Etch Damage in Magnetic Thin Film Head Materials

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Collaborating with:
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Anusha Natarajarathinam
Mark Kief

<http://www.ncnr.nist.gov/instruments/dcs/>

Hard Drives, A History

1956: IBM 305 RAMAC (5MB)

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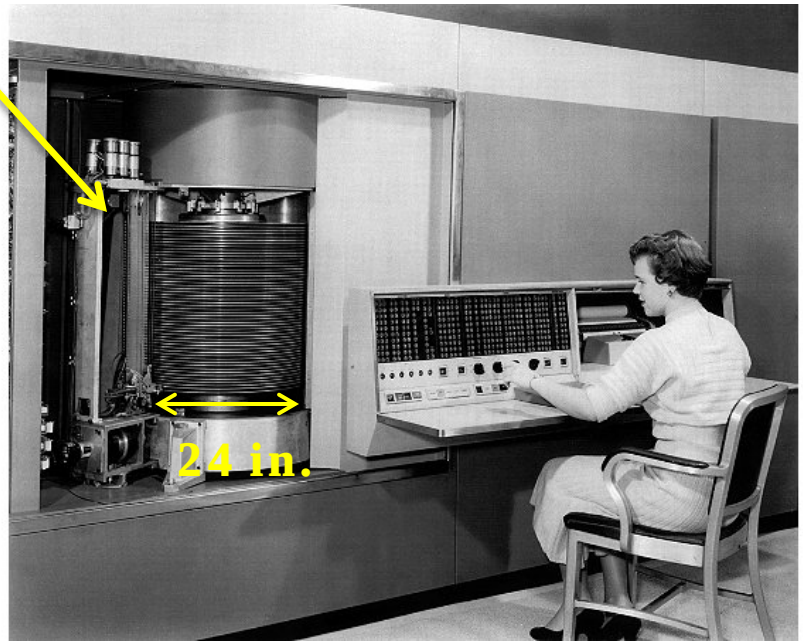

<http://www.computerhistory.org/revolution/memory-storage/8/259/1044>

Hard Drives, A History

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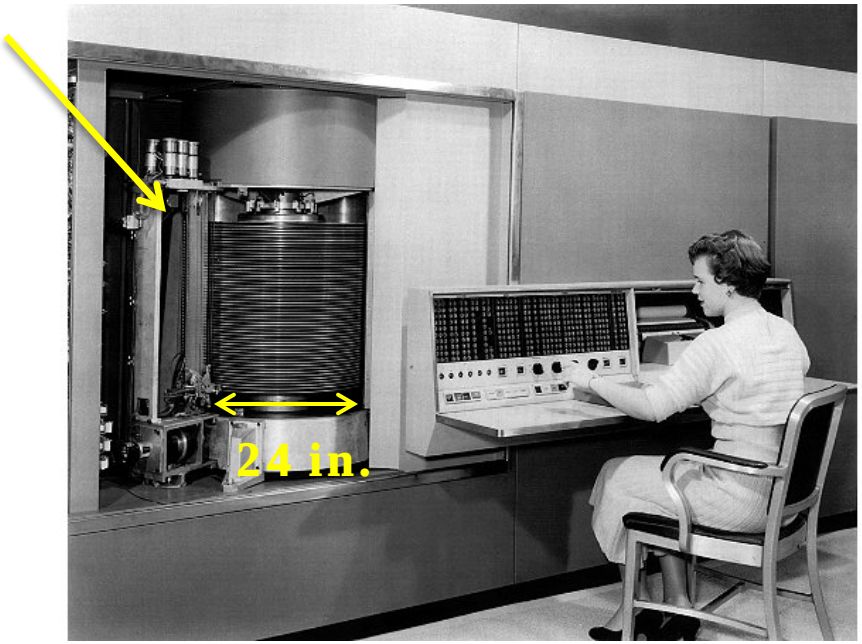

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2013: Seagate® Enterprise Turbo SSHD (600GB)

Hard Drives, A History

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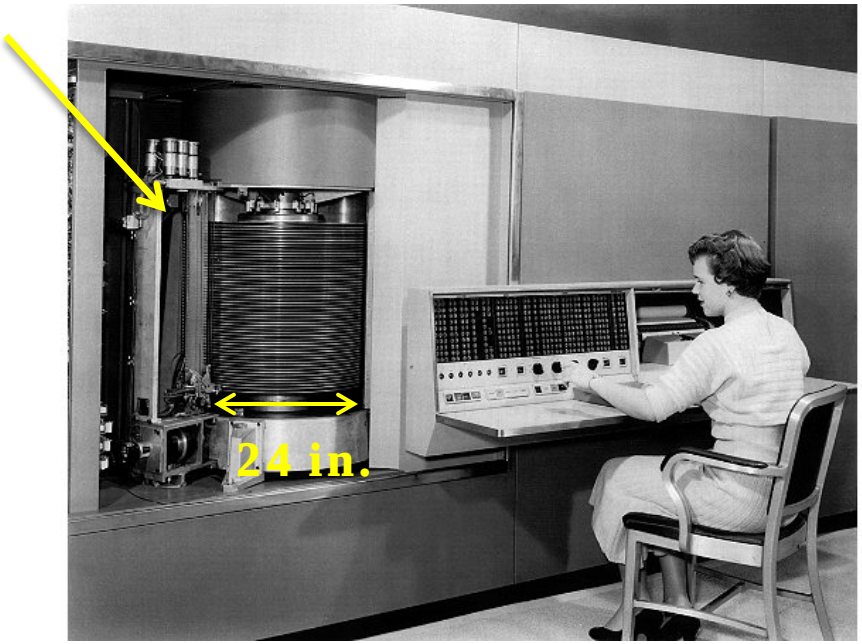

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2013: Seagate® Enterprise Turbo SSHD (600GB)

<http://www.seagate.com/internal-hard-drives/enterprise-hard-drives/sshd/enterprise-turbo-sshd/>

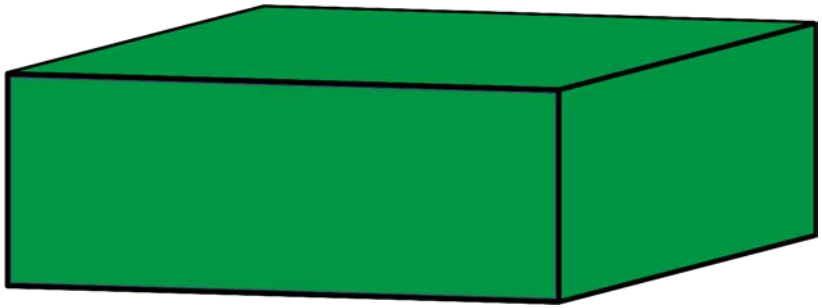
Read/Write Heads

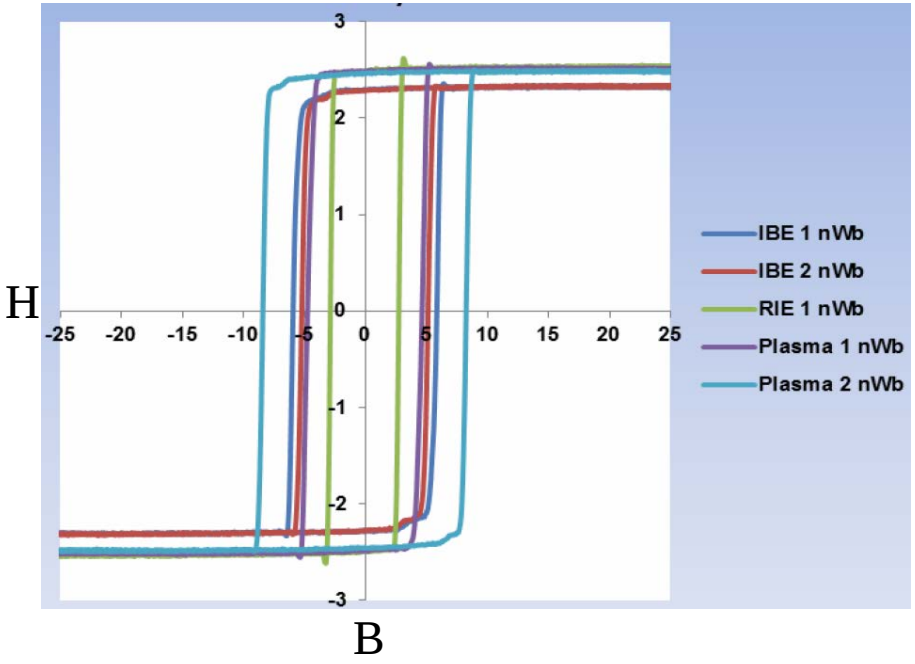
- Determines speed.
- Aggressive scaling to 10's nm.
- Fabrication of magnetic materials includes etching, milling and capping.
  - **This process damages the interfacial region of the materials!**

<http://www.123rf.com/photo_10466519_parts-of-hard-drive-in-close-up-read-write-head-and-platter.html>

CoFeB

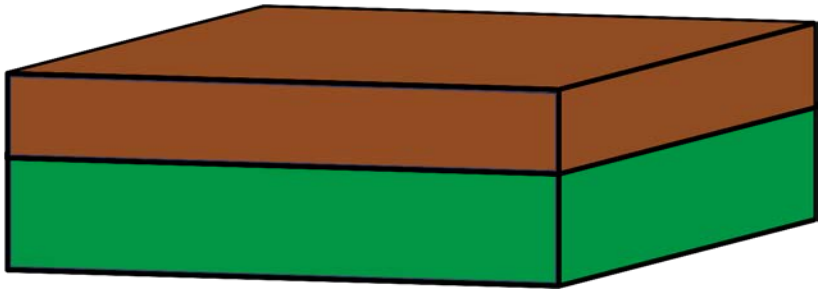
- Common read head material.
  - Ferromagnetic





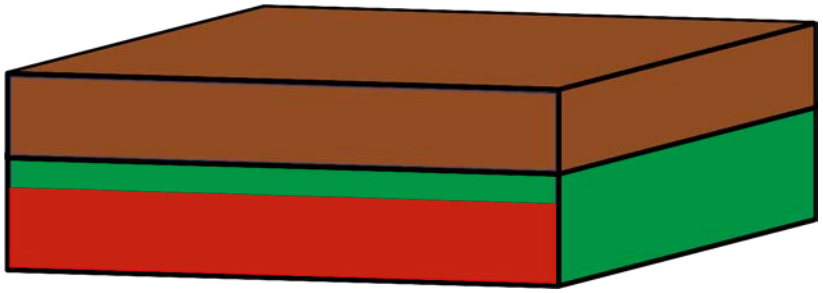
CoFeB

- Common read head material.
- Etching and capping changes electronic state at the interface.



CoFeB

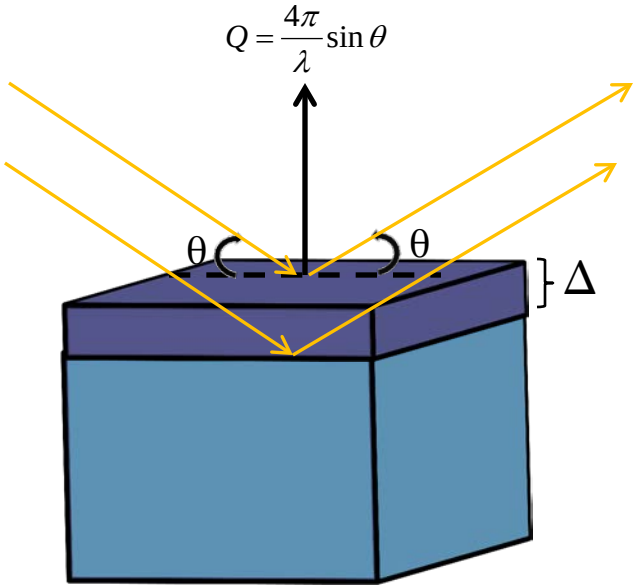
- Common read head material.
- Etching and capping changes electronic state at the interface.
- Dead layers up to 3.5 nm?



