Microwave spectroscopy of single-crystalline ferromagnetic films at low temperature

Cyrille Armel Sayou Ngomsi

University of Strasbourg

Objective

participate in the measuremens of the microwave response (1-50Ghz) of ferromagnetic thin films at variable temperatures (5-100K). The used devices are characterized by three types of measurements (FMR, propagating spin-wave spectroscopy and current-induced Doppler shift)

Magnetic energies

- Zeeman energy $\epsilon_{ze} = -\frac{\mu_0}{V}\int_V \overrightarrow{H_{ext}} \cdot \overrightarrow{M}$
- Exchange energy $H_{ext} = -\sum_{ij} J_{ij}\overrightarrow{S_i} \cdot \overrightarrow{S_j}$(discrete) or $\epsilon_{ex} = \frac{A}{V}\int_V (\nabla|\overrightarrow{M}|)^2$
- Demagnetizing energy $\epsilon_{de} = -\frac{\mu_0}{2V}\int_{sample} \overrightarrow{H_{de}} \cdot \overrightarrow{M}$
- Anisotropy energy

$$
\begin{aligned}
\epsilon_{ku} &= -K_1(\vec{n} \cdot \overrightarrow{M})(bulk\ uniaxial\ anisotropy) \\
\epsilon_{ks} &= \begin{cases} -\frac{K_{top}(M^x)^2}{M_s^2}\delta(x - \frac{l}{2})\text{if } x = \frac{l}{2} \\ \frac{-K_{top}(M^x)^2}{M_s^2}\delta(x - \frac{l}{2})\text{if } x = -\frac{l}{2} \end{cases}
\end{aligned}
$$

for phenomenological uniaxial surface anisotropy

Landau-Liftshiftz-Gilbert equation

$$\frac{\partial \vec{M}}{\partial t} = -\gamma \mu_0 \vec{M} \times \overrightarrow{H_{eff}} + \frac{\alpha}{|\vec{M}|} \vec{M} \times \frac{\partial \vec{M}}{\partial t}$$
$$\overrightarrow{H_{eff}} = \overrightarrow{H_{ze}} + \overrightarrow{H_{ex}} + \overrightarrow{H_{de}} + \overrightarrow{H_{ku}} + \overrightarrow{H_{ks}}$$

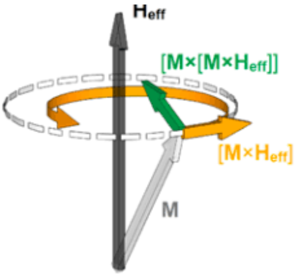


Figure 1: Illustration

Linearization of the LLG equation

$$\overrightarrow{H} = \overrightarrow{H_{eff}} + \overrightarrow{\tilde{h}}$$

$$\vec{M} = \overrightarrow{M_s} + \overrightarrow{\tilde{m}}$$

$$\overrightarrow{\tilde{h}} = \vec{h}e^{i\omega t}$$

$$\overrightarrow{\tilde{m}} = \vec{m}e^{i\omega t}$$

$$\vec{m} = \overline{\chi}\vec{h}$$

$$Re(\chi_+) = \frac{\gamma\mu_0 M_s(\gamma\mu_0 H - \omega)}{(\gamma\mu_0 H - \omega)^2 + (\alpha\omega)^2}$$

$$Im(\chi_-) = \frac{-\alpha\gamma\mu_0\omega}{(\gamma\mu_0 H - \omega)^2 + (\alpha\omega)^2}$$

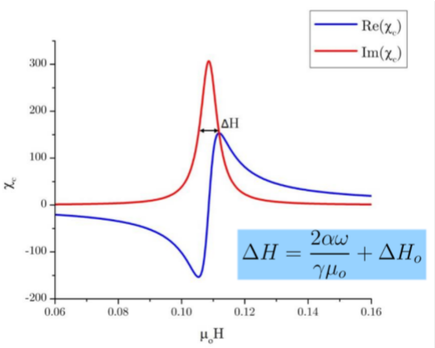


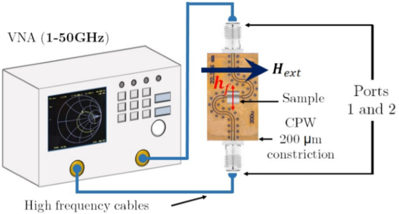
Figure 2: Representation of the real and imaginary part of the susceptibility

