Magnetic Anisotropy of Nickel Thin Films

Troy Messina
ALPhA vBFY 2021

Rationale

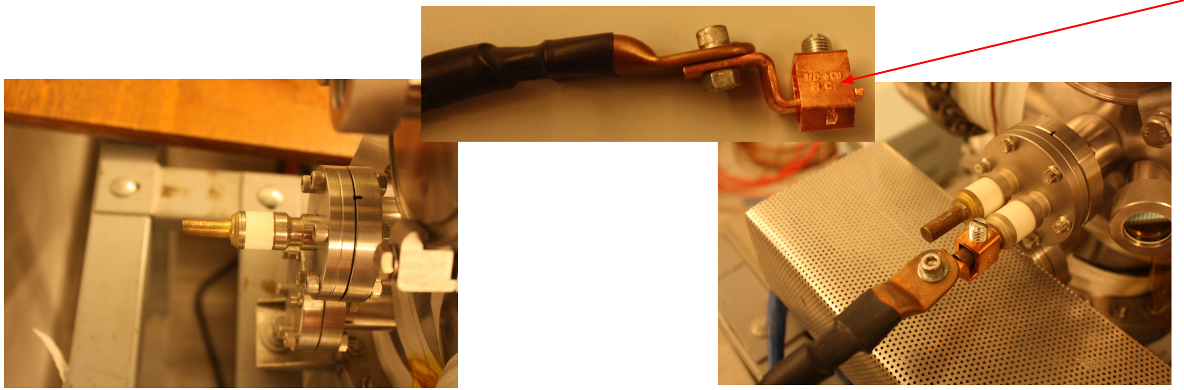
Berea College's curriculum gives students only cursory exposure to magnetism. The Advanced Lab and Senior Capstone courses are the only place students have the opportunity to explore magnetic properties of materials.

Vacuum systems and thin film deposition are tools used in a wide variety of applied and experimental physics & engineering. Exposure to these tools gives students practical skills they can take to graduate school or industry careers.

Magnetic anisotropy is a phenomenon relevant to magnetic recording media (magnetic hard drives) and spintronics (encoding spin information in electronic circuits -- MRAM). Some understanding of these could encourage students to pursue this field further or give them an advantage with gaining careers at companies like Seagate, Western Digital, Toshiba, etc.

Vacuum Deposition System

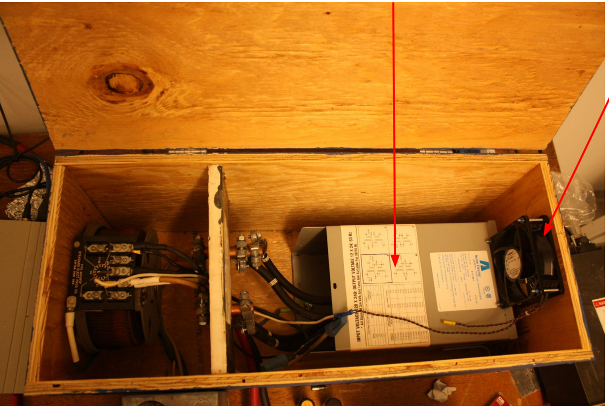
Hardware store



- Roughing and turbo pump
  - Base 10^{-7} Torr
  - Ion gauge
- High current feed-throughs
  - Single “ground”
  - Double high potential side
    - Two metal deposition
- 110 V - 30 A circuit to buck-boost 12 V - ~300 A
- Variac control