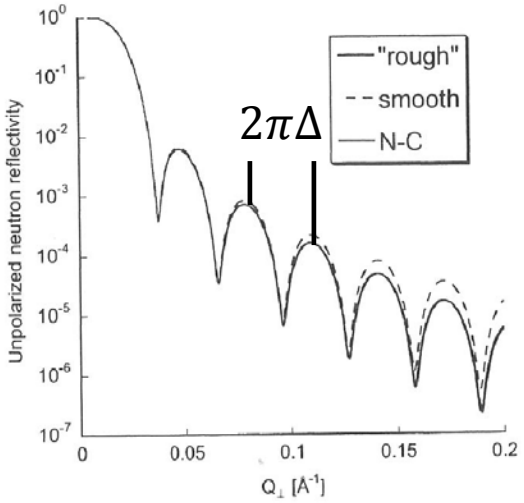
Proposition

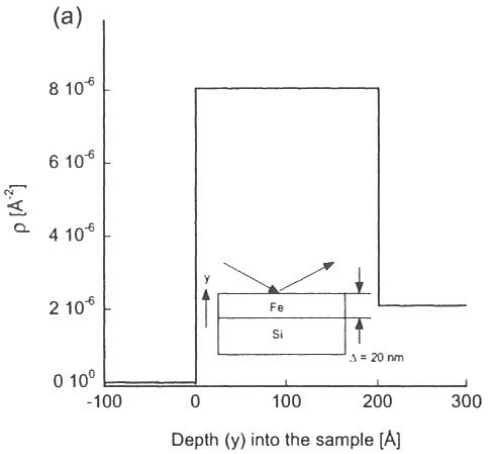
Use Polarized Neutron Reflectometry (PNR) to determine the nature of interfacial damage to magnetic materials produced by industrially relevant fabrication techniques.

Reflectometry



$$reflection \quad amplitude: \quad R(Q) = \left| \frac{4\pi}{iQ} \int \underline{\rho(z)} \psi(k_z, z) e^{ikz} dz \right|^2$$





"Modern Techniques for Characterizing Magnetic Materials." Ed. By Yimei Zhu. Kluwer Acad. Publishers (2005).

Why Neutrons?

- Highly penetrating with little absorption.
- Sensitive to nuclear composition (scatters from nuclei).
- **Magnetic**
  - Neutrons are made up of three quarks that distribute their charge radially creating a magnetic moment with no net charge.

Polarized Neutron Reflectometry

$$reflection\ \ amplitude: \ \ R(Q) = \left| \frac{4\pi}{iQ} \int \underline{\rho(z)} \psi(k_z, z) e^{ikz} dz \right|^2$$

- Non-spin flip scattering length density:

$$\rho_{\pm} = \rho_{nuclear} \pm \rho_{magnetic}$$

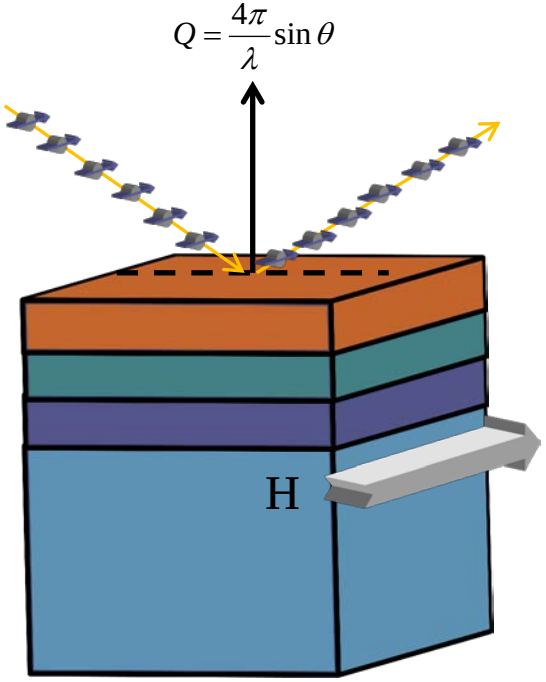
$$\rho_{nuclear} = \sum_i N_i b_i,$$

$$N = number\ \ density, \ \ b = scattering\ \ length$$

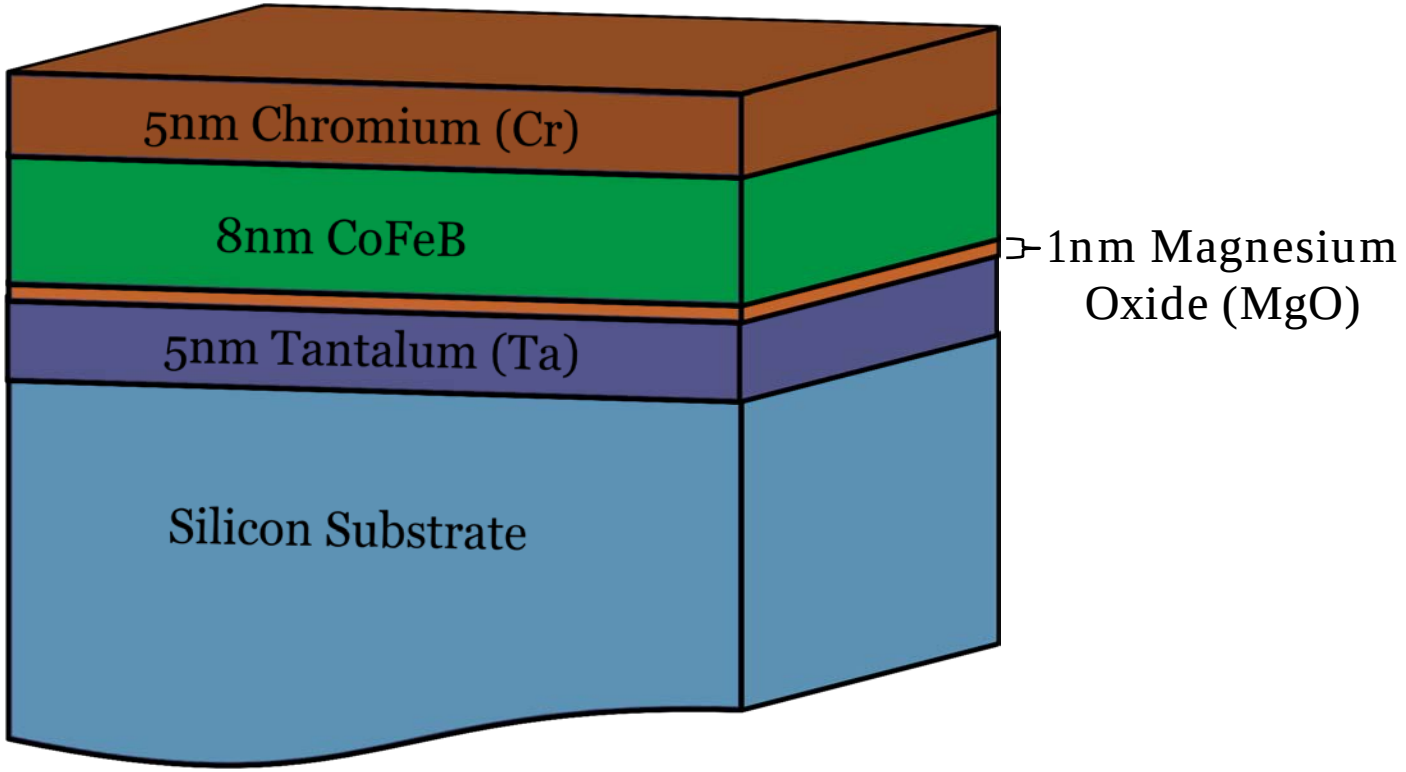
$$\rho_{magnetic} = CM,$$

$$C = const., \ \ M = in\ \ plane\ \ magnetization\ \ (M \| H)$$

- Spin flip scattering length density purely magnetic ($M \perp H$).

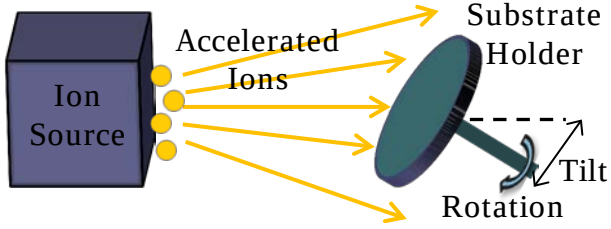


Expected Sample Structure

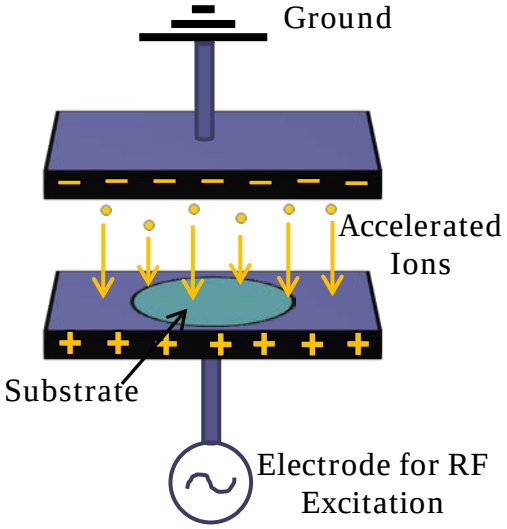


Etch Methods

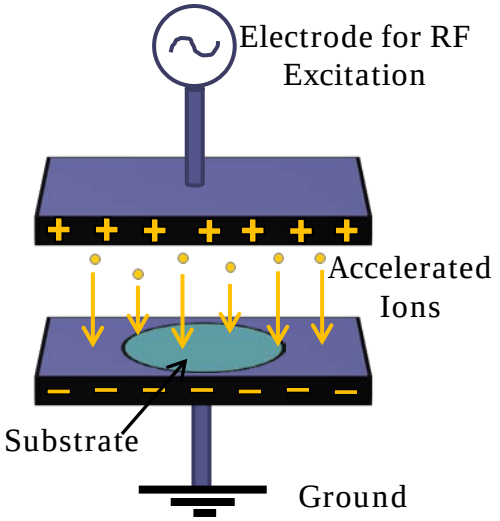
Ion Beam Etching (IBE)



