Probing magnetic properties in buried interface of FeCo/GaAs

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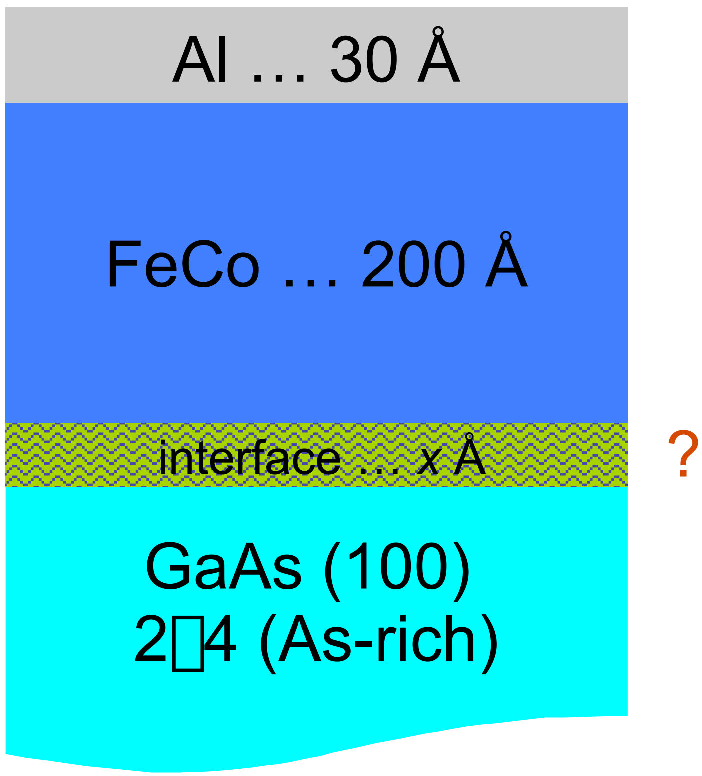
(University of Minnesota)

<u>LANSCE Neutron Scattering Winter School</u>

Jan. 16, 2004

Los Alamos

Introduction



- Spin injection into semiconductors at room temperature requires ferromagnet contacts.
- How does the magnetization of the FeCo/GaAs interface affect the polarization of spin current passing through the interface?
- Concern: we might have an electrically conducting nonmagnetic layer.
  - (1) A a source of unpolarized spins ?
  - (2) Spins passing through the interface may suffer spin flip scattering ?

Molecular Beam Epitaxy Growth and Characterization Facility

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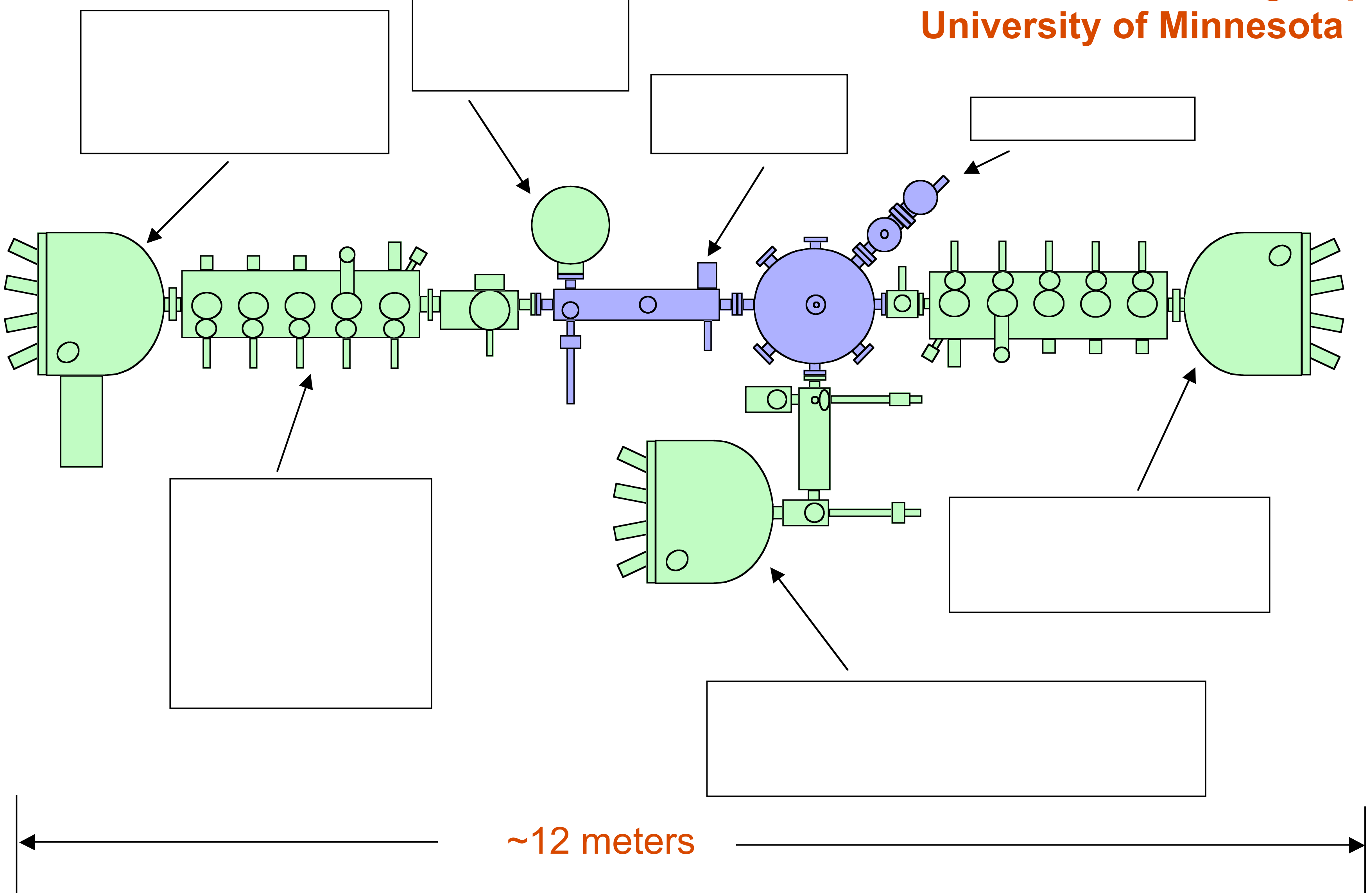
Chris Palmstrøm's group
University of Minnesota