Resonance condition :

$$f = \frac{\gamma}{2\pi}\mu_0 \left(H_{eff} + H_x][H_{eff} + H_y]\right)^{\frac{1}{2}} (In - plane\ magnetization)$$

The theoretical results and the images are taken from the Jose Solano Master thesis 2007

Experimental set up



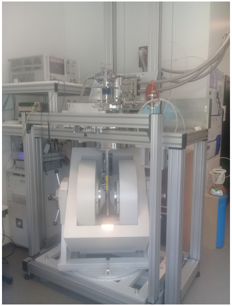
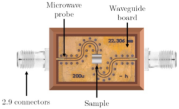
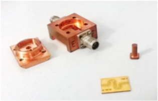
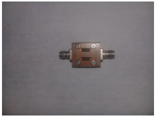


Figure 3: VNA and magnet


Microwave
probe
Waveguide
board
2.9 connectors
Sample





Results for the In-plane with the Permalloy

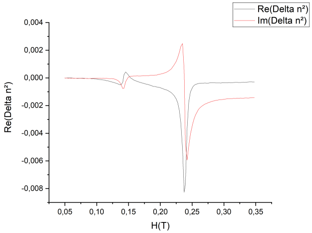
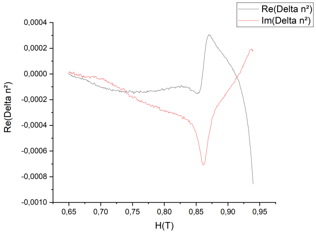
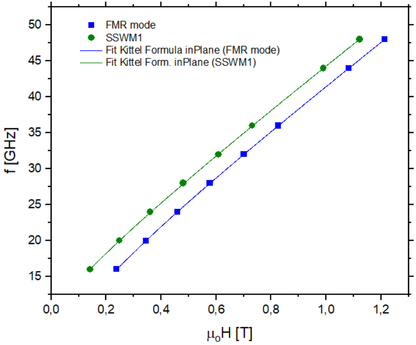


Figure 4: 16 GHz





We could do it for nine different frequencies from 16 GHz to 48 GHz

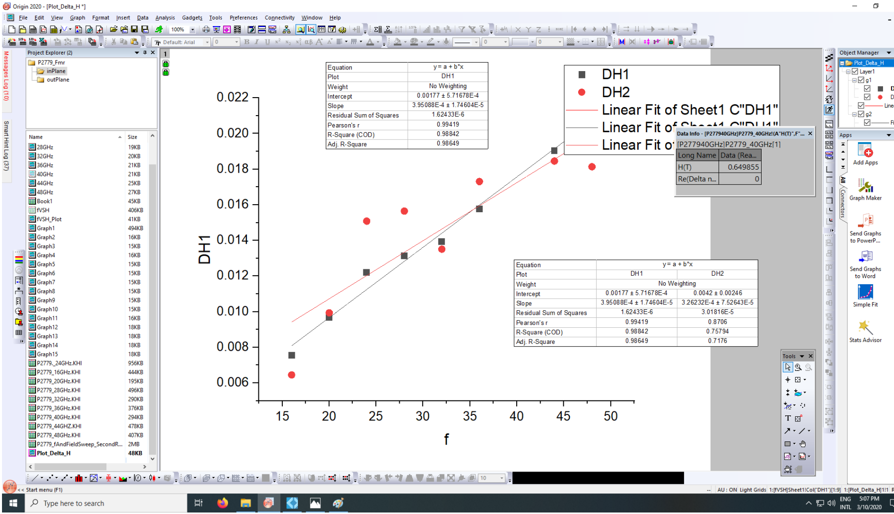


Figure 6: Caption

After the fitting with the resonance condition equation and the linewidth formulas we found :

$$H_x = 0.00299$$
$$H_y = 0.9965$$
$$\alpha = 7.6E - 4$$

Conclusion

- No concordance between the measured values and the values from the literature
- Occurred because the instruments got broken after measuring only high frequencies case
- Unable to end the pursue the experiment because of the coronavirus crisis