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Characterization and optimization of thin films using local magnetometer.

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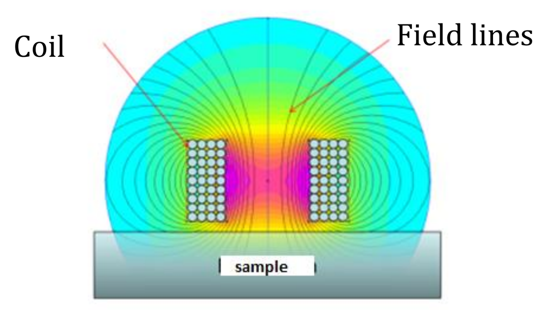
Nanometric ($d<\lambda_L$), superconducting multilayers have been proposed to increase the maximum accelerating field of Nb RF cavities because of their high $H_{C1} > H_{C1}^{Nb}$ [1]. Measuring H_{C1} on samples is not straightforward. ***One tool able to measure directly H_{c1} is a local magnetometer*** *as being developed at CEA, Saclay. The sample to be measured should be larger than the coil, thus the sample acts as an infinite plane for the coil allowing to neglect the edge and demagnetizing effect .**The transition is measured via 3rd harmonic analysis** using a Lock-In amplifier.*

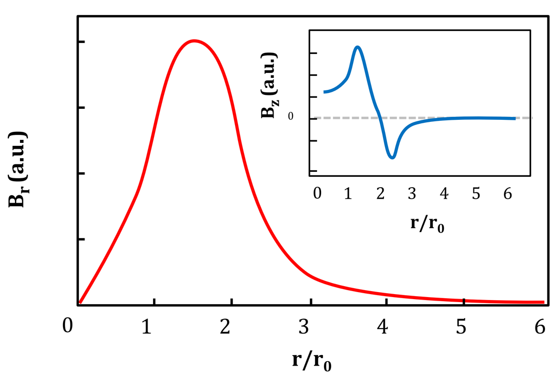
Why the need of local magnetometer

- Conventional Magnetometer (SQUID) give ambiguous results for very thin samples because of demagnetization effects (field on the back and sides, alignment issues)
- With Squid measurement, the samples exhibit a strong transverse moment, due to misalignment, which is sufficient to let vortices enter the material.
- Exact field configuration not known (applied uniform field + remnant perpendicular moment).

Local magnetometer principle

- Based on infinite slab approx. (B ~ 0 @ 5-6 mm away from the center of the sample).
- 3rd harmonic measurement of H_{C1} developed by INFM Napoli at low field and T > 4.5 K. [2,3]
- Design adapted at Saclay to approach accelerating cavities operating conditions **(T= 2-4 K, B ≥ 200 mT)**.
  - Coil able to provide 150 mT (upgrade ~ 400 mT)
  - Experiment under vacuum (thermal insulation)
  - Minimal contact b/w coil & sample (glass beads)
- A coil provides excitation field and detection of transition signal.
- If $r_{sample} > 4\, r_{coil}$: Sample ≡ infinite plate => no edge effect and demagnetization effect.





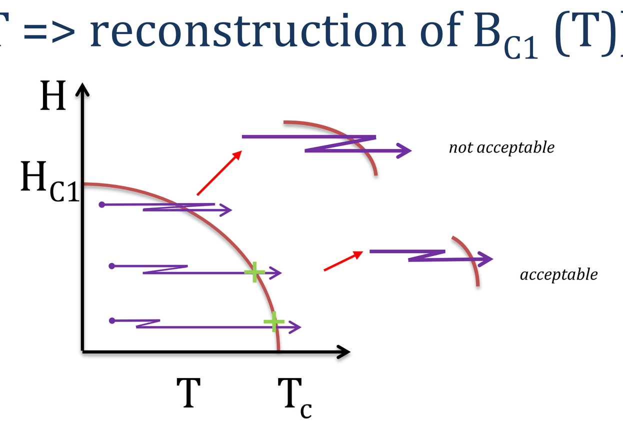
- Sample is zero field cooled @ $T<T_c$
- In Meissner state , sample = perfect magnetic mirror => no perturbation in the coil => only fundamental ω signal