eBay

Old computer fan

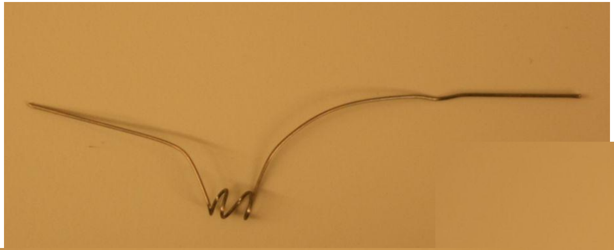


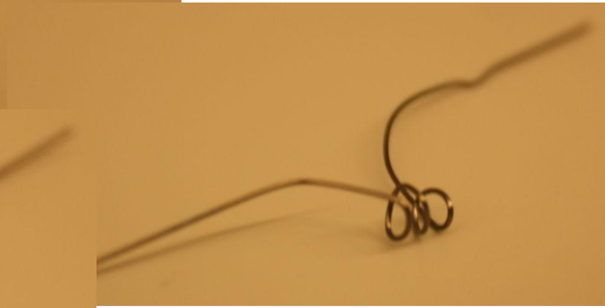
Hardware store

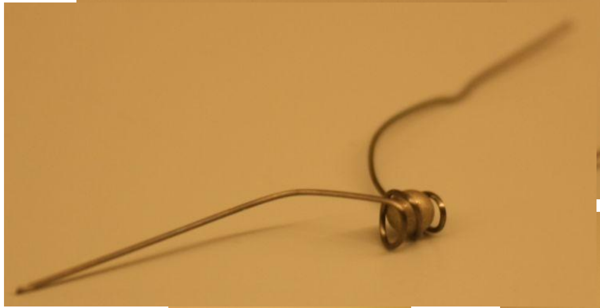
eBay

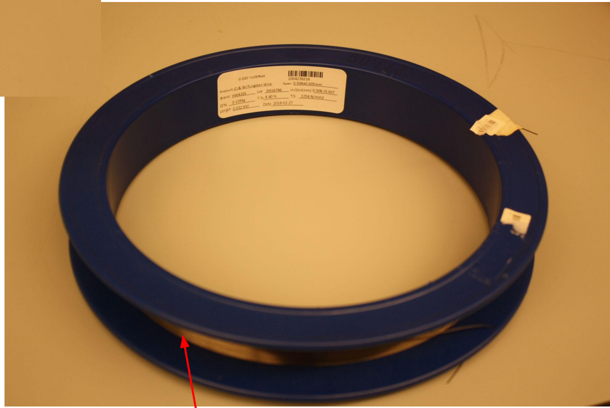
Thermal Evaporation

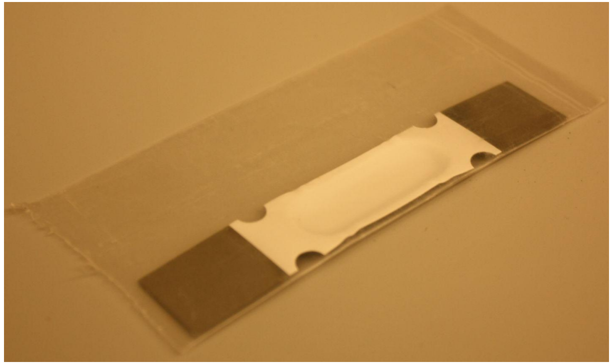
- Wrap nickel in a tungsten coil
- Connect to current feed-throughs









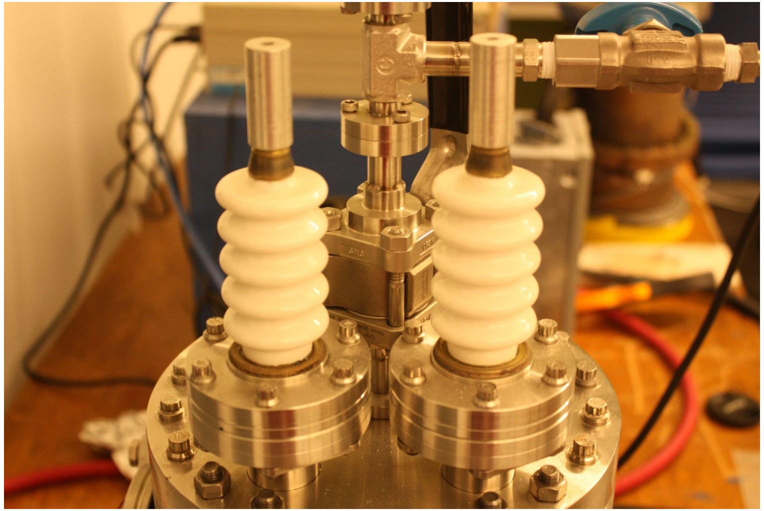


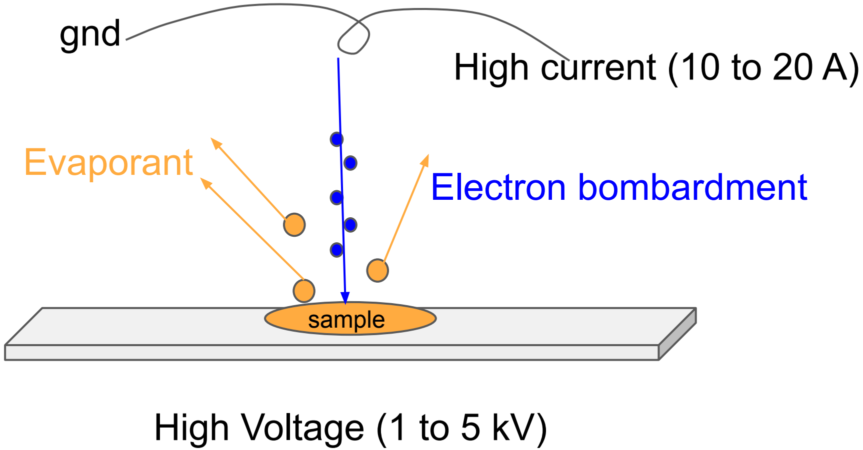
1987!!!

