Improving Magnetic Media Storage Capacity Using Phenomena Seen in Magnetic Multilayers

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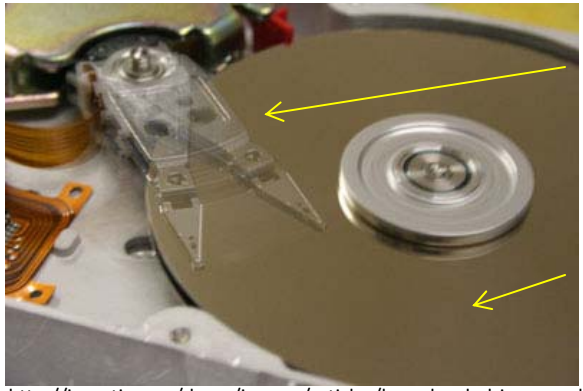
Magnetic Media - Current Technology



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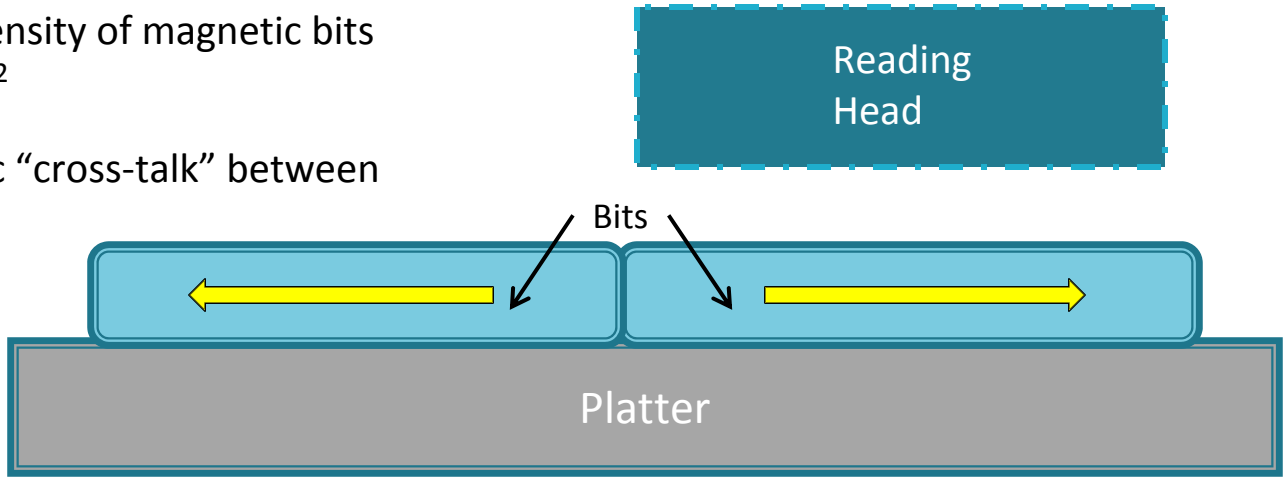
Platter:
Made of a thin film with magnetic domains that are magnetized to store information – form "bits"

Reading/Writing:
The reading arm is able to detect the direction of magnetization of a given bit.

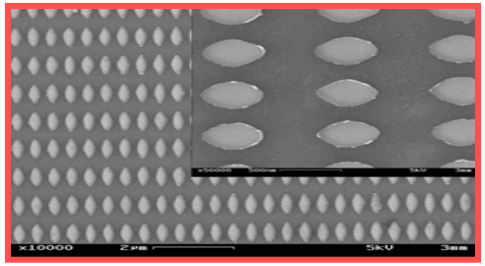
Storage Capacity:
- Want to increase density of magnetic bits to the level of Tb/in^2

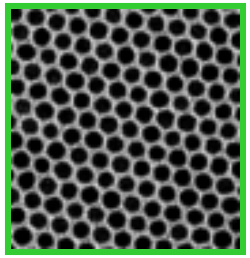
- Limited by magnetic "cross-talk" between bits