Measurement techniques

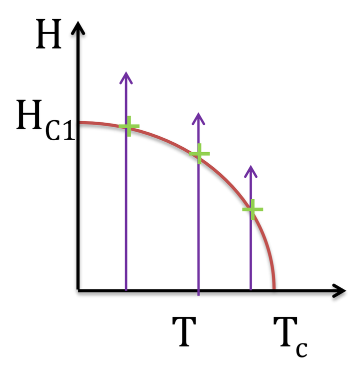
1) Initial method

- Fixed $I_0 \cos(\omega t)$ applied in the coil (field = $b_0 \cos(\omega t)$)
- Temperature ramp ($T \rightarrow T_c$)
- Third harmonic signal (3ω) appears @ T_{b0}, when b_0 reaches B_{C1} (T_{b0})
- Series of b_0 => series of transition T => reconstruction of B_{C1} (T))

Issue : thermal stabilization at high field (high current in the coil => heating + thermal inertia of cooling system)



2) New method



- Fixed temperature
- $I\cos(\omega t)$ applied in the coil (field = $b\cos(\omega t)$)
- I (B) is increased slowly in the coil
- Third harmonic signal (3ω) appears @ I_o, when b reaches B_{C1} (T_b)
- Series of experiment at different T => reconstruction of B_{C1} (T))

Experimental set up

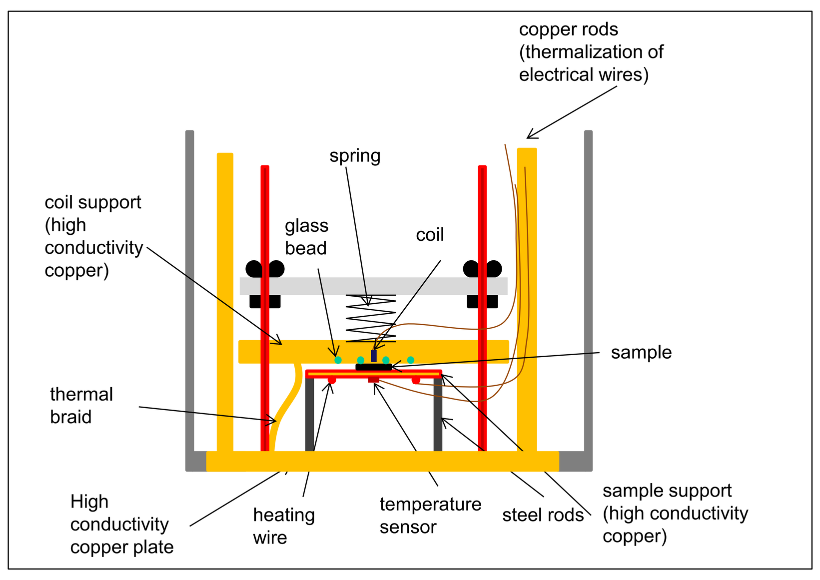


Fig 1: Schematic of Local Magnetometer

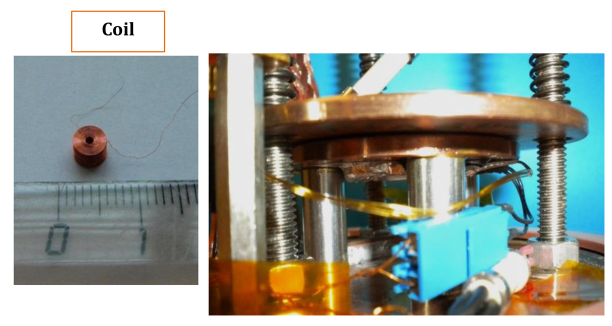


Fig 2: a) Coil (r=0.2cm);b) sample holder

- Radius of coil ≈ 0.25 cm << sample size ≥ ≈ 2 cm.
- T sensor is mounted beneath the sample holder disc.