Amazon

e-Beam Evaporation

Pendant drop e-beam evaporation





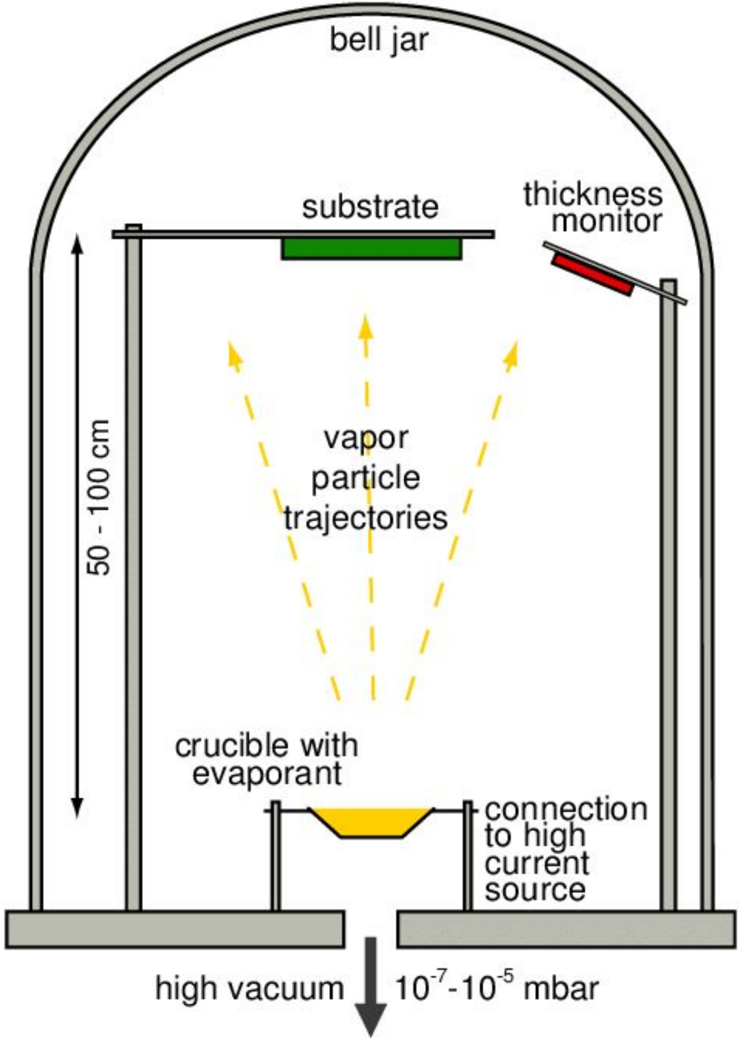
Bell Jar Thermal Evaporator

All you need is a flange with feed-throughs for current and vacuum.

The pumps are the expensive parts.

Alternatives: Sputter coater

Check eBay, BidService, etc.!!!



Or Skip Film Deposition...

https://www.mtixtl.com/nicoatedsiliconwafer.aspx

Nickel<111> Film (100nm) Coated SiO2/Si Wafer -(100) P/Boron ,10x10x0.5mmSSP, R:1-20 ohm.cm - Ni-SO/Si-101005S1

Sale Price: USD$39.95
If you are international, please click this.

In stock
Item Number: FmNic100SO300onSiBa10100525C1

Quantity: 4 BUY

Email this page to a friend

Quantity Discounts

Quantity	Amount
100 to 499	USD$37.95

Nickel Film

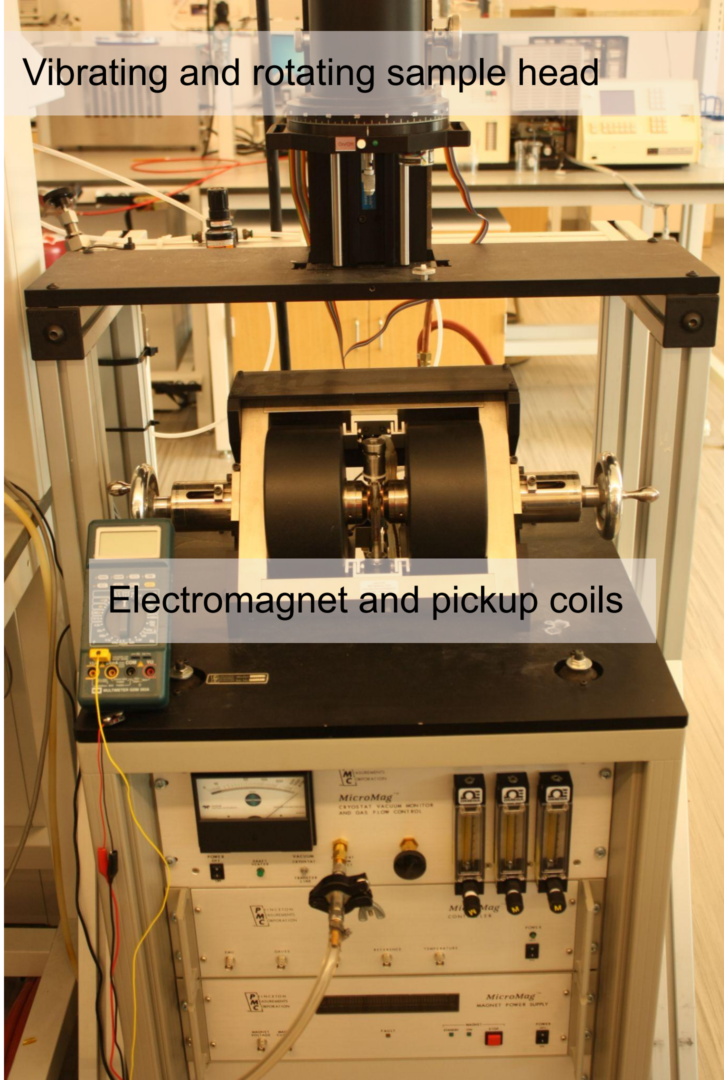
- Nickel Film Thickness: 100nm
- Film Crystallinity: **(111) - oriented polycrystals**

Silicon Wafer Specifications:

- Conductive type: Si P- type, B-doped
- Resistivity: 1-20 ohm-cm
- Size: 10x10x0.5mm
- SiO2 Thichness: 300 nm
- Orientation: (100) +/- 0.5^{o}
- Polish: One sides polished
- Surface roughness: Prime
- Packing: Vacuum packed on a 4" single wafer carrier
- Optional: you may need tool below to handle the wafer (click picture to order)

