Contactless Resistivity Measurement for Quantum Phenomenon Studies

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Abstract : This work explores a contactless resistivity measurement method dedicated to the study of quantum phenomena. The method belongs to the category of RadioFrequency (RF) eddy currents and is based on a gradiometric inductive coil.

Context

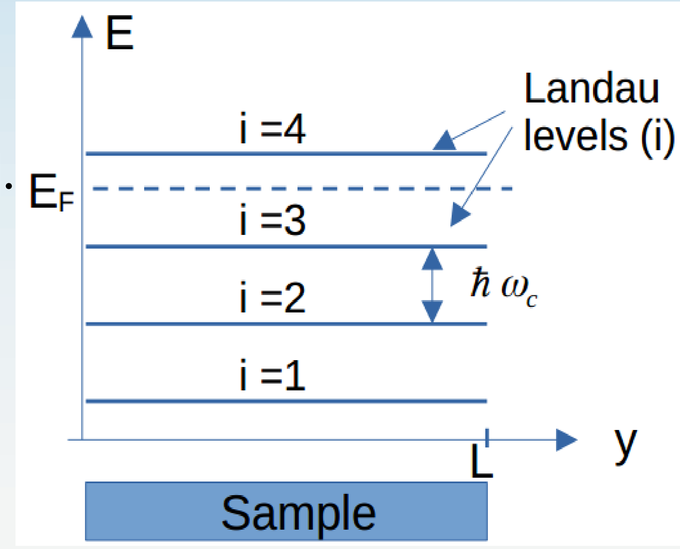
Context : The resistivity measurement is a trivial way to characterize and study electronic properties of materials.
The experimental methods based on electrical contacts (needle probe and/or wire bonding) are :
- Van der Pauw method [1]
- Hall effect

$$\sigma = qn\mu \qquad V_H = IB/nq$$

Drawbacks : parasitic contact resistance, mechanical alteration of the surface, Schottky barrier or thermoelectric effect.
Contactless resistivity measurement methods: capacitive, **RF eddy current**, or microwave [2,3].

Resistivity oscillations phenomenon @ low T and high B

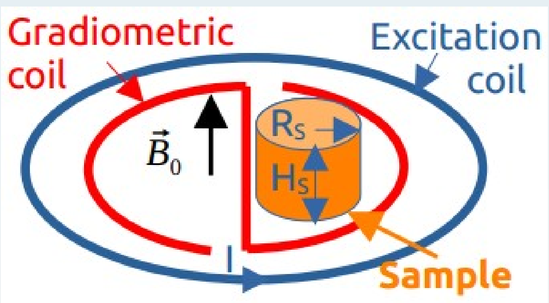
Low temperature reveals the quantization of energy levels.
Magnetic field (B) accentuates the separation of the energy levels [4,5].
When an energy level (i) crosses the Fermi level (E_F), it becomes depleted and the result is a release of charge carriers modifying the resistivity.
Thus, when B increases resistivity oscillations occurs (=Shubnikov de Haas oscillations).
The period of oscillations is related to the carrier concentration :



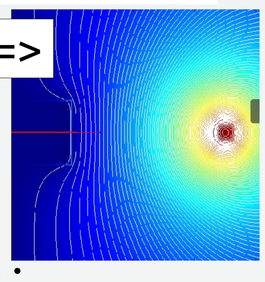
$$\Rightarrow \Delta\left(\frac{1}{B}\right) = \frac{2q}{nh}$$

The susceptometer : a RF eddy current technique

Excitation coil produces a variable magnetic field inducing eddy currents inside the sample to be characterized => the magnetic field is expelled



FEM Simulation=>

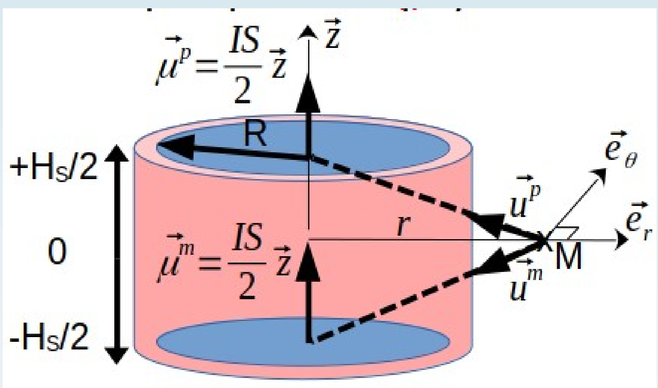


Gradiometric coil measures the unbalanced induced voltage :

$$\delta e \propto \omega \delta\phi(\rho, \omega, R_S, H_S)$$

Overview of the analytic modelling

Resolution of the Maxwell-equations
=> Bz distribution inside the sample
+ dipolar magnetic moment ($B_\mu(r)$) :



$$B_z(r) = B_{sample} + \frac{\mu_0 I R_S^2}{4\left(r^2 + \left(\frac{H_S}{2}\right)^2\right)^{3/2}}\left(\frac{3H_S^2}{4\sqrt{r^2 + \left(\frac{H_S}{2}\right)^2}} - 1\right)$$