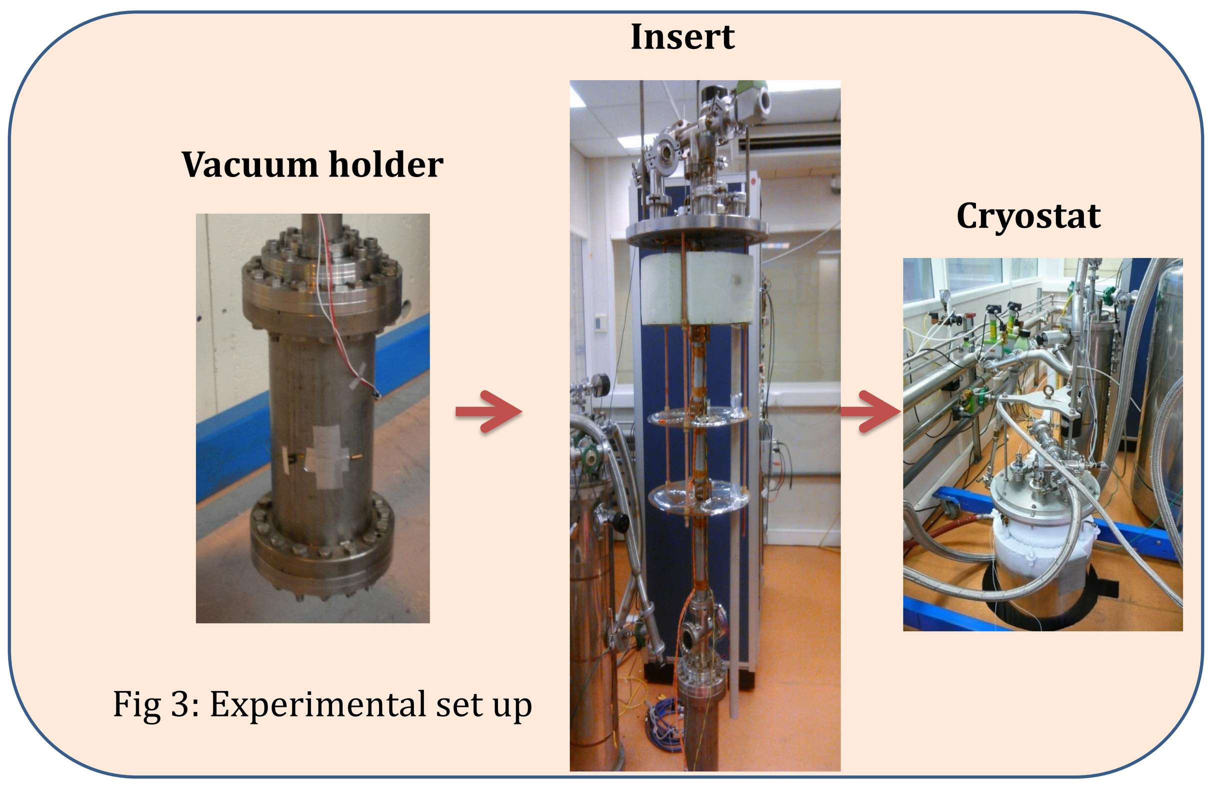


Fig 3: Experimental set up

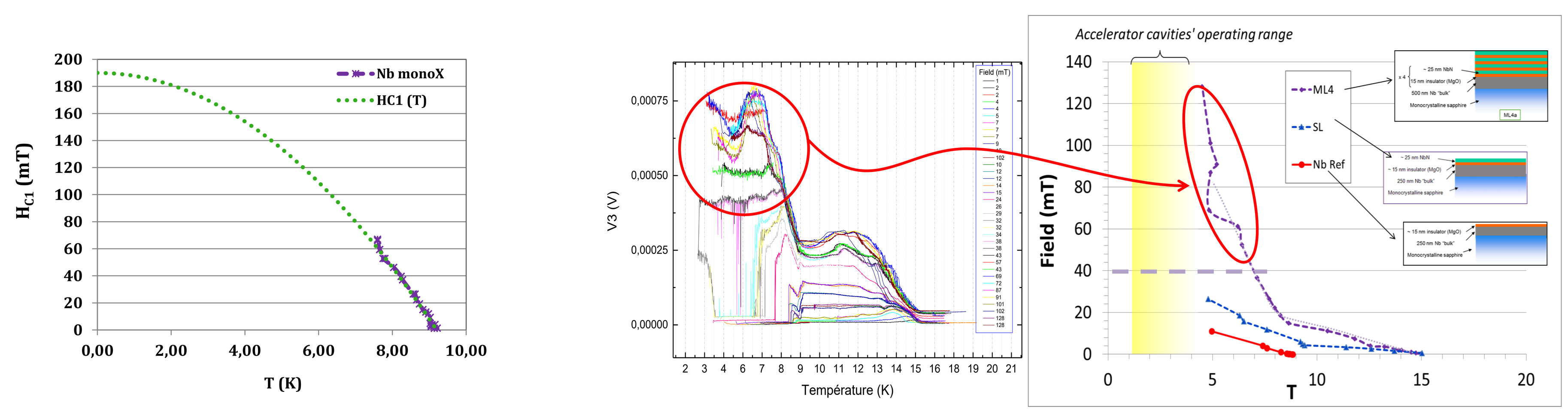
Analysis :

- Lock-in amplifier gives reference signal $I_0 \cos(\omega t)$
- Ref. signal is amplified and goes to the coil.
- Hall effect clamp sends the signal (exiting the coil) to L.I. Amp.
- Intensity and phase of the 3ω signal is monitored
- Acquisition of data w. LabVIEW

Experiment problems

- Magnetometry is very sensitive to EMC signals (other experiments, magnetic field etc.).
- Refurbishment of grounding and shielding of all connecting wires were necessary.

Examples of Experimental results



Conclusion and perspectives

- Main issue is **thermal stabilization** at high field because of high I in Cu coil, so experiment done under vacuum (thermal insulation).
  - Semiconductor wire dissipative.
  - R/W heads too difficult to assemble.

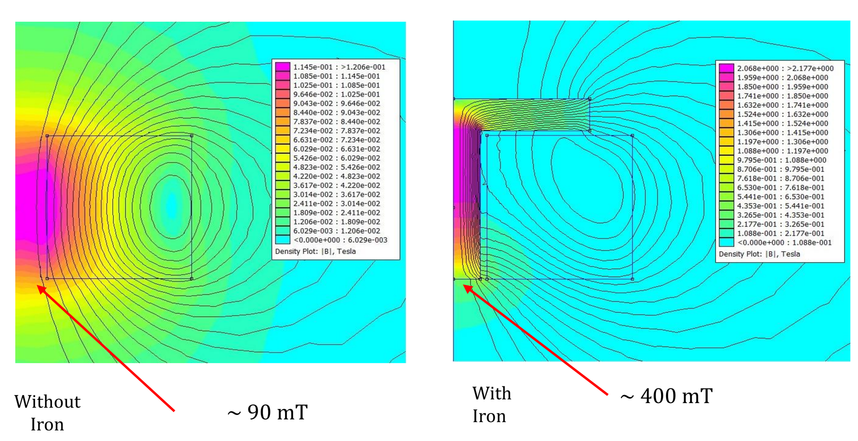


Fig 4: Field lines before and after the insertion of iron core inside the coil to enhance the magnetic field >150 mT on the sample.

- Magnetometry has proven to be effective at measuring vortex penetration in conditions close to cavities operating condition and undergoing upgrade.
- A series of ML samples with varying thickness to be measured in near future.

References:

[1] A. Gurevich, "Enhancement of RF breakdown field of SC by multilayer coating". Appl. Phys.Lett., 2006. 88: p. 012511.

[2] C.Z. Antoine, S. Berry, S. Bouat, J.F. Jacquot, J.C. Villegier, G. Lamura, and A. Gurevich, "Characterization of superconducting nanometric multilayer samples for SRF applications: first evidence of magnetic screening effect". PRST AB 2010. 13: p. 121001.

[3] G. Lamura, M. Aurino, A. Andreone, and J.C. Villegier, "First critical field measurements by third harmonic analysis ". Journal of Applied Physics, 2009. 106: p. 053903 ..