s}$

$v_{\text{Abrikosov}} << 1 \text{ km/ s}$

$v_{\text{kinematics}} \sim 1 - 10 \text{ km/ s}$

Cu coating of superconducting wires

Better stability by reducing the speed of penetration of the flux jump

Thermal sink

Quench protection

Magnetic braking of vortices in semiconductor/superconductor hybrids

“significant additional damping of vortex motion caused by the eddy currents generated in the 2D electron gas”

\[
\frac{F_D}{v} = \eta_T = \eta_{SC} + \eta_{2DEG} \approx \eta_{SC} + \frac{\sigma_{2DEG}}{\sigma_n d}
\]
Deflection of flux avalanches

- The gold capping reduces the velocity $v$ of the avalanches.
- Change of propagation direction depending on the incident angle.

Open questions

✓ Is there a refraction like behavior of avalanches?

✓ Is the extra vortex damping produced by the metallic layer constant? \( \frac{F_D}{v} = \eta_{SC} + \eta_{metal} \)

✓ Can a single vortex also undergo deflection when entering the region covered by the metallic layer?

✓ Does the metallic layer influences the vortex flow at lower velocities?
Avalanche exclusion

- No thermal shunt at the nucleation point of the avalanches
- Exclusion of flux avalanches by the Cu layer
- In the smooth (critical state) flux penetration regime, there is no difference between the sample with or without the Cu triangle
Avalanche exclusion
Classical model

Brisbois et al., New Journal of Physics 16 (2014) 103003
Eddy currents and image method

A magnetic dipole suddenly appears over a conducting plane.
Eddy currents and image method

\[ v \Delta t \]

\[ w \Delta t \]

\[ m \]

\[ \rho \]

\[ w \propto \rho \]
Classical model

High velocity

Low velocity

$w \propto \rho$

Classical model

\[ F_D = \frac{\mu_0 q^2}{16 \pi z_0^2} \frac{w}{v} \left( 1 - \frac{w}{\sqrt{v^2 + w^2}} \right) \]

\[ \frac{F_{LO}}{v} = \frac{\eta}{1 + \left( \frac{v}{v^*} \right)^2} \]

\( \sim 0.1 \text{ km/s} \)

\( \sim 1 \text{ km/s} \)
\[
F_{\text{lat}} = -C_m \left( \frac{1}{y^2 + z_0^2} + \frac{y}{(y^2 + z_0^2)^{3/2}} \right) \hat{y}.
\]
Vortex trajectories

Brisbois et al., New Journal of Physics 16 (2014) 103003
Damping of ratchet motion

\[ \eta \nu = (J - J_c) \Phi_0 \]

Adami et al., unpublished.
Conclusion

- We are able to explain in classical terms the deflection of magnetic flux by a conducting layer.
- Our classical analogy suggests a non-monotonous $F_D(v)$ relation.
- Typical MOI experiments need an Al mirror of about 100nm. Does this mirror influence the measurements? and the cold finger?
- The metallic layer affects the effective vortex ratchet.
- Next step: what about replacing the Cu layer by a superconducting film?
Thank you