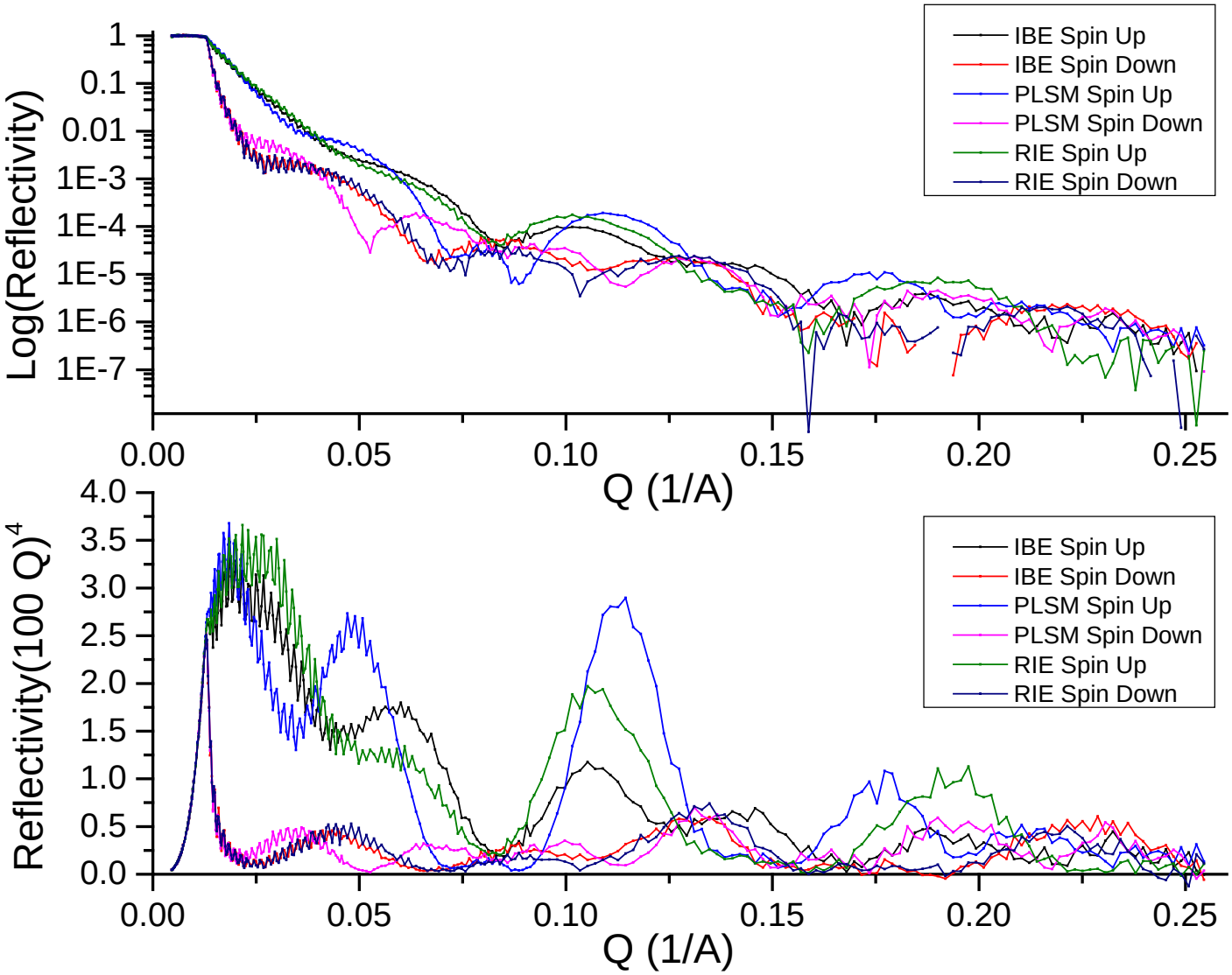
Reactive Ion Beam Etching (RIE)



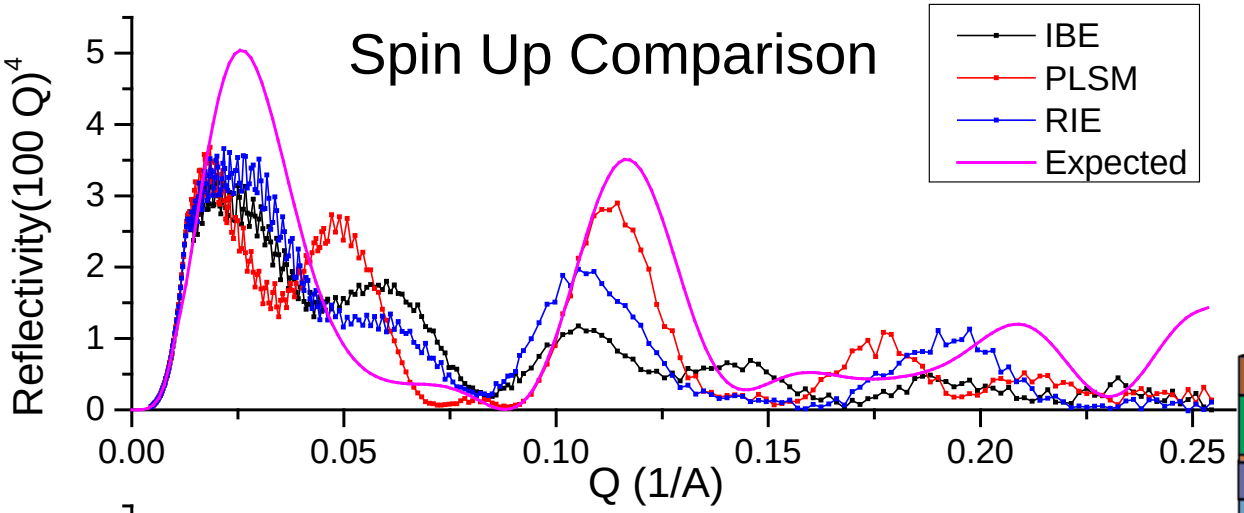
Plasma Etching (PLSM)

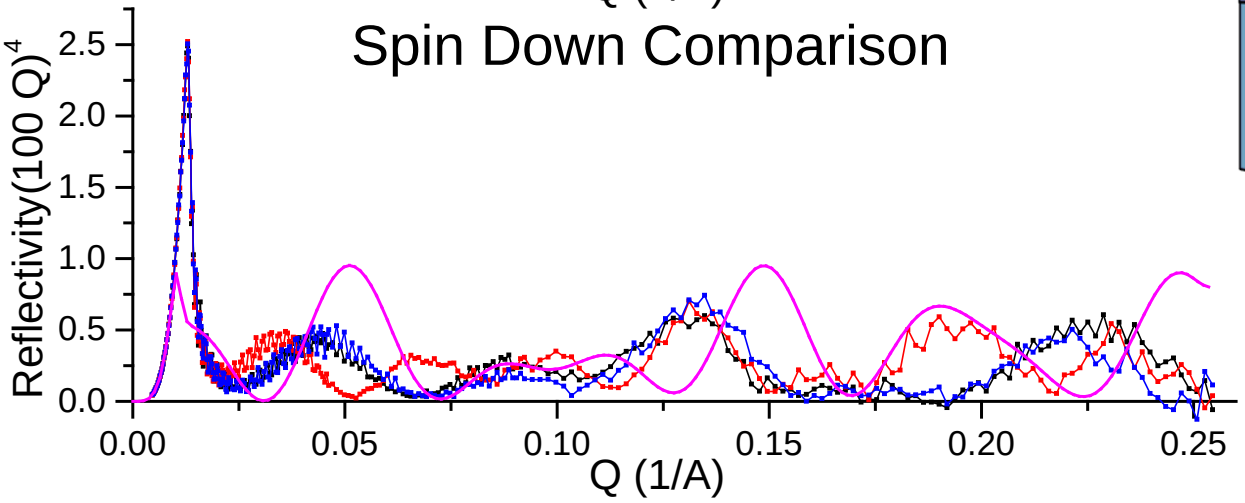


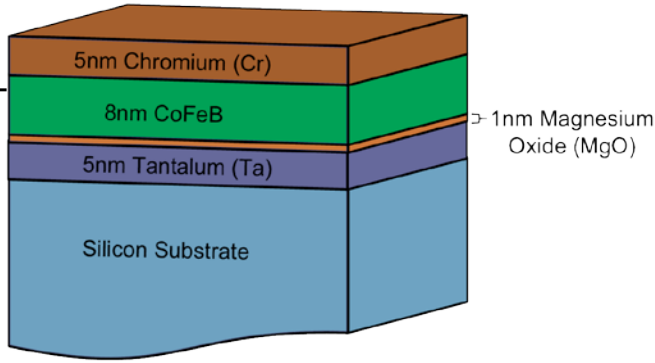
Results


Log(Reflectivity)
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
0.00
0.05
0.10
0.15
0.20
0.25
Q (1/A)
IBE Spin Up
IBE Spin Down
PLSM Spin Up
PLSM Spin Down
RIE Spin Up
RIE Spin Down
Reflectivity(100 Q)^4
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.00
0.05
0.10
0.15
0.20
0.25
Q (1/A)
IBE Spin Up
IBE Spin Down
PLSM Spin Up
PLSM Spin Down
RIE Spin Up
RIE Spin Down