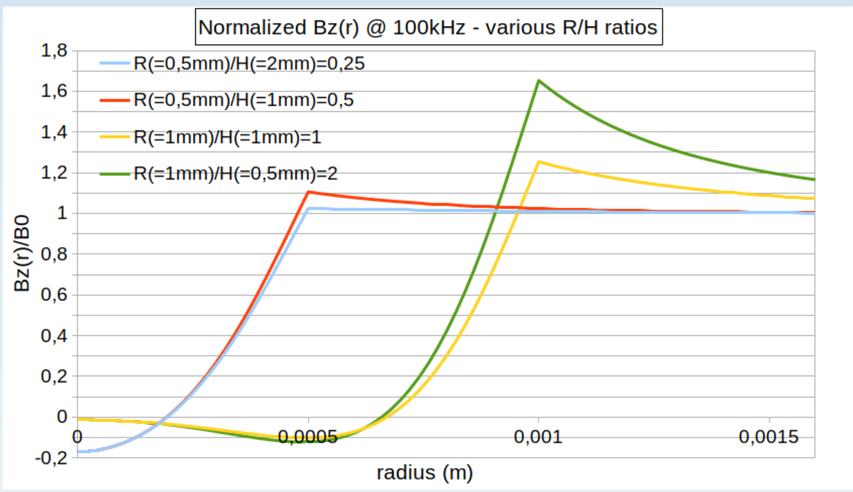
Inside the sample ($r<R_S$):

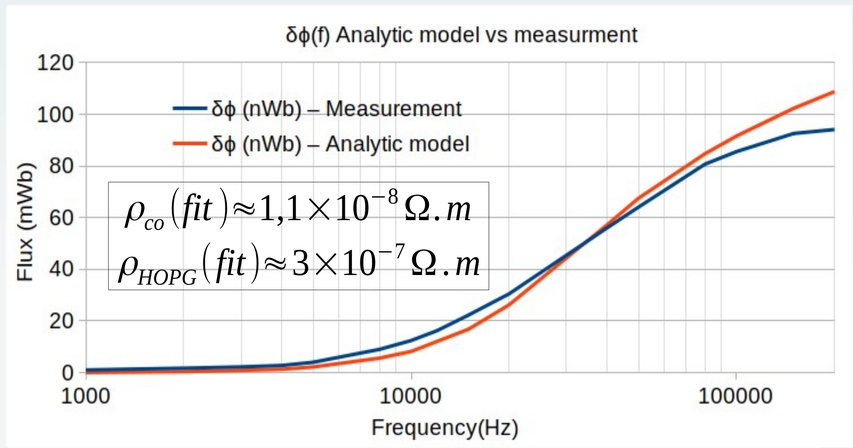
$$B_{sample} = B_0 \frac{J_0(r/k)}{J_0(R_S/k)} \quad \& \quad I(r) = \int_0^r j_\theta(r')2\pi r' H_S dr'$$

with $k^2 = -1/(j\omega\sigma\mu_0)$

Outside the sample ($R_S>r>R_{gradio}$)

$$B_{sample} = B_0 \quad \& \quad I = \int_0^{R_S} j_\theta(r')2\pi r' H_S dr$$

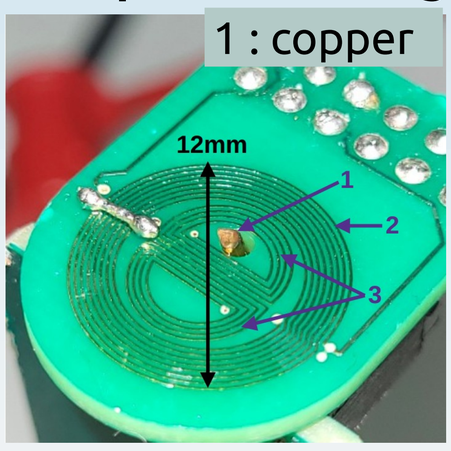




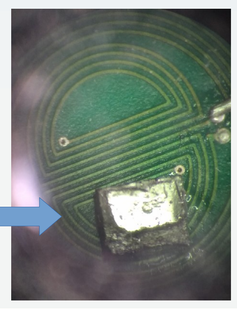
$$\rightarrow \delta\phi(\rho, \omega, R_S, H_S) = \int_0^{R_{gradio}} B_z(r)2\pi r\, dr$$