Magnetic Media - Improving Storage Capacity

Patterned nanoparticles:
- Physically separate magnetic domains





Reduce magnetic cross-talk
- Reorient the magnetic axis out-of-plane to reduce magnetic interaction between bits

- Normally, ferromagnetic films prefer to magnetize in-plane so the energy requirements to rotate the axis are prohibitively large

- By exploiting interface effects, it is possible to reduce this energy and even force the "easy-axis" to be the perpendicular axis

Bulk material: magnetized in-plane

$Co_1|Ni_2$ Multilayer: magnetized out-of-plane

Magnetic Multilayers as a Source of Normal Magnetization

Magnetic Axis Rotation in Multilayers:

• If grown on Au substrate, [x Co | 2x Ni] multilayers up to x = 6 angstroms have their magnetic easy-axis parallel to the sample normal

• If grown on Cu substrate though, even the thinnest multilayers magnetize in-plane

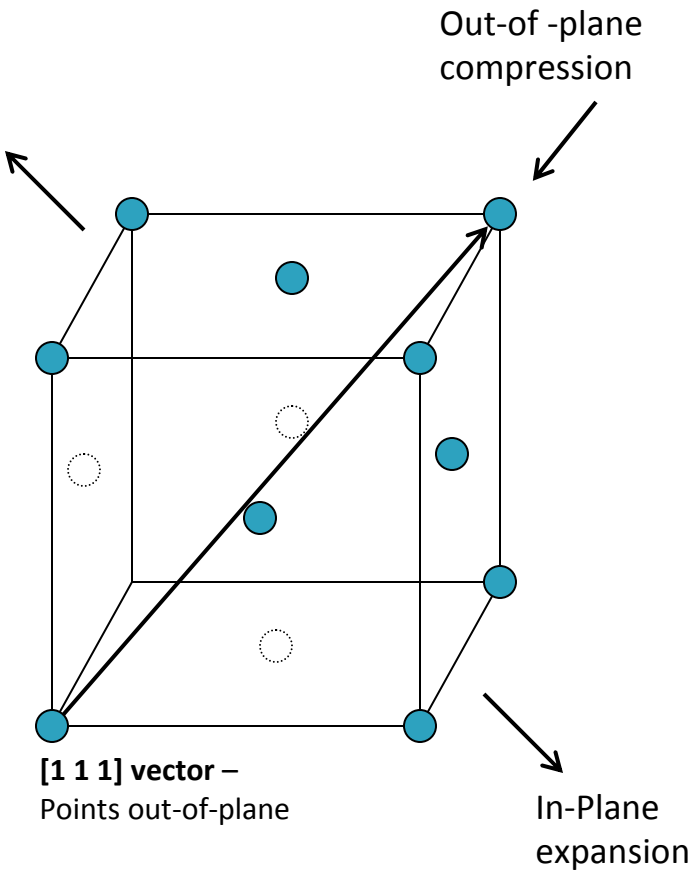
Possible Explanation: <u>Lattice strain</u>

• In such thin-film samples Cu, Co, and Ni all form very similar face-centered cubic crystal lattices.

• Co|Ni appears to be strained by the Cu (diffraction data):

- ➢ out-of-plane compression by 0.64%
- ➢ in-plane expansion by 1.3%

• Lattice strain increases the energy required to pull the magnetic axis out of plane enough to negate the multilayer effect