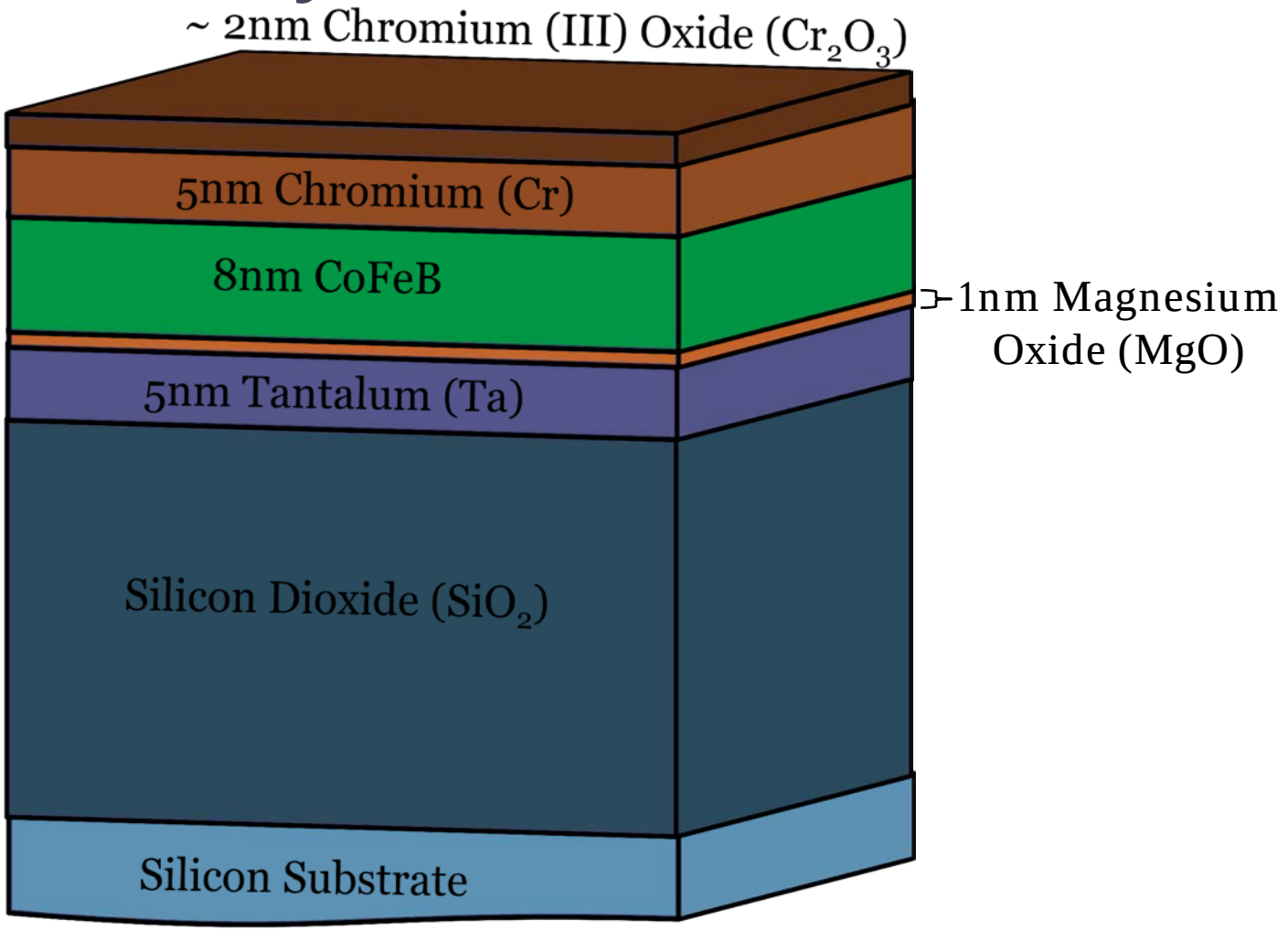
Step 1: Calculate what we expect



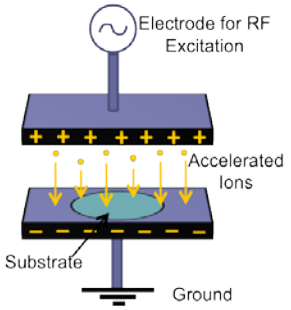


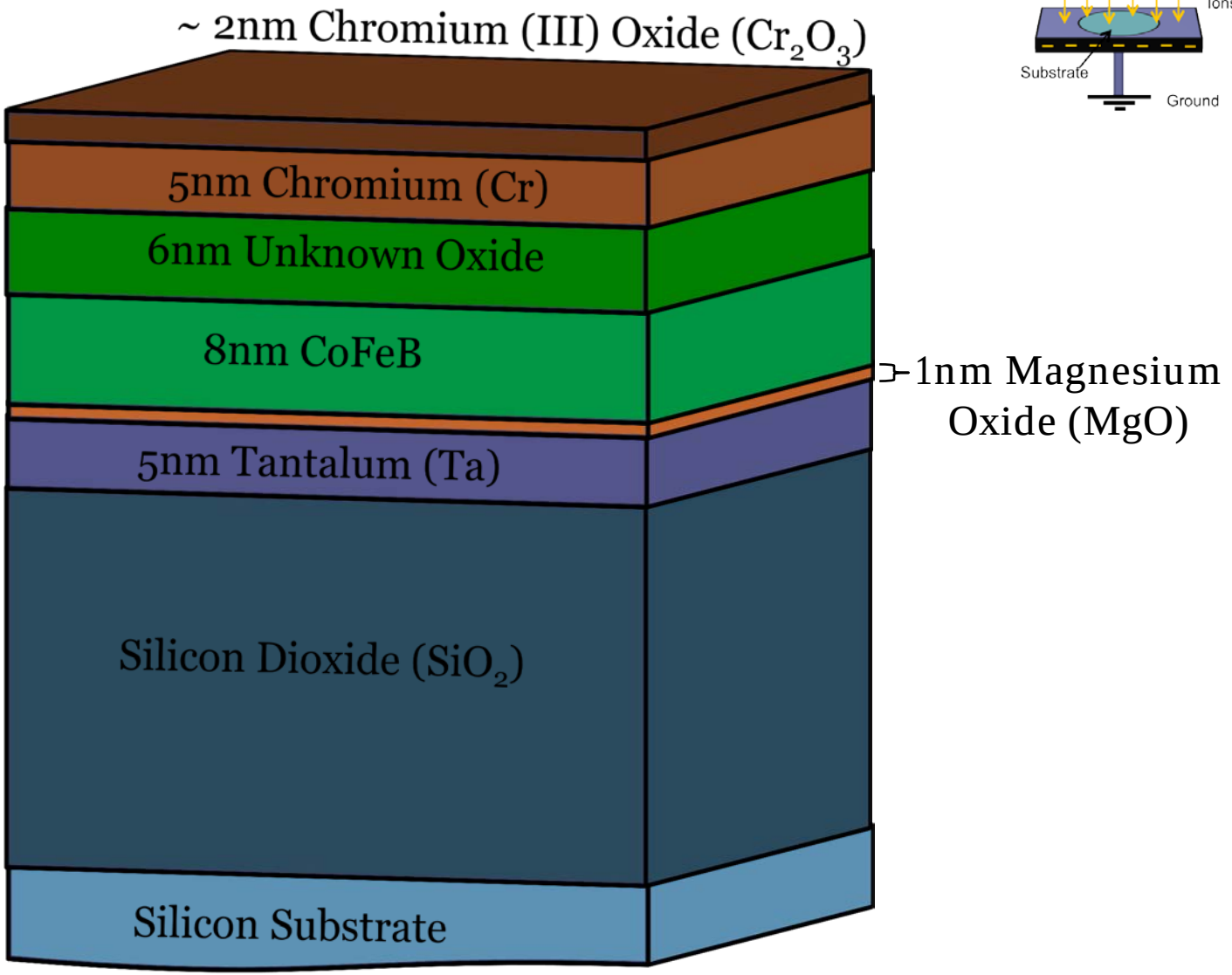


Step 2: Modify structure

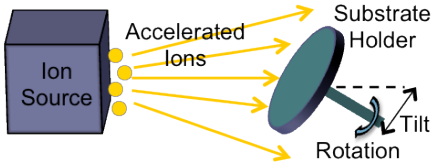


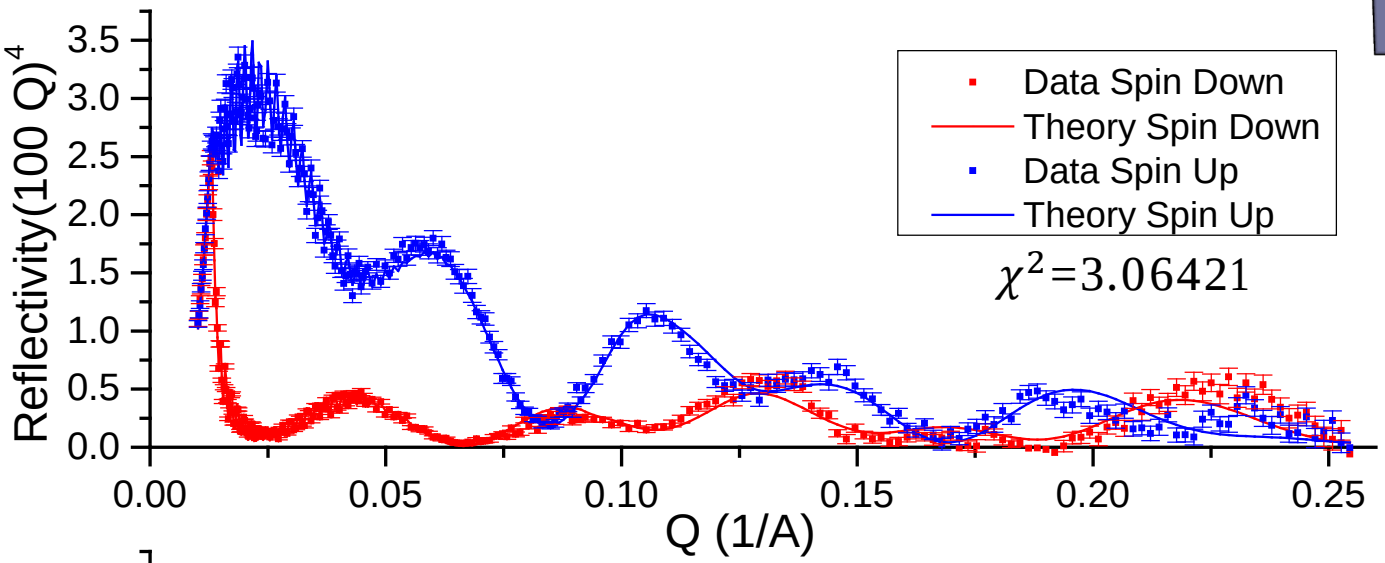
PLSM

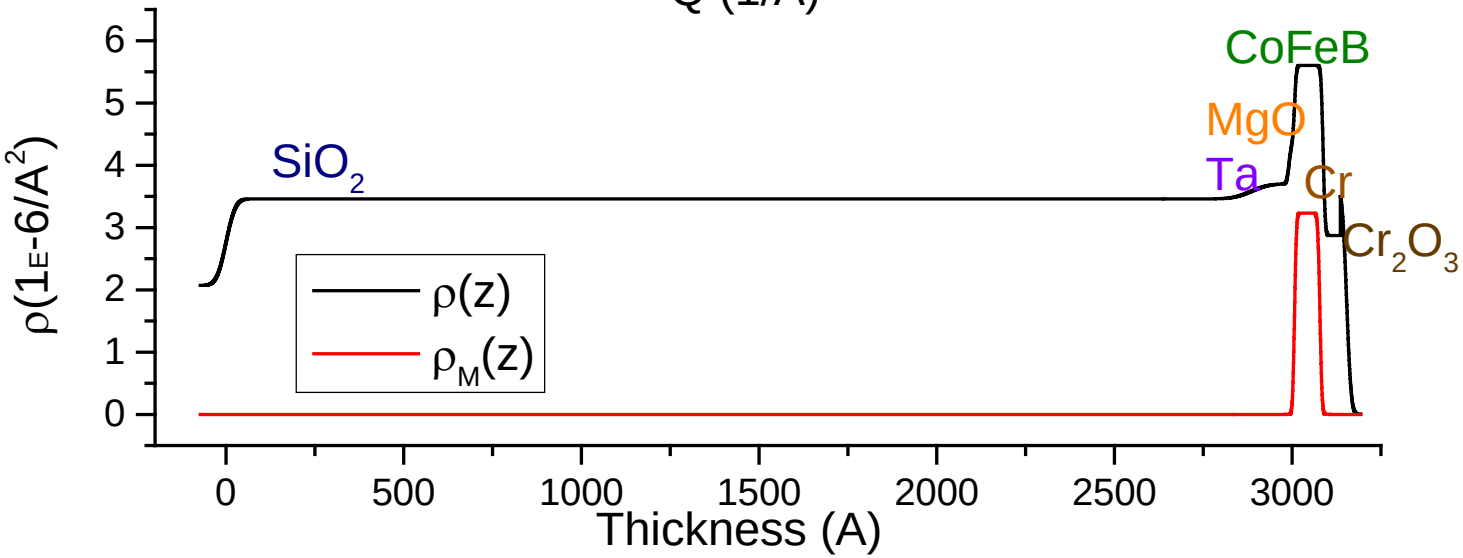

Electrode for RF Excitation
Accelerated Ions
Substrate
Ground

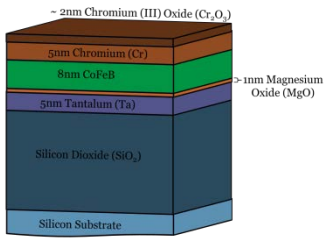

~ 2nm Chromium (III) Oxide (Cr_2O_3)
5nm Chromium (Cr)
6nm Unknown Oxide
8nm CoFeB
1nm Magnesium Oxide (MgO)
5nm Tantalum (Ta)
Silicon Dioxide (SiO_2)
Silicon Substrate

IBE

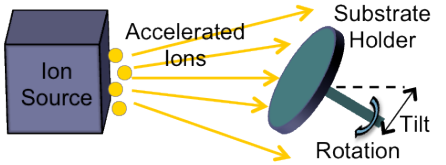

Ion Source
Accelerated Ions
Substrate Holder
Tilt
Rotation

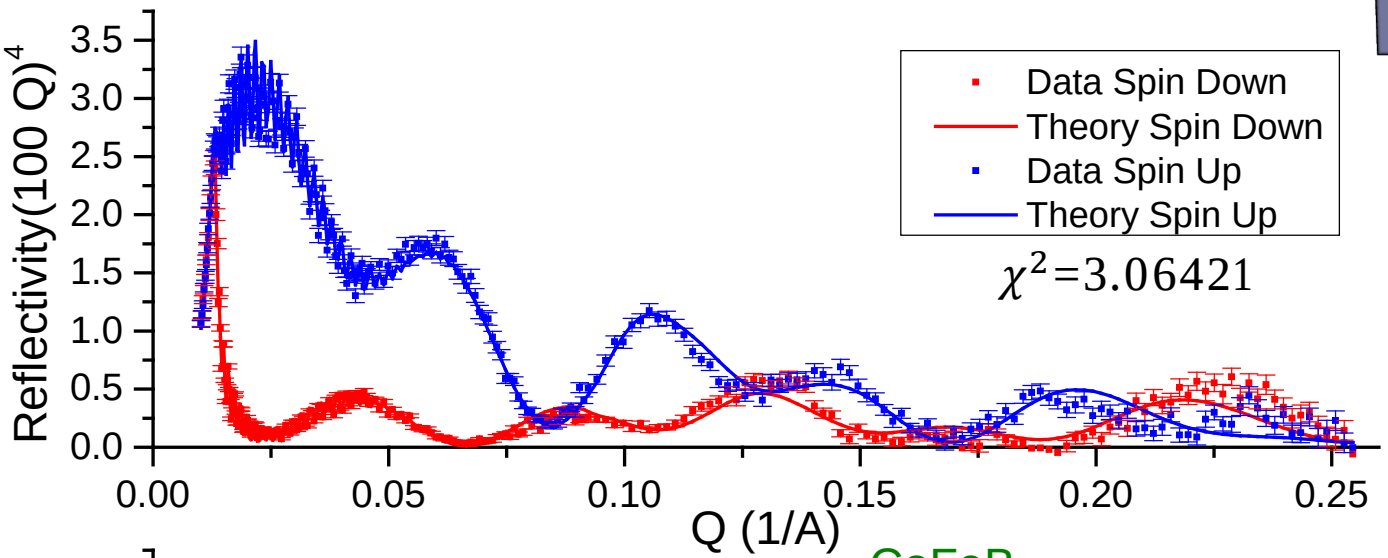

Reflectivity(100 Q)^4
Q (1/A)
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
χ^2=3.06421

