Magnetic Anisotropy of Nickel Thin Films

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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

- 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
Thermal Evaporation

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

Pendant drop e-beam evaporation

- High Voltage (1 to 5 kV)
- High current (10 to 20 A)

Evaporant
Electron bombardment
Sample

Diagram showing the setup with high voltage and electron bombardment.
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
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”
DIY VSM

- “An Automated Home Made Low Cost Vibrating Sample Magnetometer”
- Pasco Mechanical Wave Driver

**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.

\[ M_R = \text{remanent magnetization at } H = 0 \]

\[ M_s = \text{saturated magnetization at } H = H_{\text{max}} \]

\[ \theta = \text{angle between the applied field, } H, \text{ and the easy axis} \]

\[ \frac{M_R}{M_s} \propto \cos^2(\theta) \]
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.

Analysis

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

![Graph showing magnetic properties](image)
References

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