Strained Face centered cubic structure

Magnetic Multilayers – Purity of Layers

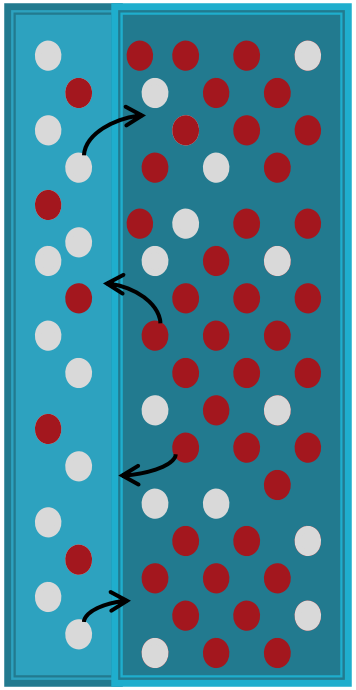
Alternate Explanation – <u>Multilayer is not Pure</u>

- Co_1Ni_2 alloy would clearly not show magnetic axis rotation.

- **Needed to show that the samples were <u>truly layered</u> for the lattice strain hypothesis to make sense**

- Since layers are so thin, atomic diffusion during fabrication could have prevented well-defined layers from forming.

- **Method:** Use a combination of <u>x-ray and neutron reflectivity</u> as a probe of the crystal and magnetic structure of our samples



Expected Structure of the Sample

Layer	Thickness (Å)
Pt	50
Cu	100
Co | Ni	6 | 12 (perfect layering)
Cu	100
Pt	50

Specular Reflectivity as a Probe of Structure

General Principle

- Reflected waves interact constructively/ destructively depending on incident angle, wavelength, and lattice spacing to produce a measurable scattered wave

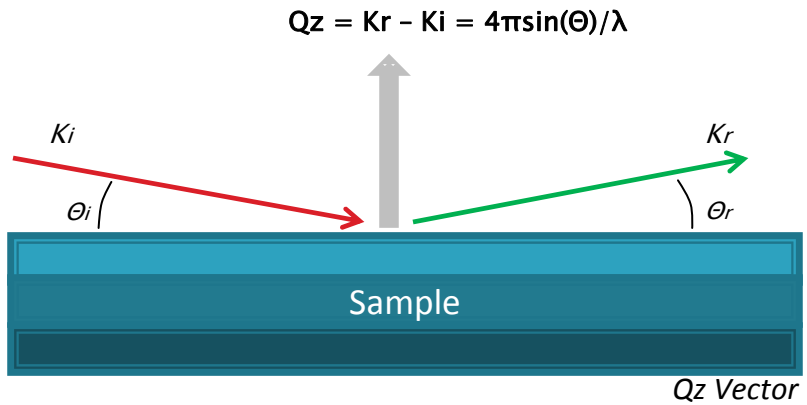
- Measure intensity of scattered wave at various scattering angles

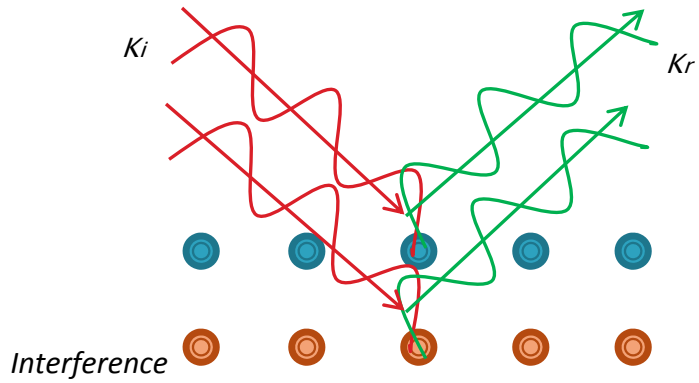
Sensitivity

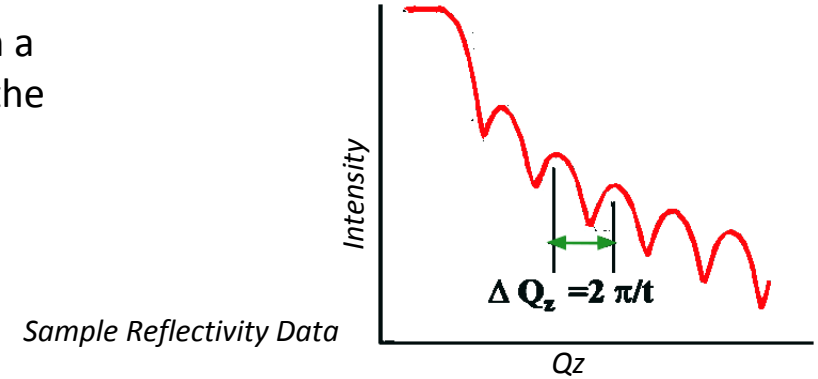
- Intensity at a certain angle is determined by **depth dependant** changes in "index of refraction".

