Fabrication and Magnetic Characterization of Nickel Nanowires

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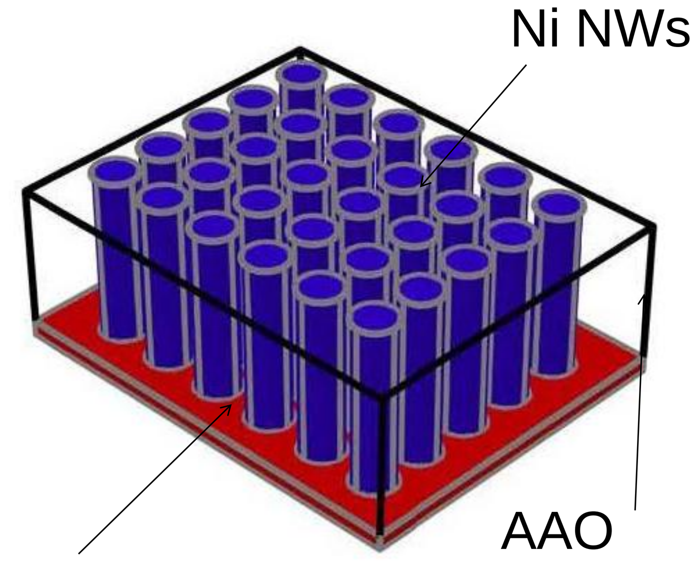
Introduction

What? – Magnetic nanowires (NWs) of Nickel with different lengths supported in non-magnetic templates were studied. With the aim to study interplay between dipolar interaction and length effects, the NWs have had the same diameter and pore-to-pore distance**.**

Why? – NWs are highly desirable materials with technological and academic interests. Development of nanostructure materials with controlled magnetic properties to meet requirements of electromagnetic devices, sensors and magnetic recording media was desired.

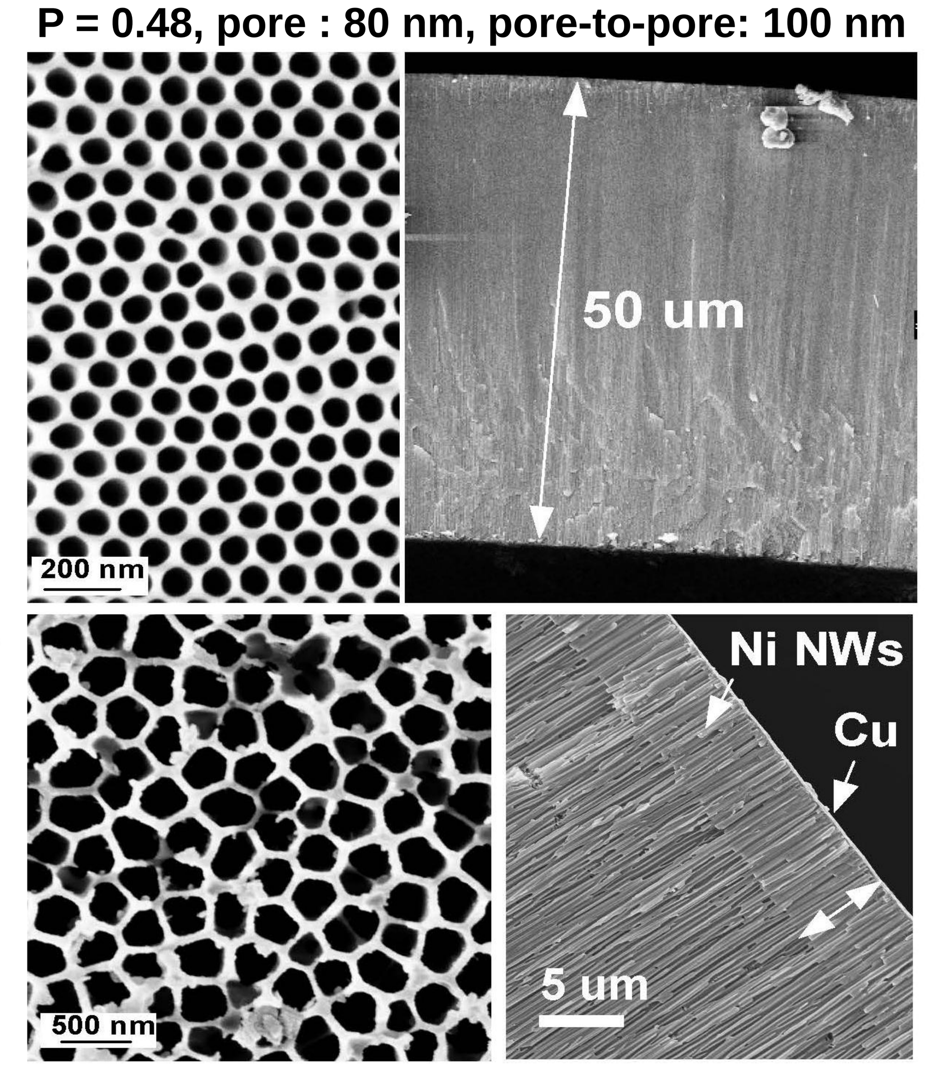
How? – An electrodeposition method using anodic Alumina templates was used. The process was simple and low cost. Magnetic measurements were done by Vibrating Sample Magnetometer (VSM) and X-band (9.8 GHz), Ferromagnetic Resonance spectrometer (FMR).