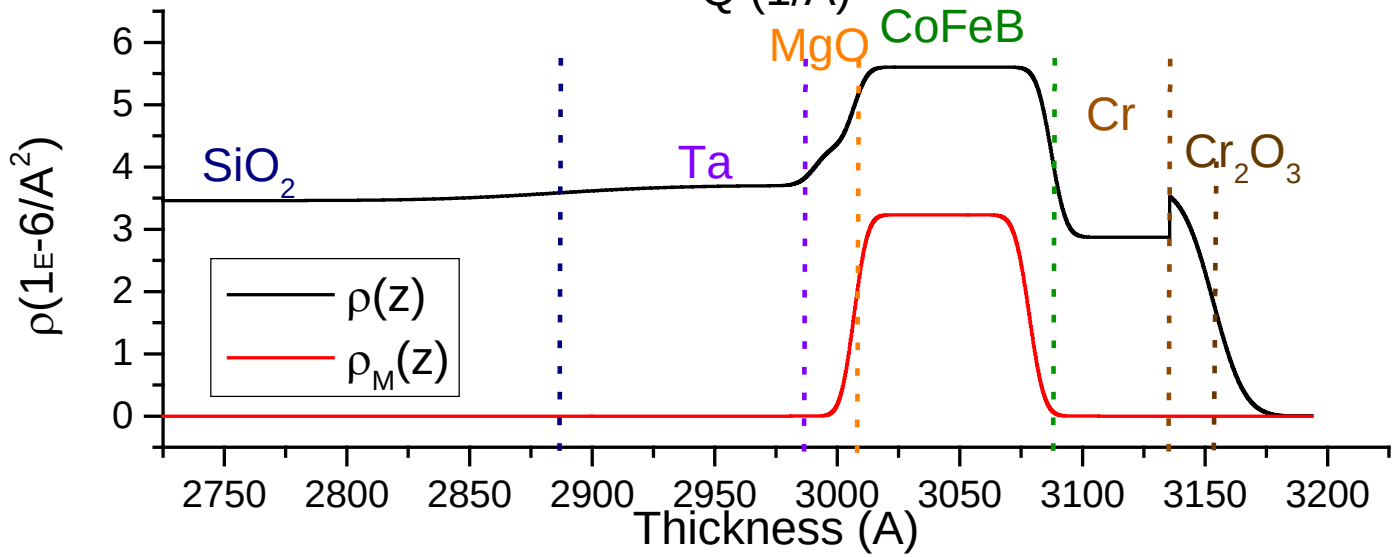

ρ(1E-6/A^2)
Thickness (A)
SiO2
CoFeB
MgO
Ta
Cr
Cr2O3
ρ(z)
ρM(z)

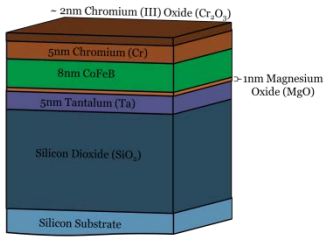

~ 2nm Chromium (III) Oxide (Cr2O3)
5nm Chromium (Cr)
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO2)
Silicon Substrate
~ 1nm Magnesium Oxide (MgO)

IBE


Ion Source
Accelerated Ions
Substrate Holder
Tilt
Rotation


Reflectivity(100 Q)^4
Q (1/A)
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
χ²=3.06421


ρ(1E-6/A²)
Thickness (A)
SiO2
Ta
MgO
CoFeB
Cr
Cr2O3
ρ(z)
ρM(z)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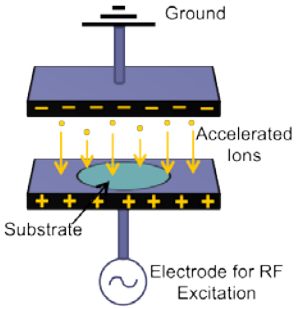
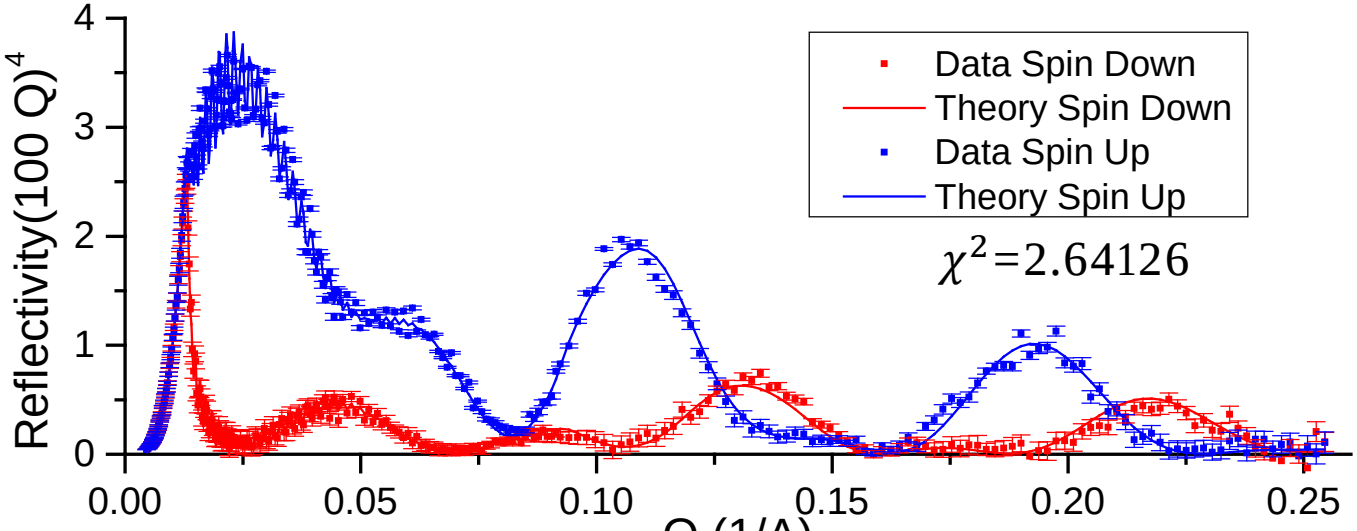
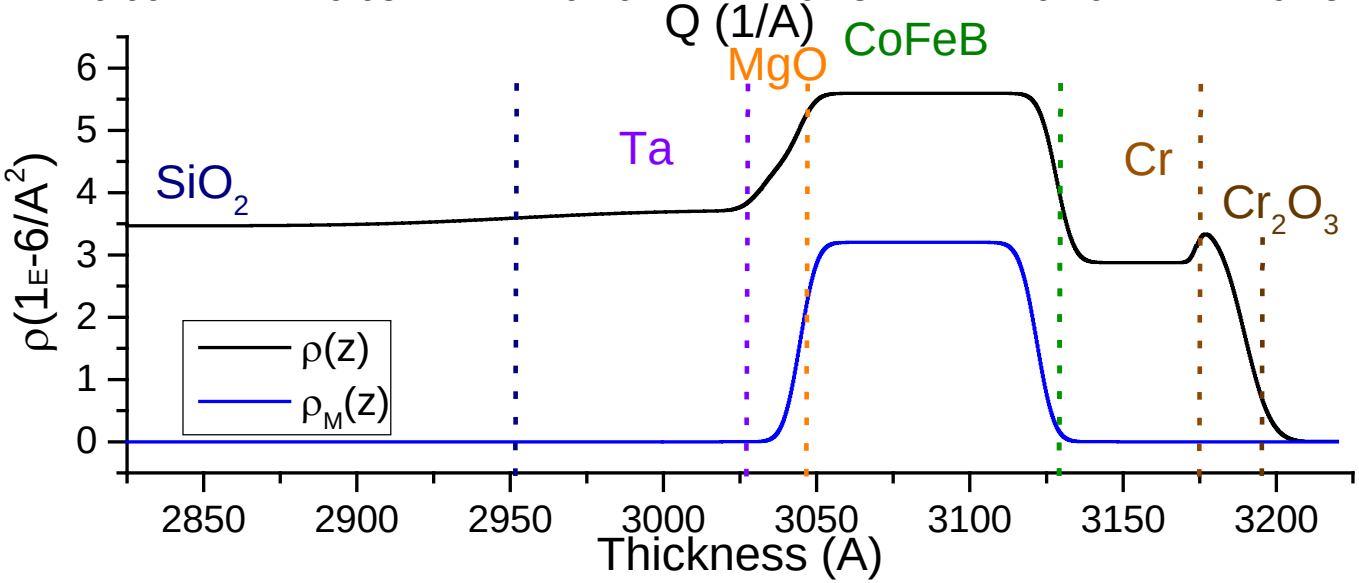
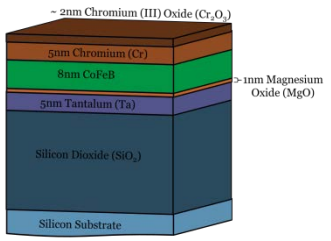
5nm Chromium (Cr)
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO2)
Silicon Substrate
~ 1nm Magnesium Oxide (MgO)

RIE


Ground
Accelerated Ions
Substrate
Electrode for RF Excitation


Reflectivity(100 Q)^4
Q (1/A)
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
χ²=2.64126