- "Index of refraction" is **material-specific** so can be used to determine layer composition.

- Result is peaks occurring approximately with a frequency of $2\pi/t$ where t is the thickness of the scattering layer







Reflectivity – Why use X-Rays?

Properties of X-Rays:

- Intensity of scattering is dictated by **electromagnetic effects**, proportional to Z^2, where Z is the number of electrons

- Ability of a certain atom to scatter x-rays is dictated by its **Scattering Length Density (SLD),** which depends on its "atomic scattering factor" and its crystal structure.

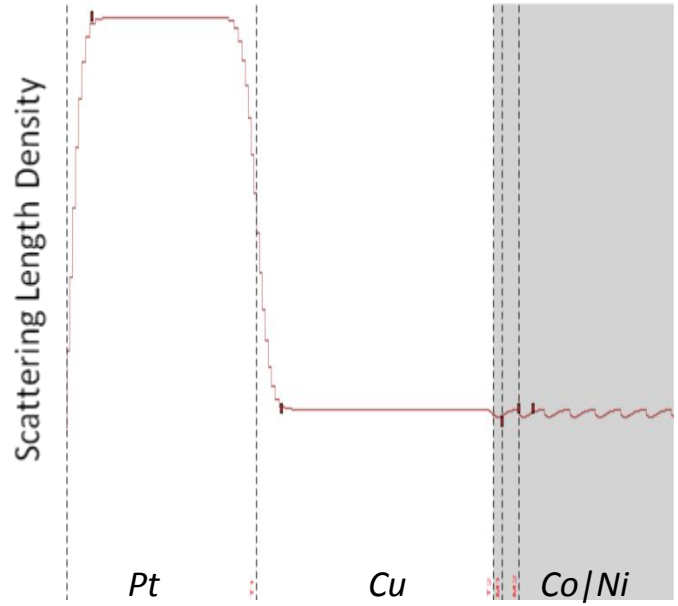
Use in Determining Structure:

- Pt is very different from Cu, Co, and Ni in its electron structure, so its thickness and purity can be determined very precisely

- X-Rays are sensitive to the **overall thickness** of Cu and the Co | Ni multilayer

- Cannot distinguish between layers within the multilayer

X-Ray Scattering Length Densities of Pt, Cu, Co, Ni



Reflectivity – Why use Neutrons?

Properties of Neutrons

• Have a magnetic moment but no charge so can be used to probe **nuclear structure** and **magnetization**

• Have a spin so can be polarized to determine internal magnetization

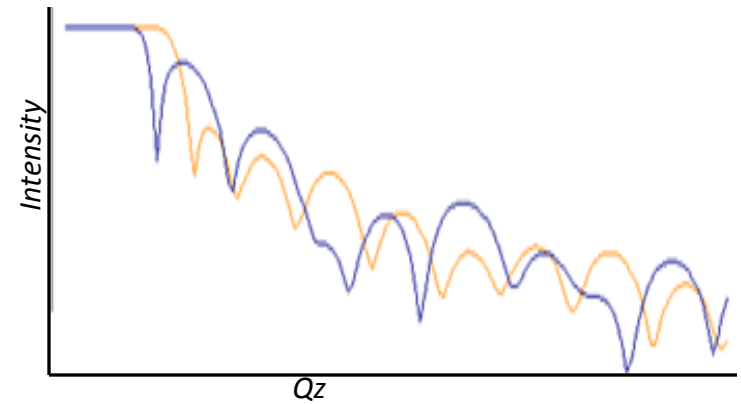
Use in Determining Structure:

• Can **distinguish between the Co and Ni** since, to neutrons, they are very different both structurally and magnetically

• Can determine the direction of **internal magnetization**

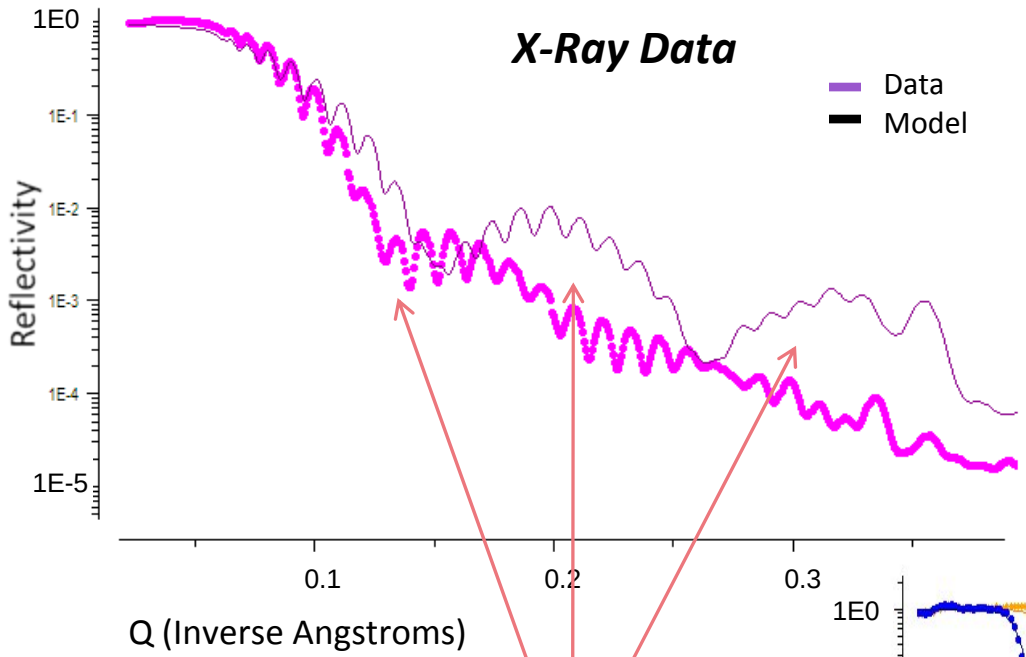
• Can be used to determine magnetic purity

Polarized Neutron Scattering Sample Data



Since neutron scattering is in general given by a relation of the form N ± M, where N gives the nuclear scattering and M gives the polarization- dependant magnetic scattering, when this equation is squared to yield intensity, the result is $N^2 \pm 2NM + M^2$, where the ±2NM term accounts of the "beating oscillations" seen on the graph above.