SEM top-view and cross-section

Top: Lab membrane
Bottom: Commercial membrane

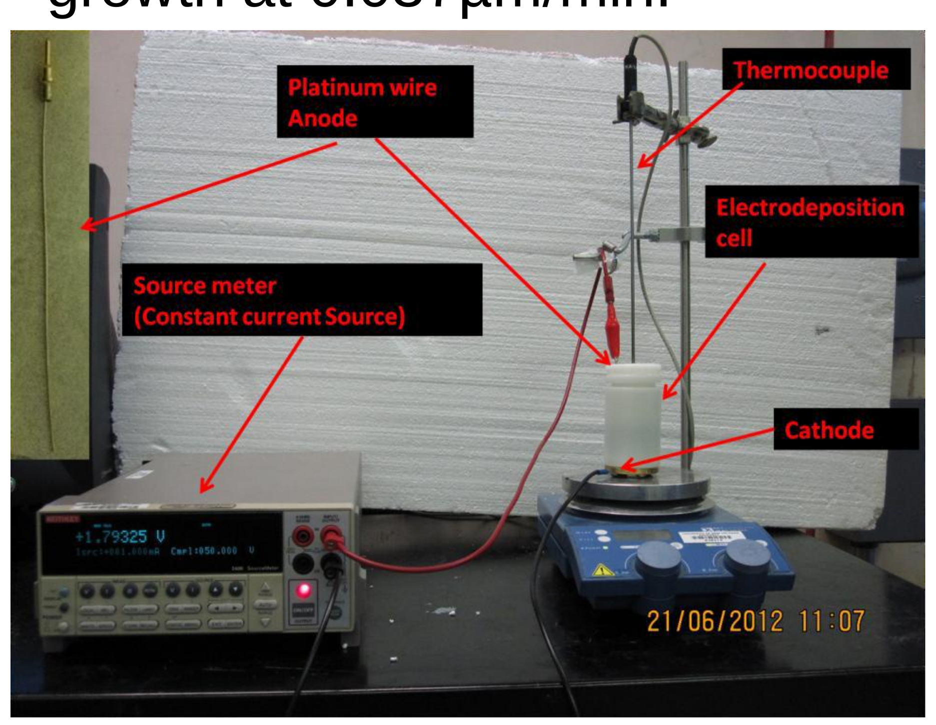
P = 0.48, pore : 80 nm, pore-to-pore: 100 nm