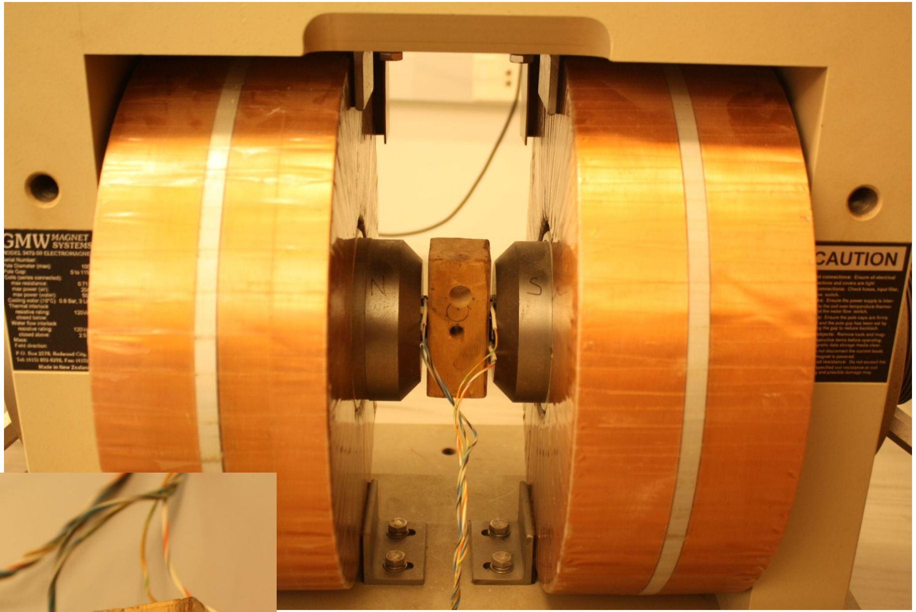
Vibrating Sample Magnetometer

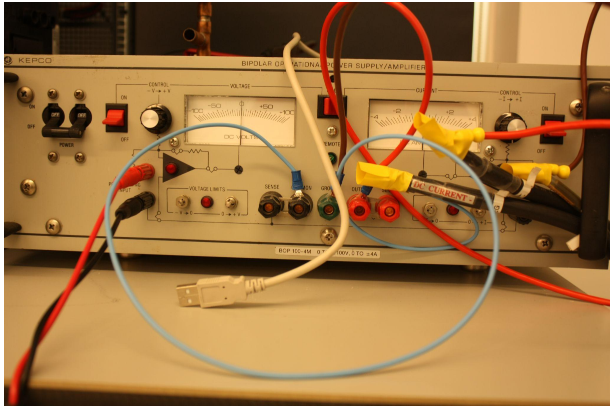
Princeton Measurement Corporation (now Lakeshore Cryotronics) VSM 3600



DIY VSM

- Coils from a relay fit into the gap of an electromagnet
- Bipolar Kepco BOP +/- 100 V at 2 A
  - eBay
- “An Automated Home Made Low Cost Vibrating Sample Magnetometer”
  - https://arxiv.org/ftp/arxiv/papers/1105/1105.6313.pdf





DIY VSM

- "An Automated Home Made Low Cost Vibrating Sample Magnetometer"
  - https://arxiv.org/ftp/arxiv/papers/1105/1105.6313.pdf
- Pasco Mechanical Wave Driver
  - https://www.pasco.com/products/lab-apparatus/waves-and-sound/ripple-tank-and-standing-waves/sf-9324

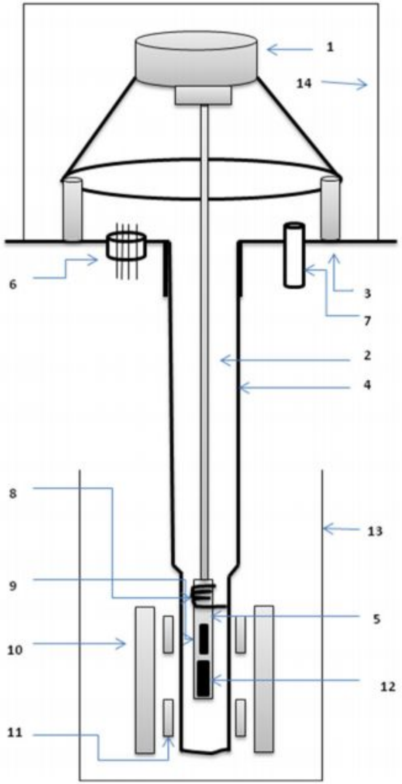
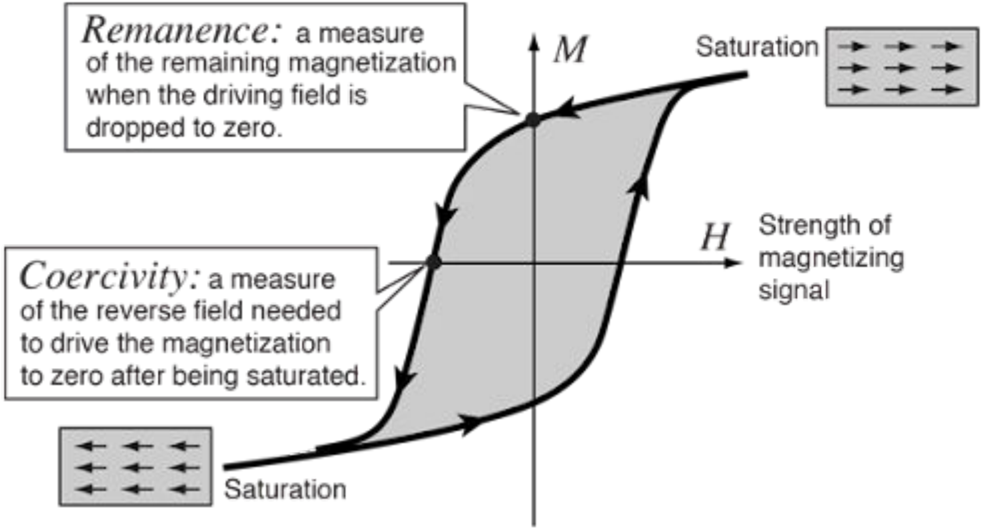


FIGURE 1. Schematic of the VSM (1) loud speaker, (2) sample holder rod, (3) brass plate, (4) glass tube, (5) sapphire sample holder, (6) electrical feed through, (7) vacuum port, (8) heater wire, (9) cernox temperature sensor, (10) primary coil, (11) pickup coils, (12) sample, (13) liquid nitrogen container, (14) perspex cover.