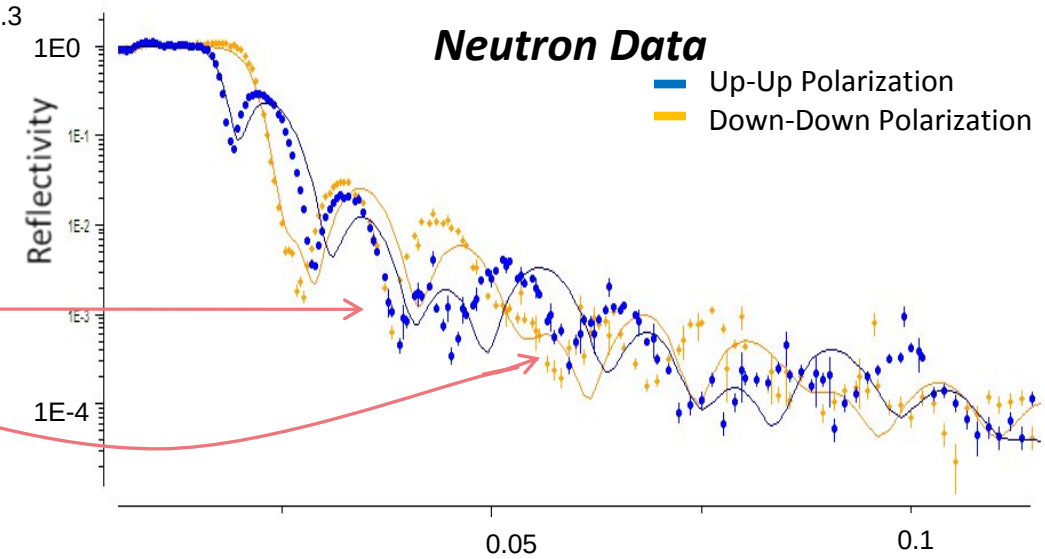
Reflectivity Data and Models
- Perfectly Layered Model -