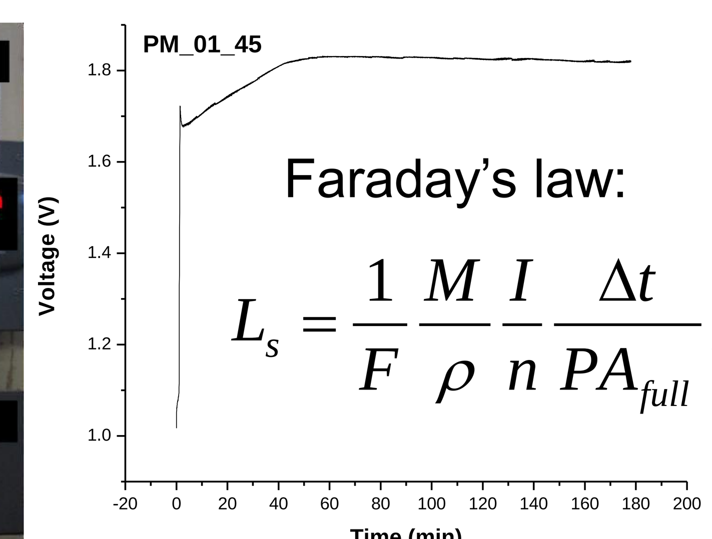


P = 0.41, pore : 300 nm, pore-to-pore: 330 nm

Fabrication

Nickel NWs were grown using galvanostatic electrodeposition at a current of 1mA. Eight samples in a series were deposited at times ranging from 18 to 525 minutes (room temperature). Rate of theoretical wire growth was calculated at 0.057µm/min and magnetic growth at 0.037µm/min.[1]





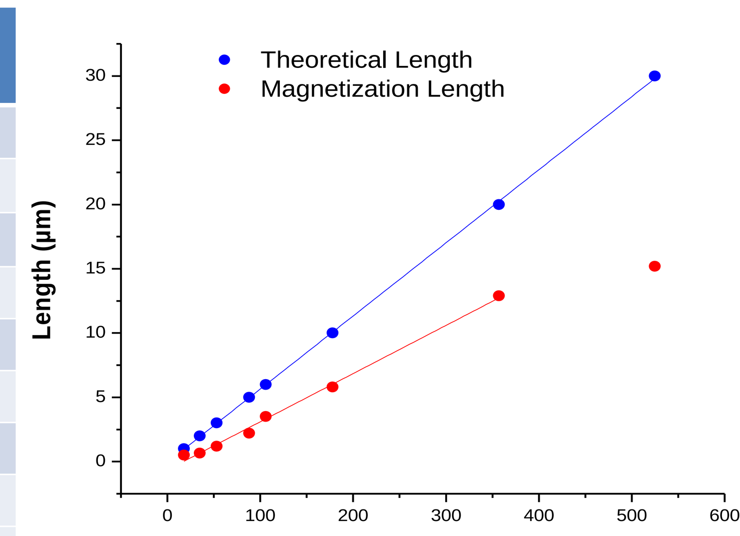
Faraday's law:

$$L_s = \frac{1}{F}\frac{M}{\rho}\frac{I}{n}\frac{\Delta t}{PA_{full}},$$

Electrodep.: Voltage vs. Time

Sample #	Deposition Time (min)	Mag. Length (µm)	Aspect Ratio
PM_01_41	18	0.5	1:1.7
PM_01_40	35	0.66	1:2.2
PM_01_42	53	1.2	1:4
PM_01_43	88	2.2	1:6.7
PM_01_44	106	3.5	1:11.7
PM_01_45	178	5.8	1:19.3
PM_01_46	357	13	1:43.3
PM_01_47	525	15	1:50
AAO_6 (lab)	17 hours	20.5	1:256