ρ(1E-6/A²)
Thickness (A)
SiO2
Ta
MgO
CoFeB
Cr
Cr2O3
ρ(z)
ρM(z)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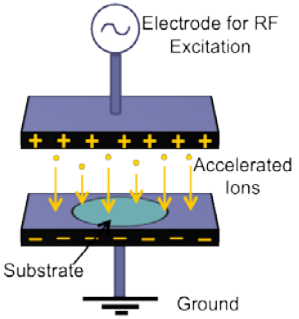
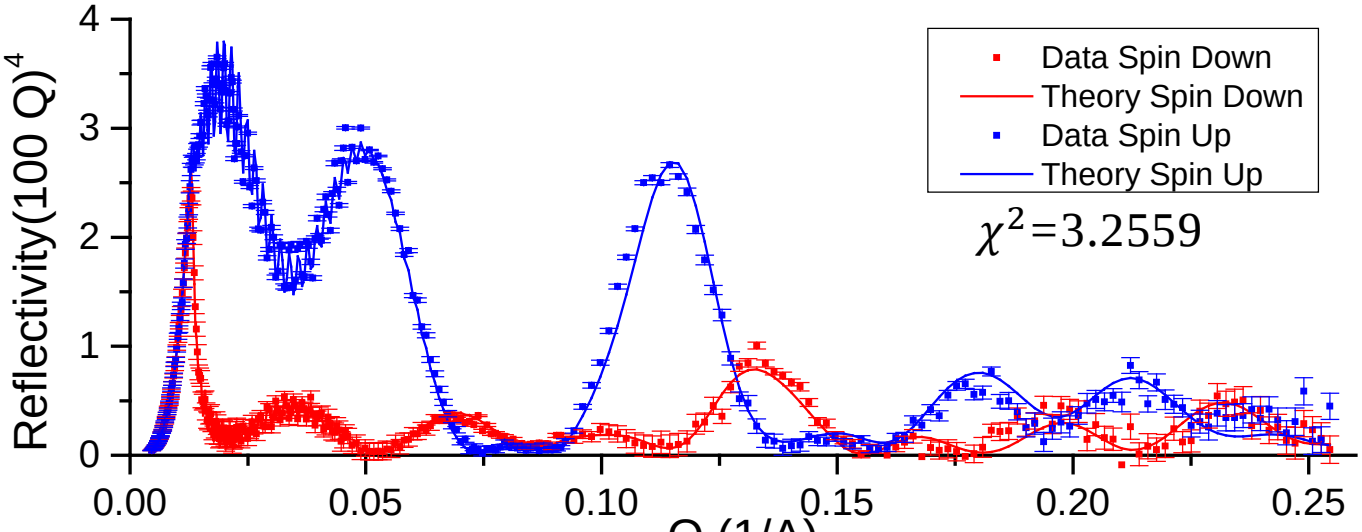
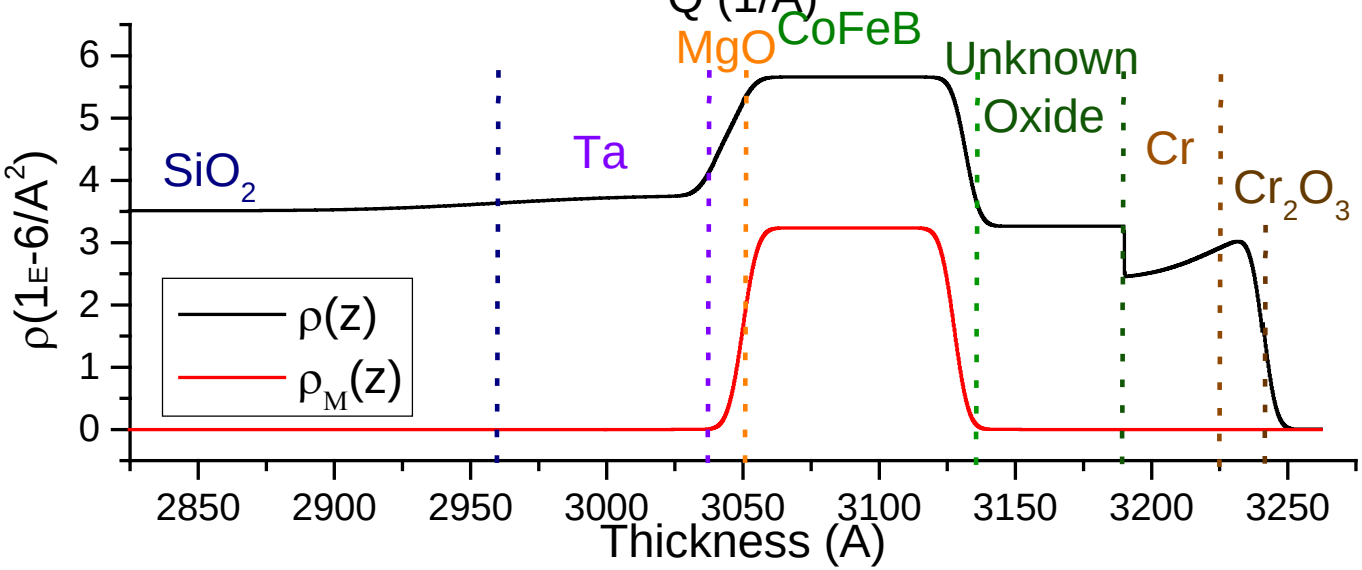
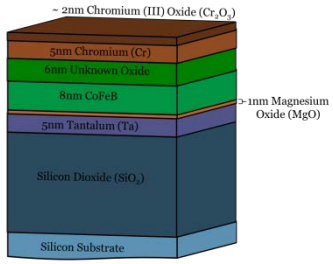
5nm Chromium (Cr)
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO2)
Silicon Substrate
~1nm Magnesium Oxide (MgO)

PLSM

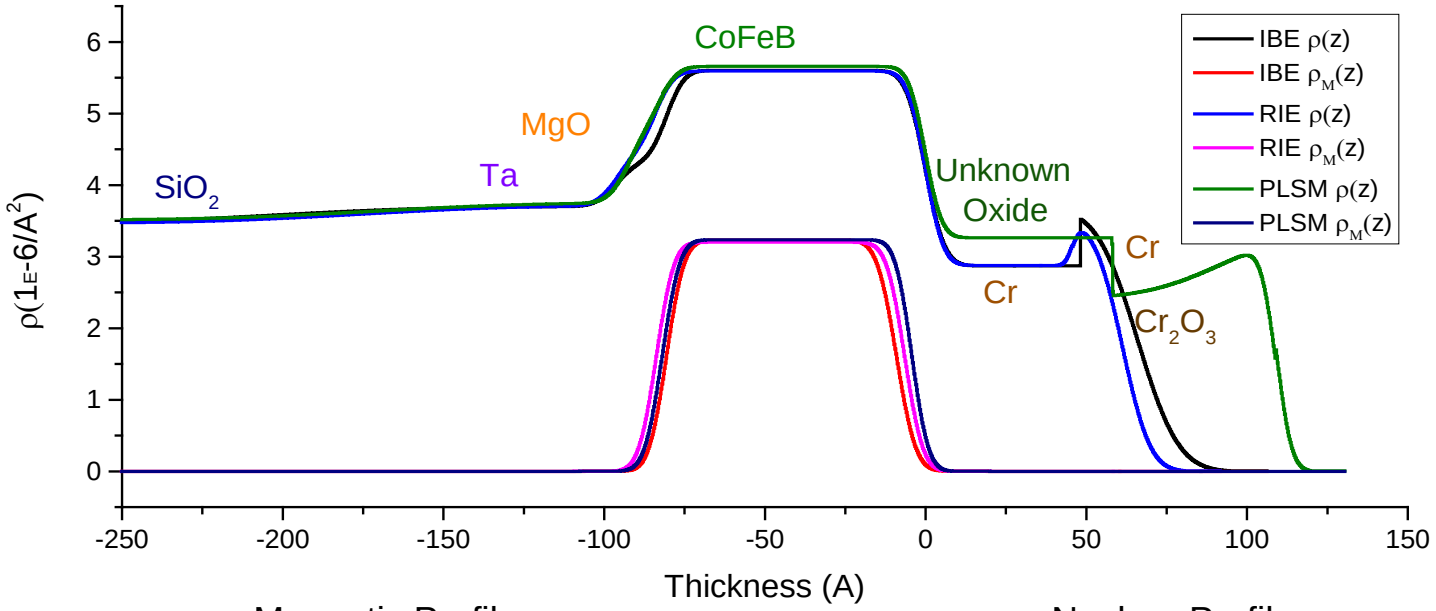

Electrode for RF Excitation
Accelerated Ions
Substrate
Ground


Reflectivity(100 Q)^4
Q (1/A)
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
χ²=3.2559

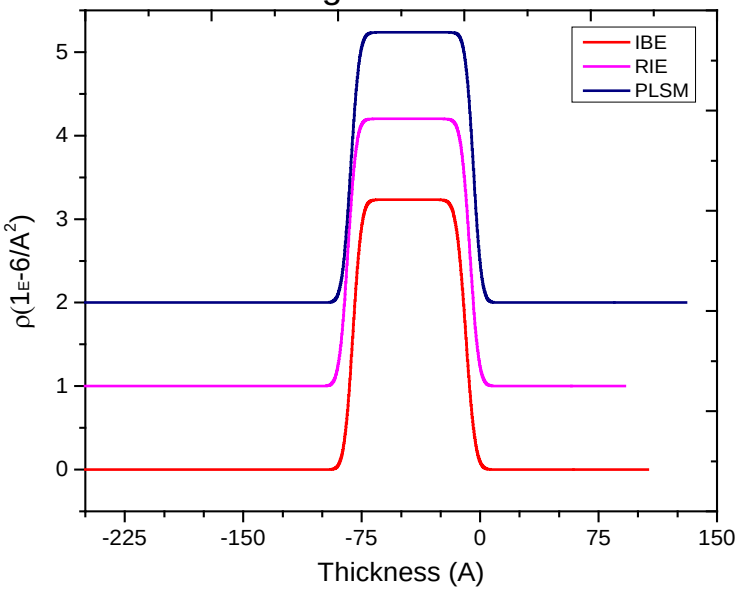

ρ(1E-6/A²)
Thickness (A)
SiO2
Ta
MgO
CoFeB
Unknown Oxide
Cr
Cr2O3
ρ(z)
ρM(z)


~ 2nm Chromium (III) Oxide (Cr2O3)
5nm Chromium (Cr)
6nm Unknown Oxide
8nm CoFeB
~ 1nm Magnesium Oxide (MgO)
5nm Tantalum (Ta)
Silicon Dioxide (SiO2)
Silicon Substrate