Magnetism Concepts

- Ferromagnetic Hysteresis
  - Applied Field
  - Coercive field
  - Remanent magnetization (retentivity)
  - Magnetic moment (emu, emu/g, emu/cm^3, etc.)



Data - What I was expecting...

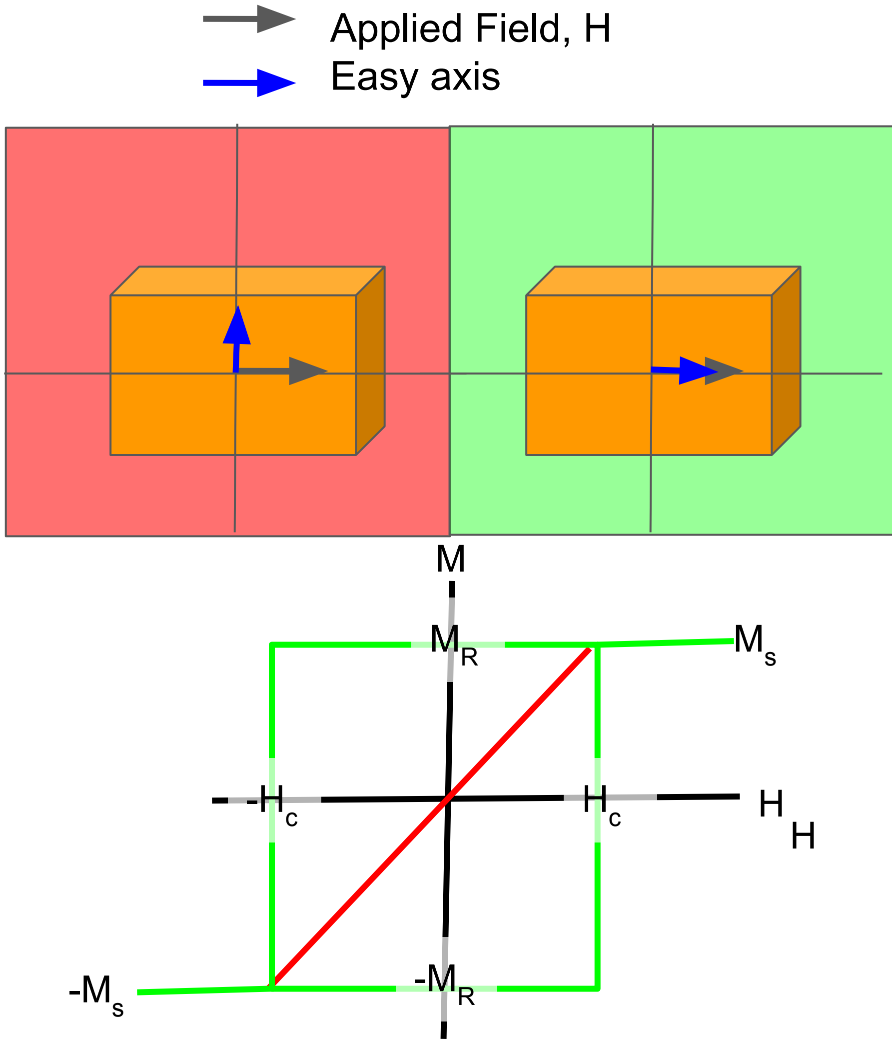
I designed this lab based on a previously designed lab, where a sample of bulk ferromagnetic powder in epoxy is placed in a magnetic field while the epoxy dried.