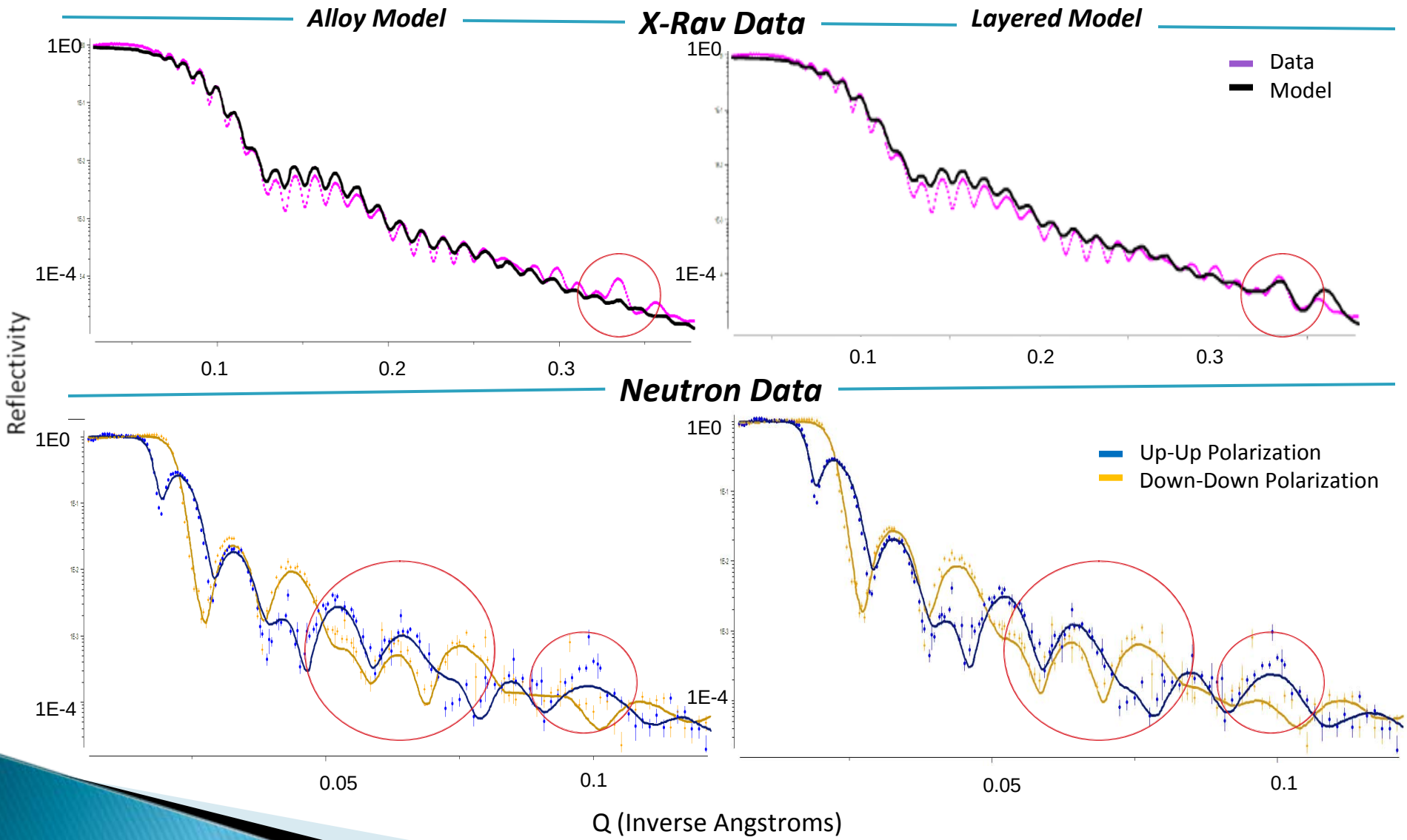
Perfectly Layered Model

Layer	Thickness (Å)
Pt	50
Cu	100
Co | Ni	6 | 12 (perfect layering)
Cu	100
Pt	50

Major features in the model do not match the data



Reflectivity Data and Models
- Alloy Model and Best Fit Layered Model -



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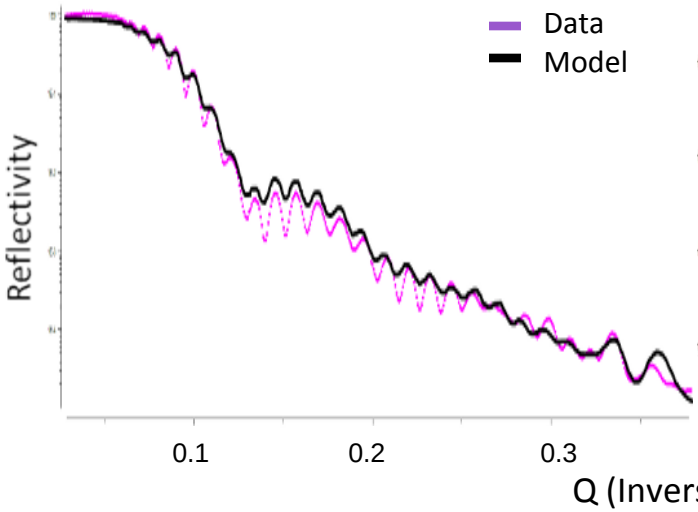
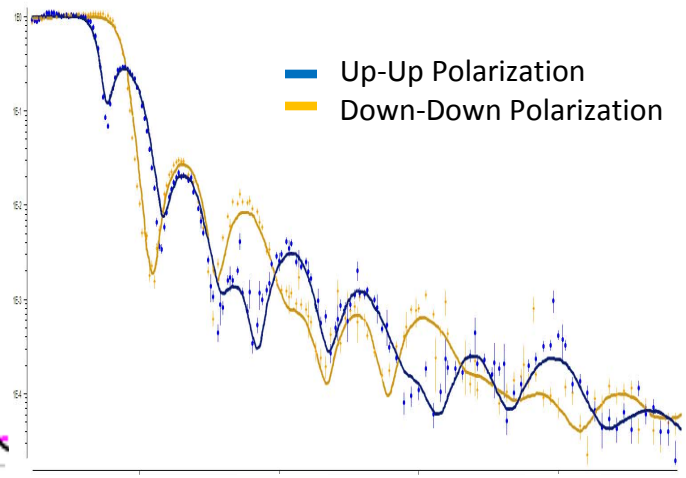
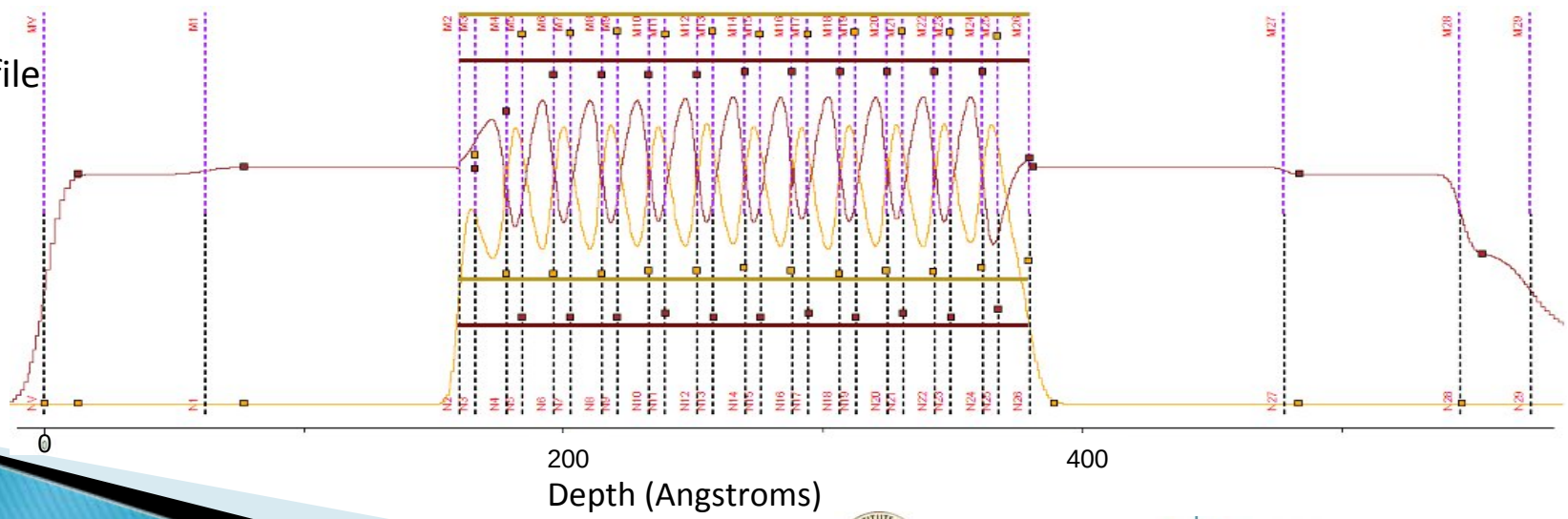
Reflectivity Data and Models
- Structure of Best Fit Layered Model -