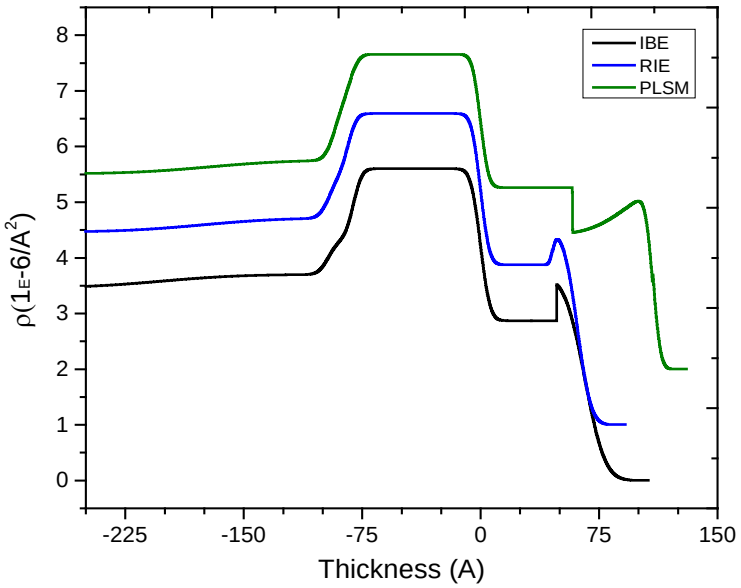
Normalized Profile



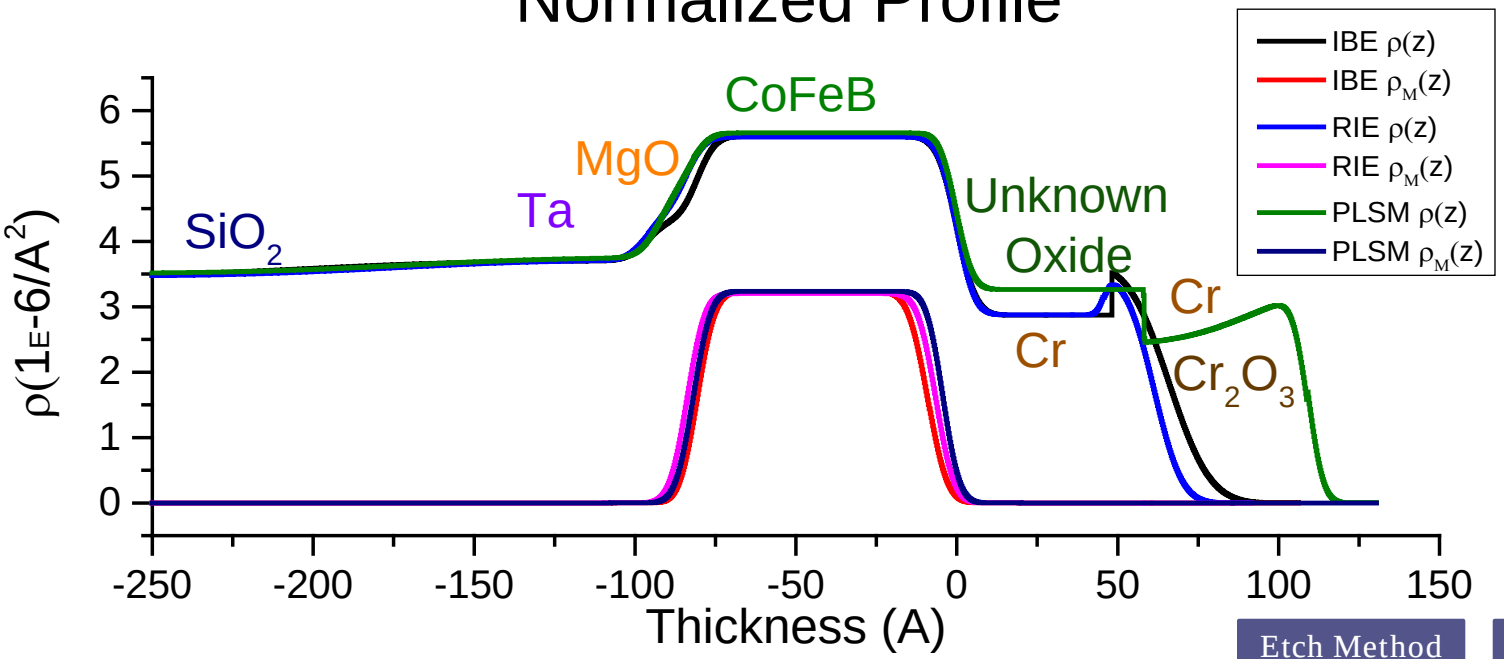
Magnetic Profile

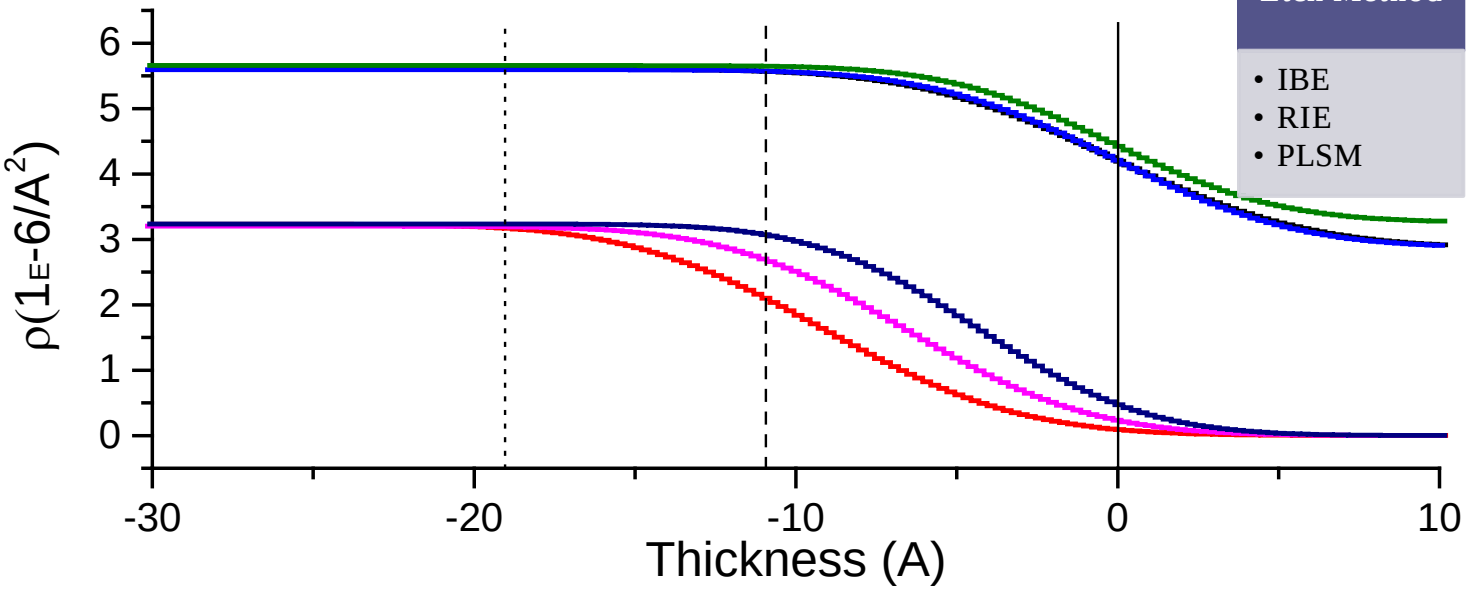


Nuclear Profile



Normalized Profile



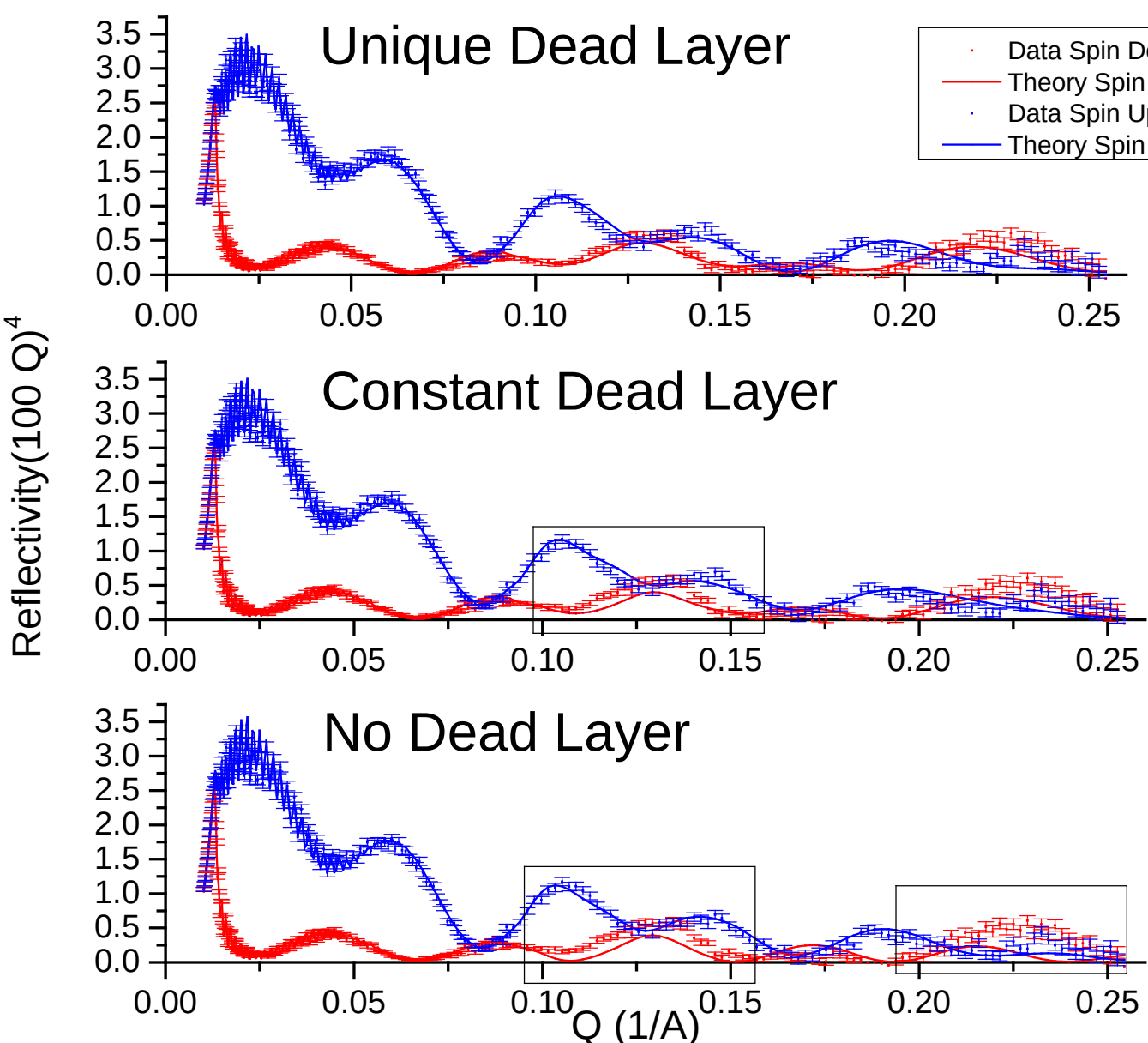


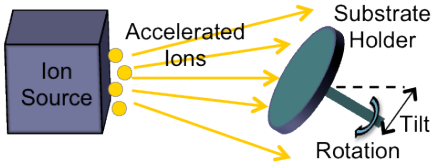
Etch Method	Dead Layer
• IBE	• 8.97129 A
• RIE	• 6.378326 A
• PLSM	• 4.153826 A

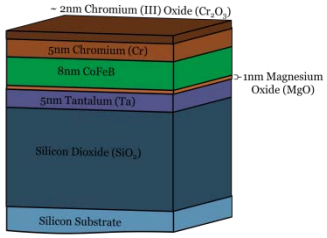
Step 3: Verify model

- Are we sure the differences are magnetic and not structural?
  - Constant dead layer.
  - No dead layer.