M_R = remanent magnetization at H = 0

M_s = saturated magnetization at $H = H_{max}$

θ = angle between the applied field, H, and the easy axis

$M_R/M_s \ \alpha \ \cos^2(\theta)$



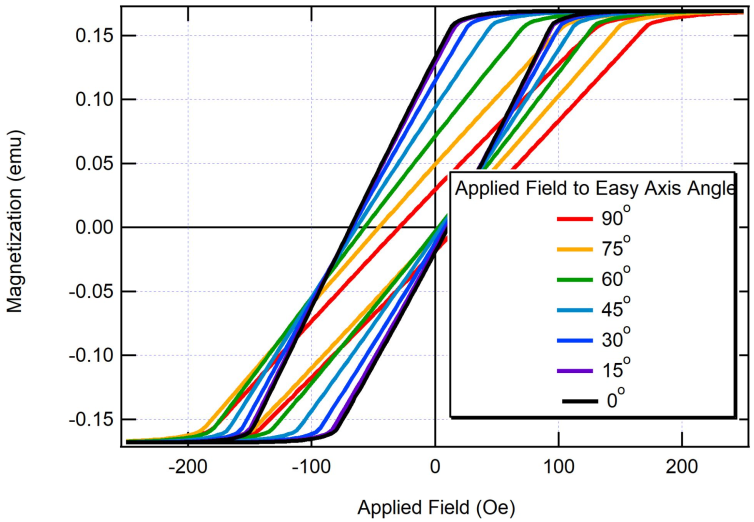
Assignments for bulk magnetism

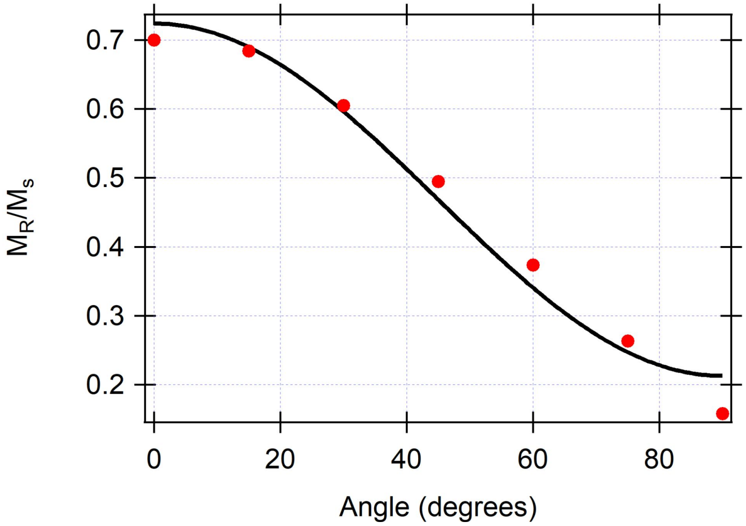
- https://docs.google.com/document/d/1_cHP7vGDDUEMZ-BMYPov0bjAQx5kuZ_5_FcYfjJsEVs/edit?usp=sharing
- https://drive.google.com/file/d/14E6j8tcRJRwesdP-QcsUYx1L6-3Nw0Hc/view?usp=sharing

Data - What I was expecting...

The aligned powder in epoxy…

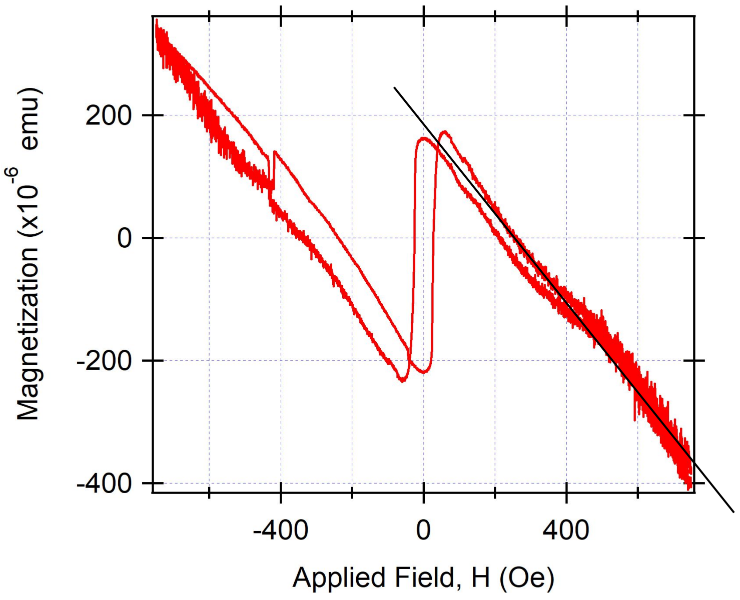
Students are given the option to go deeper and do the thin film experiment.