Table: Commercial samples of Ni NWs

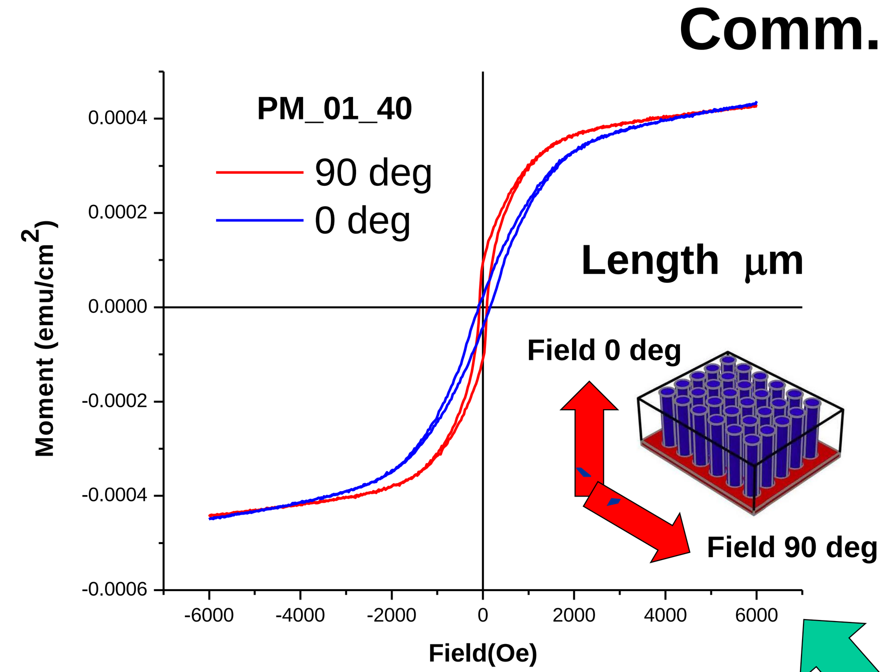


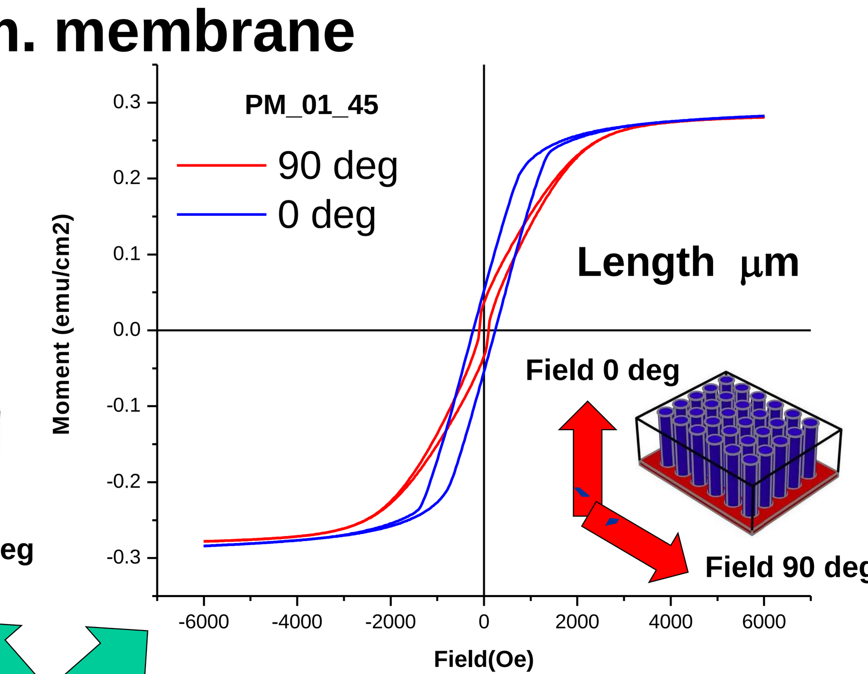
Linear fit of charge vs. length

Magnetic measurements – VSM (*M vs. H*)