Experimental Setup

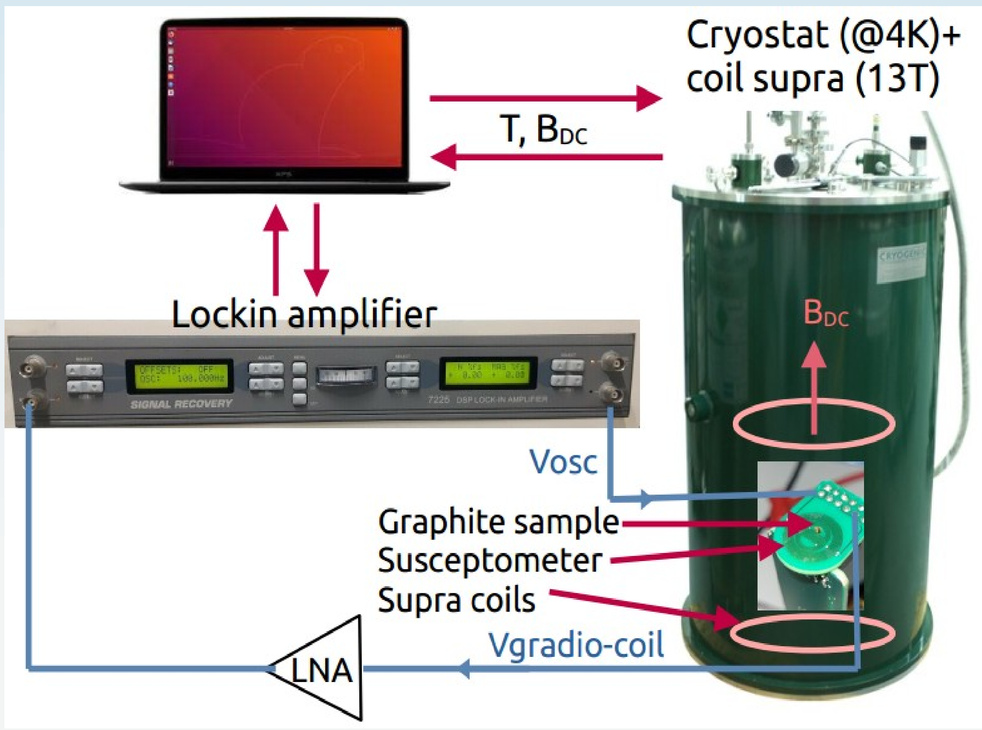
Susceptometer design



2 : HOPG (Highly Oriented Pyrolytic Graphite)

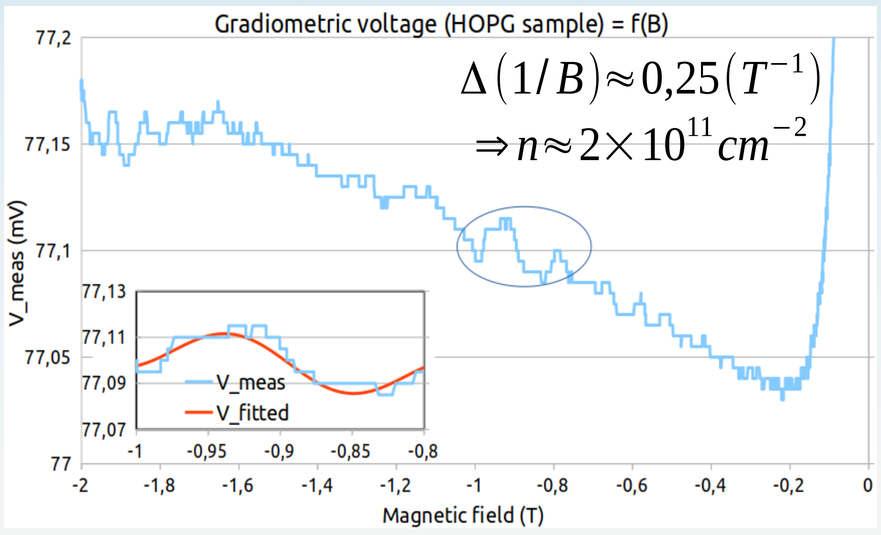


Liquid-Helium Cryostat



Results

A sample of cubic HOPG was measured into the cryostat @4,2K & @100kHz
B_{DC} field sweep : from -6T up to 6T.



The obtained carrier concentration is consistent with litterature [6]

Conclusion & Perspectives

The SdH oscillations are weak but measurable. Various possibilities will allow improving the resolution of the susceptometer, thus giving birth to a new tool for the investigation of quantum physics.

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Bibliography

[1] Van der Pauw L.J., Philips Technical Review, 20 (1958)
[2] Miller G L, Robinson D A H and Wiley J D 1976 Rev.Sci.Instrum.
[3] Krupka J., Meas. Sci. Technol. 24 (2013),
[4] J. A. Alexander-Webber et al., Phys. Rev. Lett. 111, (2013).
[5] A. Nachawaty, et al. , Phys. Rev. B. 96, (2017)
[6] Arndt et al. Phys. Rev. B 80, (2009)