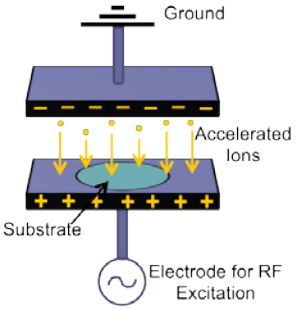
IBE

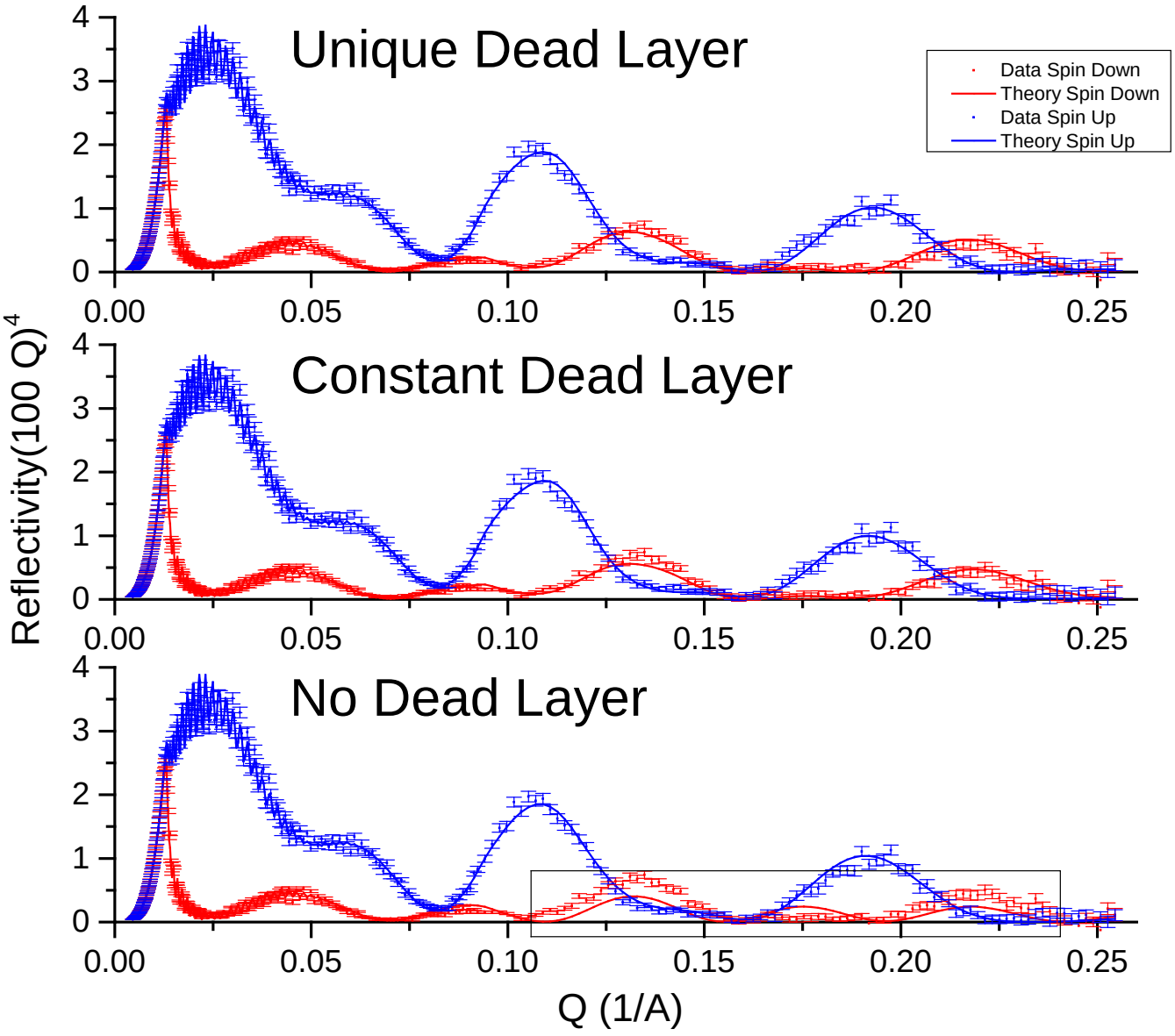

Unique Dead Layer
Constant Dead Layer
No Dead Layer
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
Reflectivity(100 Q)^4
Q (1/A)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0.00
0.05
0.10
0.15
0.20
0.25

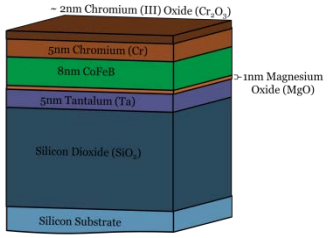

Ion Source
Accelerated Ions
Substrate Holder
Tilt
Rotation


~ 2nm Chromium (III) Oxide (Cr_2O_3)
5nm Chromium (Cr)
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO_2)
Silicon Substrate
~ 1nm Magnesium Oxide (MgO)

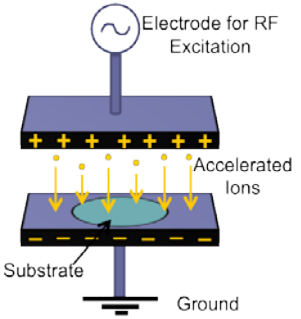
RIE

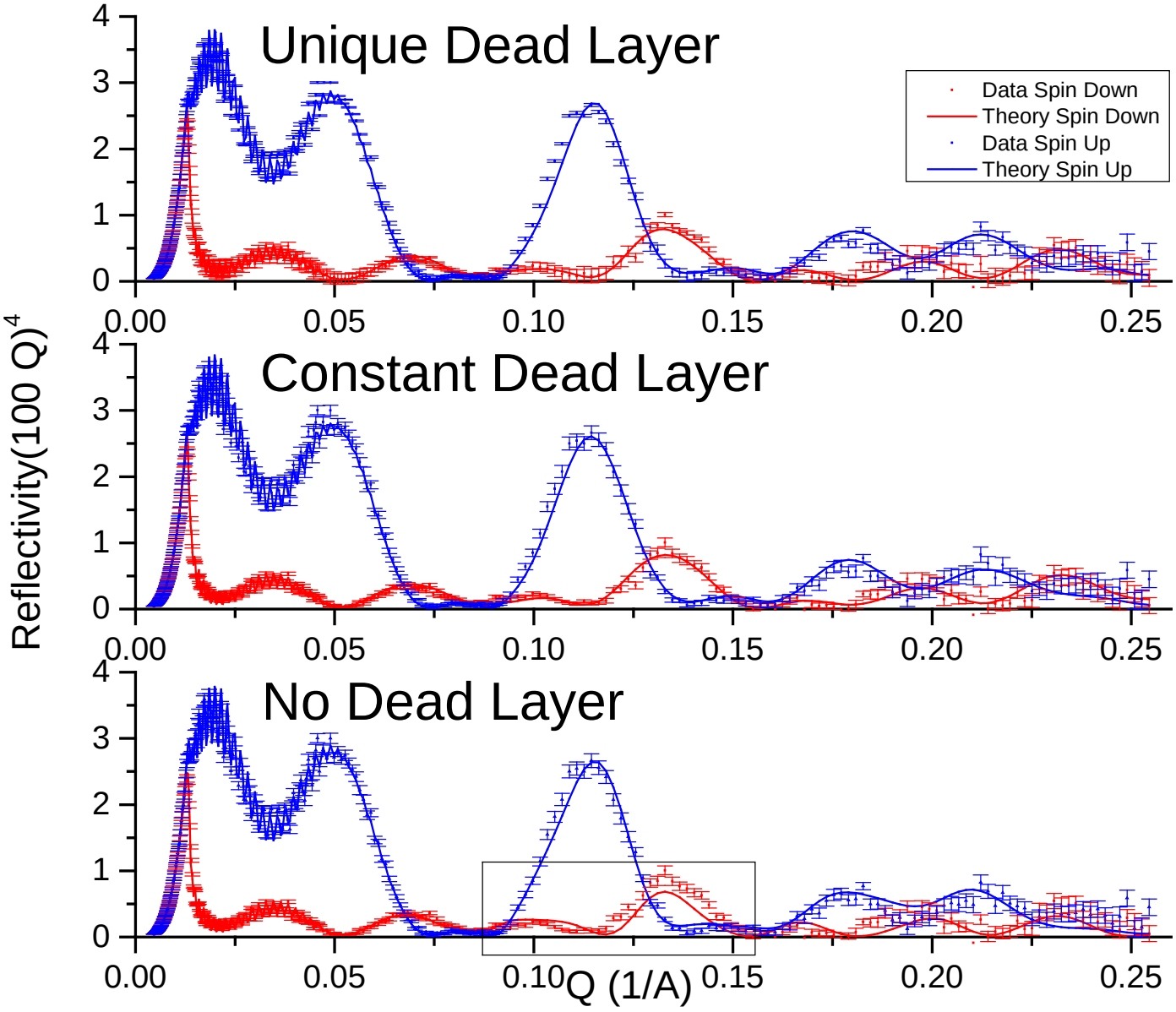

Ground
Accelerated Ions
Substrate
Electrode for RF Excitation

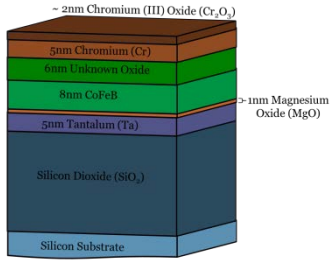

Unique Dead Layer
Constant Dead Layer
No Dead Layer
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
Reflectivity(100 Q)^4
Q (1/A)
0.00
0.05
0.10
0.15
0.20
0.25
0
1
2
3
4


~ 2nm Chromium (III) Oxide (Cr_2O_3)
5nm Chromium (Cr)
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO_2)
Silicon Substrate
~ 1nm Magnesium Oxide (MgO)

PLSM

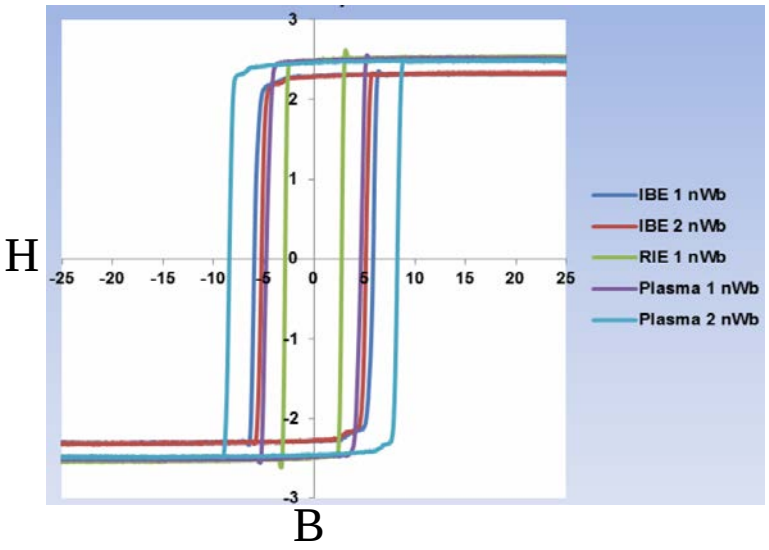

Electrode for RF Excitation
Accelerated Ions
Substrate
Ground

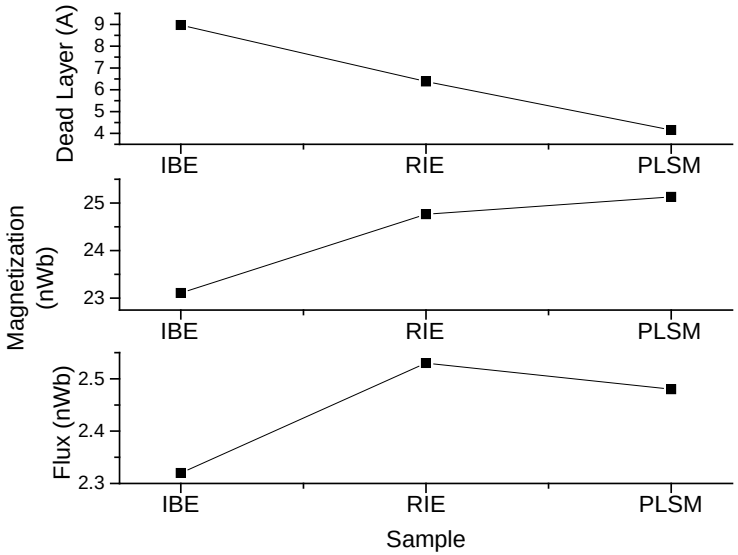

Unique Dead Layer
Constant Dead Layer
No Dead Layer
Data Spin Down
Theory Spin Down
Data Spin Up
Theory Spin Up
Reflectivity(100 Q)^4
Q (1/A)
0.00
0.05
0.10
0.15
0.20
0.25
0
1
2
3
4


~ 2nm Chromium (III) Oxide (Cr_2O_3)
5nm Chromium (Cr)
6nm Unknown Oxide
8nm CoFeB
5nm Tantalum (Ta)
Silicon Dioxide (SiO_2)
Silicon Substrate
~ 1nm Magnesium Oxide (MgO)

Trend

- Dead layer does not match expected
- Comparison of integrated magnetization with magnetic flux.





In Conclusion

- Fit is sensitive to dead layer, not just structural differences.
- Ion Beam Etching appears to have the most damage while Plasma Etching has the least.
- Magnetization consistent with Seagate data.

Future Considerations

- X-Ray Reflectometry to verify nuclear structure.
- TEM for a better image of the depth profile

Acknowledgements

- Brian Kirby
- Seagate Collaborators:
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