Interplay between dipolar interaction and demagnetization field

Comm. membrane

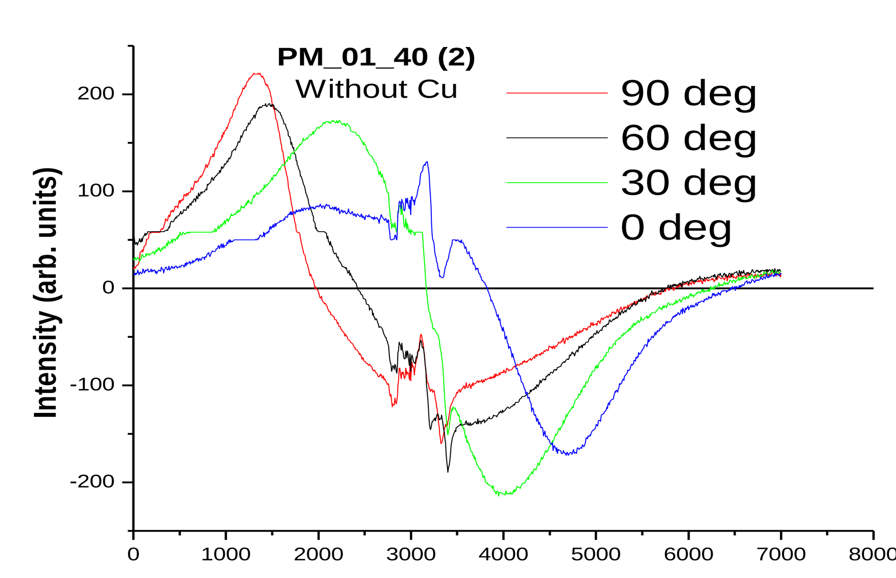


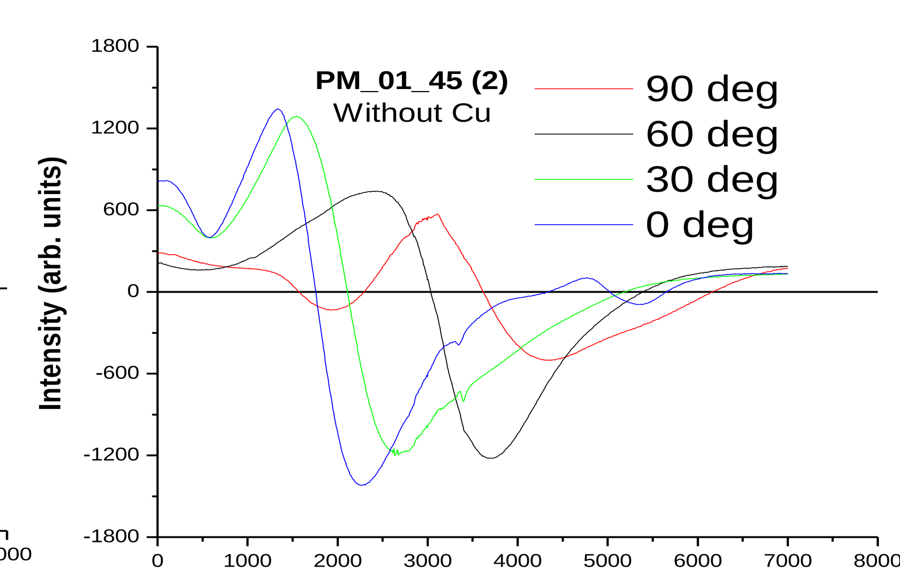


0 and 90 degree inversion of magnetic anisotropy axis![2]

Ferromagnetic resonance (X-band 9.8 GHz)