Layer	Thickness (Å)
Pt	62 ± 3
Cu	98 ± 5
Co | Ni	6.1 | 12.2 ± 0.3
Cu	98 ± 5
Pt	68 ± 3

Structural and Magnetic Profile



Conclusions

• Structural (Scattering Length Density) and Magnetic (Magnetic Scattering Density) periodicity in the multilayer region indicated that **layers do exist.**

• Scattering Length Densities are within 35% of their bulk values for Co and 15% of their bulk values for Ni so the layer smearing is acceptably low.

• Magnetic Scattering Densities are very uncertain, but are within 50% of their bulk values in all samples, indicating that structural irregularities have a strong effect on magnetization, especially **"copper poisoning".**

• The fact that the samples are layered provides strong evidence for the hypothesis that lattice straining is the reason for the lack of perpendicular magnetization in these samples. This suggests that is possible to **engineer the stability of magnetic axes using lattice strain.**

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The Future

- Test the layering of **thinner samples** – what is the thinnest multilayer that will not alloy?
- Take data at an **improved resolution** and a larger Q-range, especially for neutrons to find the superlattice peak.
- Examine **off-specular scattering** to see if we can gather additional information about the structure
- Examine the magnetic interactions between **patterned nanoparticles** via off-specular scattering

http://www.instablogsimages.com/images/2007/11/09/walking-usb-robot_7767.jpg

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