Magnetic Ground State of Industrial Sensors

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Background
Magnetic particle

Ferromagnet

Synthetic anti-ferromagnet
AKA wafer
Purpose: Determine thickness and magnetization

- No external magnetic field AKA ground state
- High resistance

- External magnetic field
- Low resistance
neutron wave
Constructive Interference

Destructive Interference

Bragg condition
\[ n\lambda = 2d \sin \theta \]
Interference from layers of varying thickness

- Reflected Intensity
- Angle of incidence

-thick layers

-thin layers
\[ Q \equiv \frac{4\pi \sin \theta}{\lambda} = \frac{n2\pi}{d} \propto \theta \]

\[ V = \frac{2\pi \hbar^2}{m} N b = \frac{2\pi \hbar^2}{m} \rho \]

\[ \rho = \rho_{\text{nuclear}} \pm \rho_{\text{magnetic}} \]

\[ \vec{M} \propto \rho_{\text{magnetic}} \]
Top View of wafer

- $M_{\parallel}$: No spin flip; tells about $\rho_{\text{nuclear}}$
- $M_{\perp}$: Spin flip; tells about $\rho_{\text{magnetic}}$

Vectors $\vec{M}_{\parallel}$ and $\vec{M}_{\perp}$ represent the magnetic moment components parallel and perpendicular to the field $\vec{H}$.
Experiment
Spin – flip scattering

- Polarizer (Spin down)
- Flipper A (on)
- Flipper B (off)
- Analyzer (Spin down)
- Detector

Non – spin – flip scattering

- Polarizer (Spin down)
- Flipper A (on)
- Flipper B (on)
- Analyzer (Spin down)
- Detector
Multilayer repeat
• Rotated the sample and detector angle in magnetic fields of 20 mT and 0.5 mT
• Detector measured the intensity of the reflected neutrons as a function of sample angle over time
Results
&
Conclusions
Data Analysis Process

Model based on assumptions → Python Script → Refl1-D → Chi squared value → Set Aside
Experimental Data at High Field

\[ Q_A = \frac{2\pi}{d} \]
\[ Q_B = \frac{4\pi}{d} \]
\[ \bar{d}_{\text{actual}} = 68 \text{ A} \]
Best Model at High Field

Scattering Length Density $x 10^{-6} (\text{Å}^{-2})$

Depth Profile of Nuclear and Magnetic SLD and Magnetization Angle

$\theta_M (^\circ)$
depth (Å)
Best Fit at High Field
Actual High Field Result

Unit cell 1
Unit cell 2
Unit cell 3
Unit cell 4

$\vec{H}$

0°

NFC seed

CoFe$_1$

NFC$_1$

CoFe$_2$

NFC$_2$

CoFe$_3$

NFC$_3$

CoFe$_4$

NFC$_4$
Experimental Data at Low Field
Best Model at Low Field

Scattering Length Density

$\times 10^{-6} (\text{Å}^{-2})$

Magnetization Angle ($^\circ$)

Depth Profile of Nuclear and Magnetic SLD and Magnetization Angle
Best Fit at Low Field
Expected Low Field Result

\[ \vec{H} \]

0°

NFC seed

NFC₁

NFC₂

NFC₃

NFC₄

CoFe₁

CoFe₂

CoFe₃

CoFe₄
Actual Low Field Result

$\theta_{\text{separation}} = 88^\circ$
$\theta_{\text{separation}} = 108^\circ$
$\theta_{\text{separation}} = 143^\circ$
$\theta_{\text{separation}} = 141^\circ$

$\theta_M$ angles are measured relative to H field
Continuing Work
Why aren’t the magnetic layers coupling anti-ferro-magnetically at low field?
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