Angular variation (out-of-plane) at room-*T*, microwave power = 0.35 mW



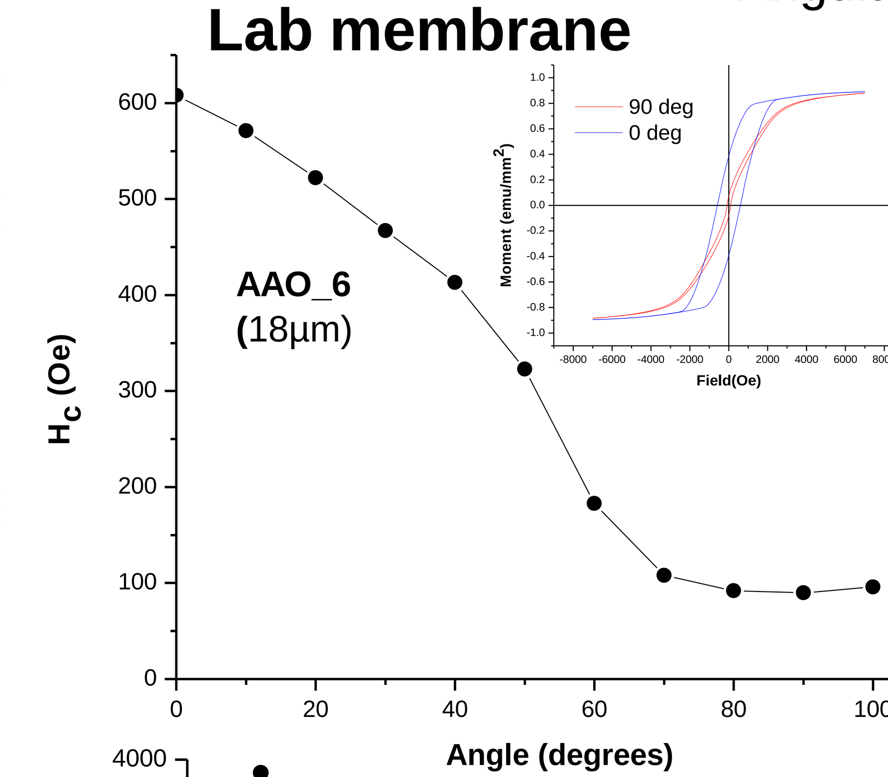


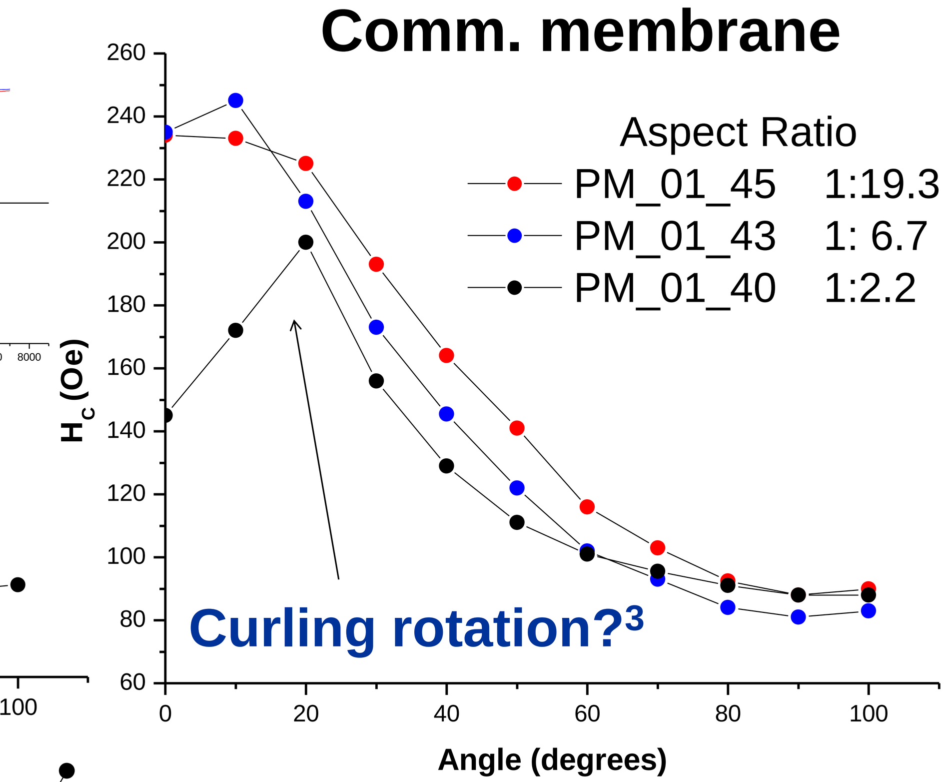
FMR spectra at different orientations

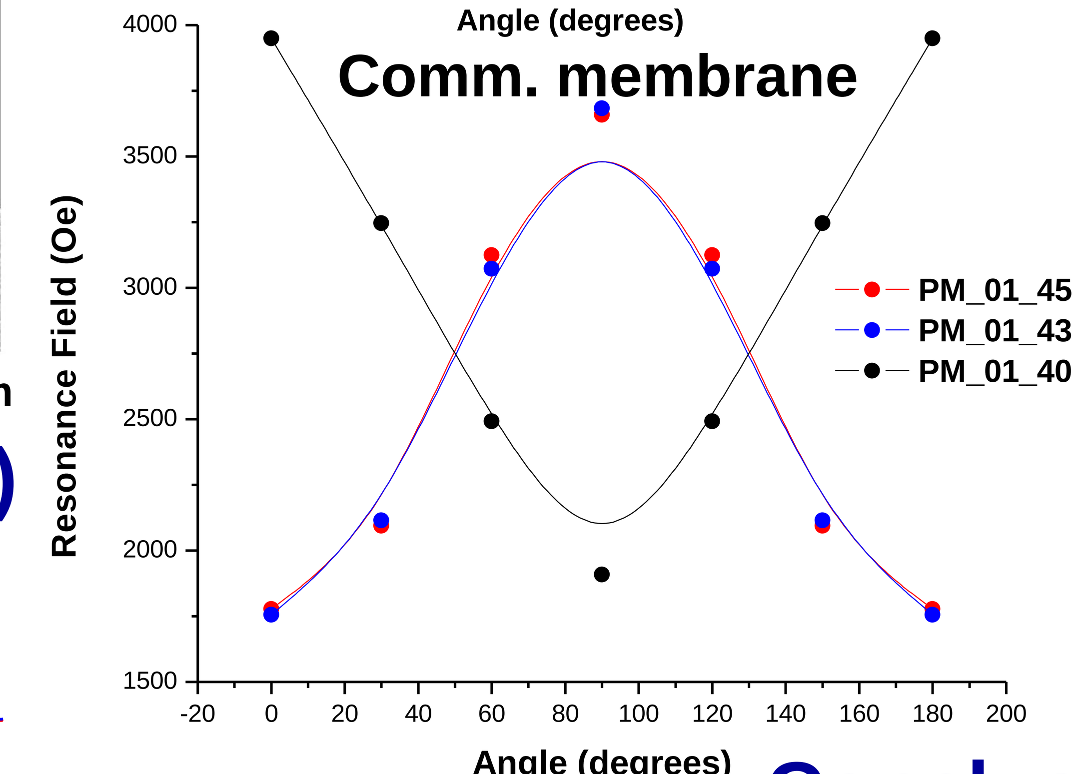
$$H_{\perp} - H_{||} = \frac{3}{2}H_A$$

$$\left(\frac{\omega}{\gamma}\right)^2 = \frac{1}{M_s^2}\left(M_s H\cos(\varphi-\varphi_H) - 2\pi M_s^2(\sin^2\varphi - 1)\right)\left(M_s H\cos(\varphi-\varphi_H) + 2\pi M_s^2\cos(2\varphi)\right)$$

Angular Variation







Above Left: Lab membrane

Above Right: Commercial membrane

Left: FMR angular variation of the resonance field.

Conclusions

- Nickel NWs were fabricated with different lengths and supported in an Alumina template (AAO).
- The mean diameter of the Ni NWs was ~ 300 nm, and the lengths were tuned from 0.5 µm to 15 µm.
- The rate of growth of the Ni NWs, estimated by the VSM measurements, dropped to a half of the value of the theoretical growth rate (Faraday's equation).
- Shape effect and dipolar interaction were observed easily in longer wires as opposed to shorter NWs that were less responsive.
- From the magnetic results (VSM and FMR), the following aspects of the AAO templates have to be improved to obtain improved signal quality: pore size homogeneity and geometrical order, native pore defects, and branched pore structure.

References

[1] Spinu et al., Phys. Rev. B 84, 134431 (2011)
[2] Spinu et al., IEEE Trans. Magnetics 40, 2116 (2004)
[3] Denardin et al., J. Appl. Phys. 106, 103903 (2009)

Acknowledgments

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