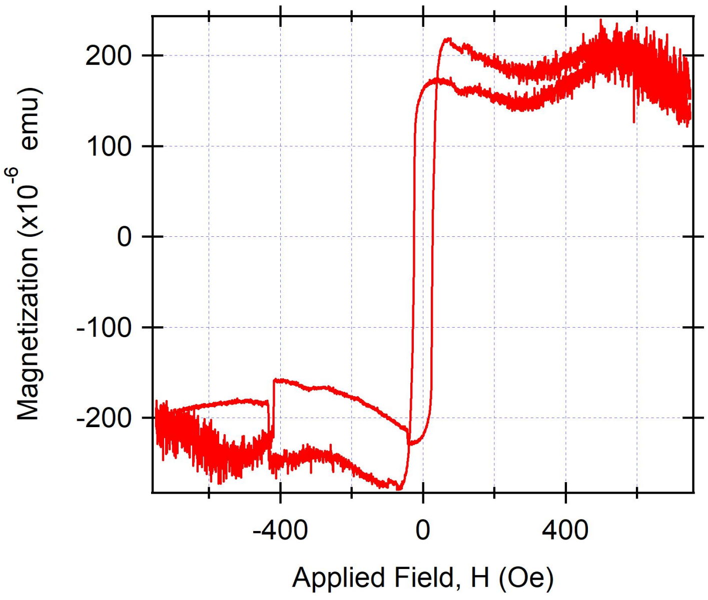


Student Thin Film Data

Raw data with diamagnetic Si signal

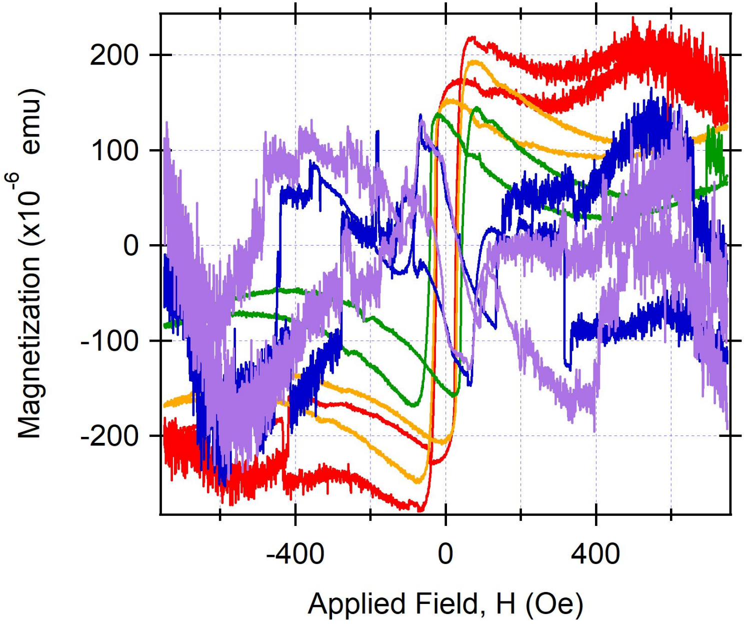


Corrected data with diamagnetism subtracted



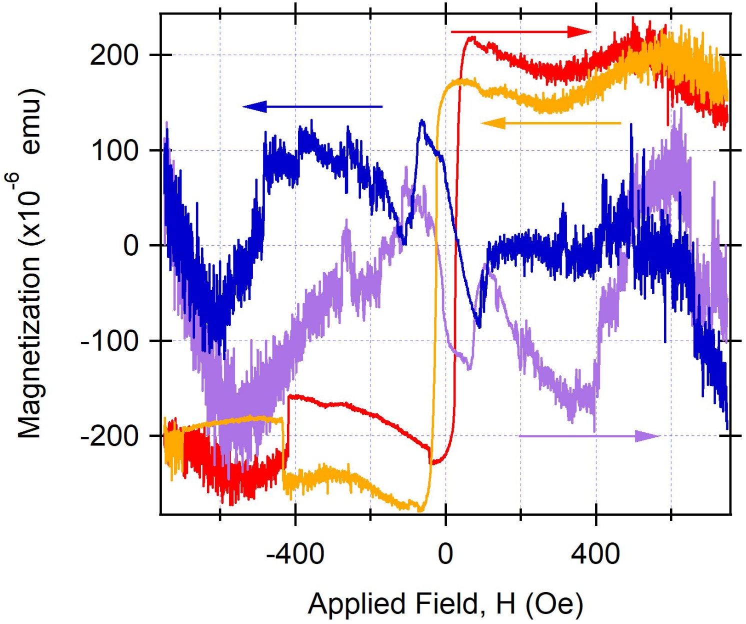
Corrected Angle Dependent Data

Multi-angle data

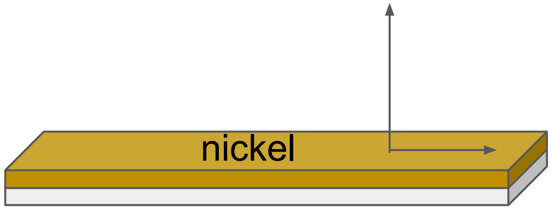


Parallel and perpendicular to easy axis

Arrows indicate changing field of loop



The Data is Messy...



… and complicated

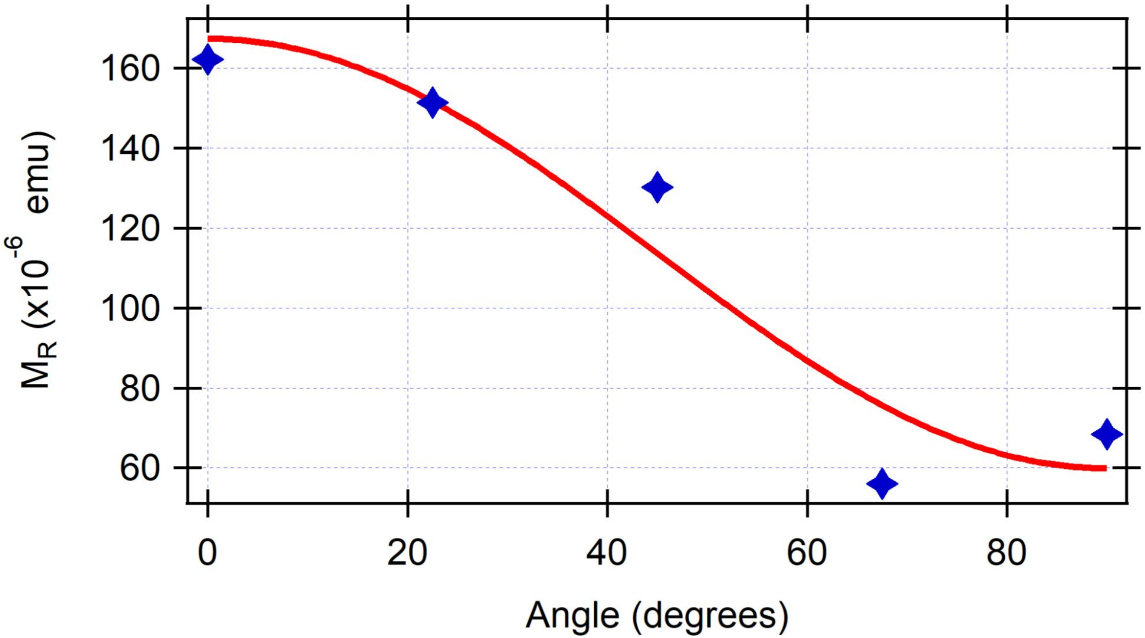
- The saturation is not the same for all angles.
- The data is noisy even with five scan averaging.
- There is possibility of multiple easy axes.
    - Nickel on silicon can preferentially grow <111>, the easy magnetic crystal axis.
    - A 2D film has an in-plane easy axis.
        - Which one wins?

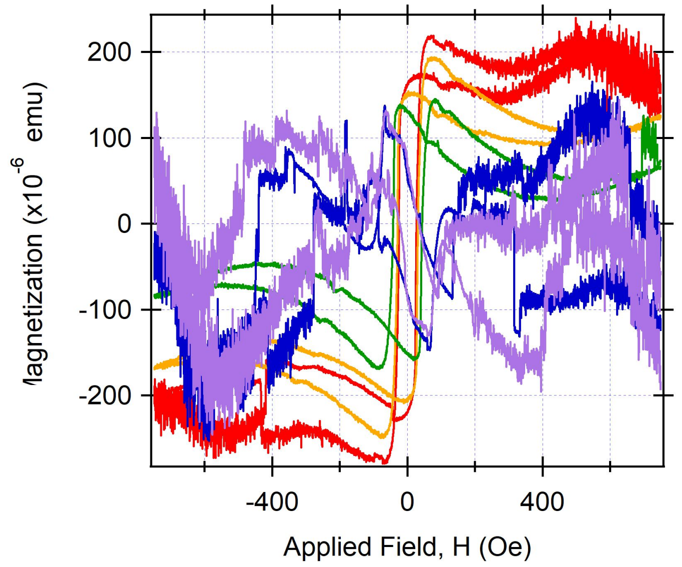
It would be ideal to find a simpler system.

https://ocw.mit.edu/courses/materials-science-and-engineering/3-024-electronic-optical-and-magnetic-properties-of-materials-spring-2013/lecture-notes/MIT3_024S13_2012lec25.pdf

Analysis

Assuming M_s should be constant, a plot of M_R can be fit to $\cos^2\theta$.



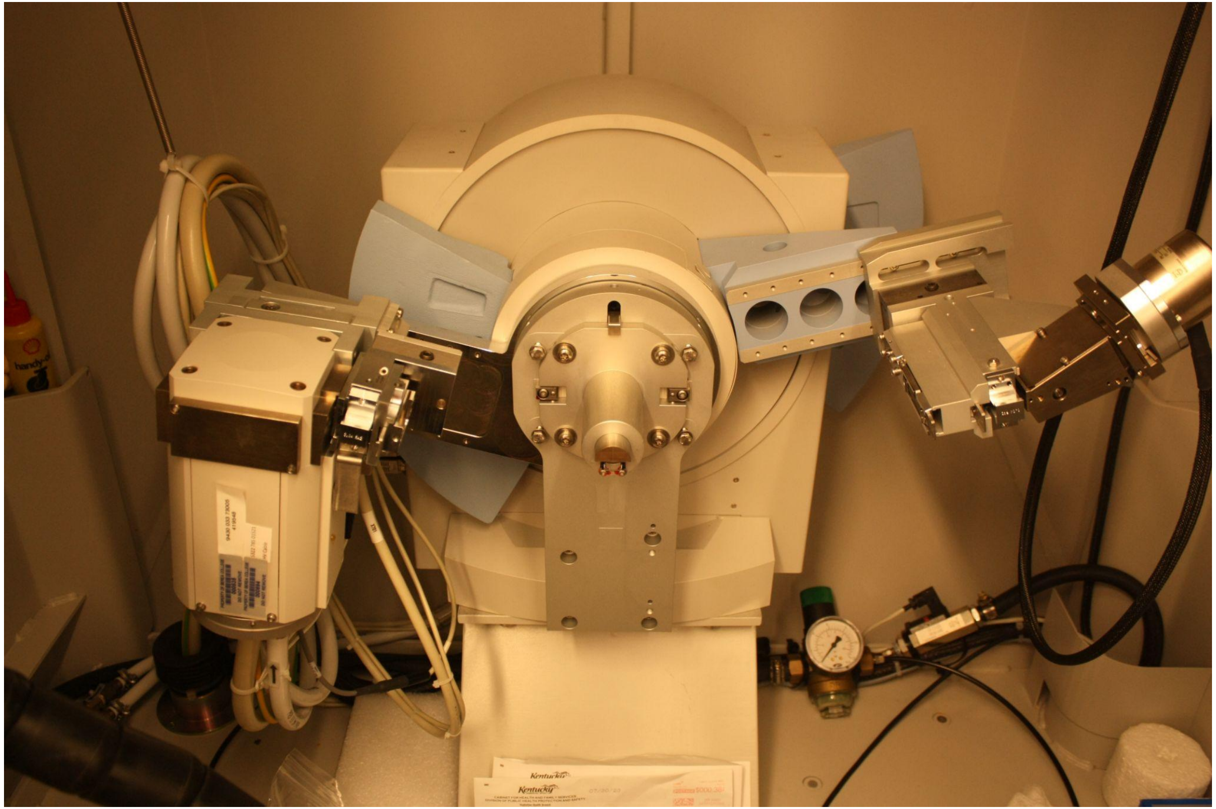


References

- Lecture 25 -- Hysteresis in Ferromagnetic Materials, https://ocw.mit.edu/courses/materials-science-and-engineering/3-024-electronic-optical-and-magnetic-properties-of-materials-spring-2013/lecture-notes/MIT3_024S13_2012lec25.pdf
- Chuan-Che Hsu et al., “Reversible 90-Degree Rotation of Fe Magnetic Moment Using Hydrogen,” Nature Scientific Reports, **8**, 3251 (2018).
- Y. Fukuma et al., “Strong uniaxial magnetic anisotropy in CoFe films on obliquely sputtered Ru underlayer.” Journal of Applied Physics **106**, 076101 (2009)
- S. Kundu and T. K. Nath, “An Automated Home Made Low Cost Vibrating Sample Magnetometer,” AIP Conference Proceedings 1349, 453 (2011). https://arxiv.org/abs/1105.6313

X-Ray Diffraction

Philips (Malvern Panalytical)
XPert powder diffractometer



Inductively measured current for evaporator power supply

An old Cenco magnet that might be found used somewhere