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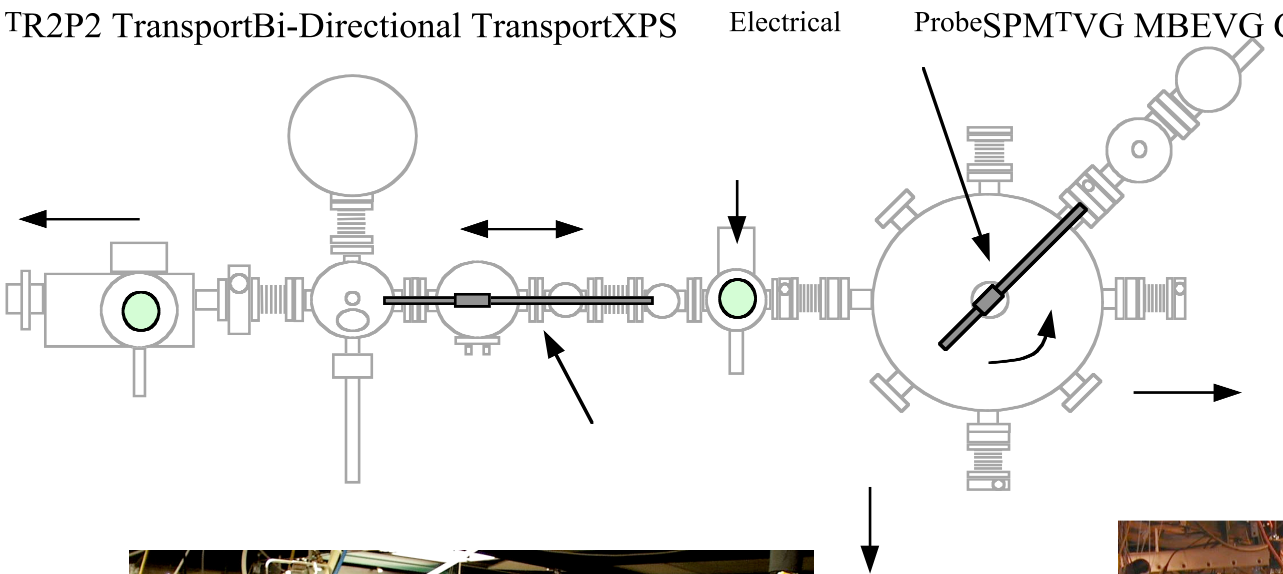
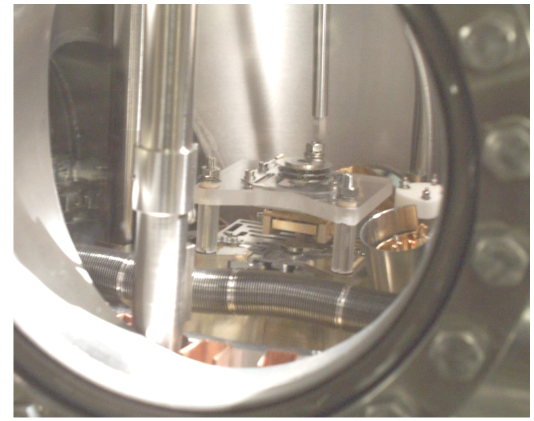
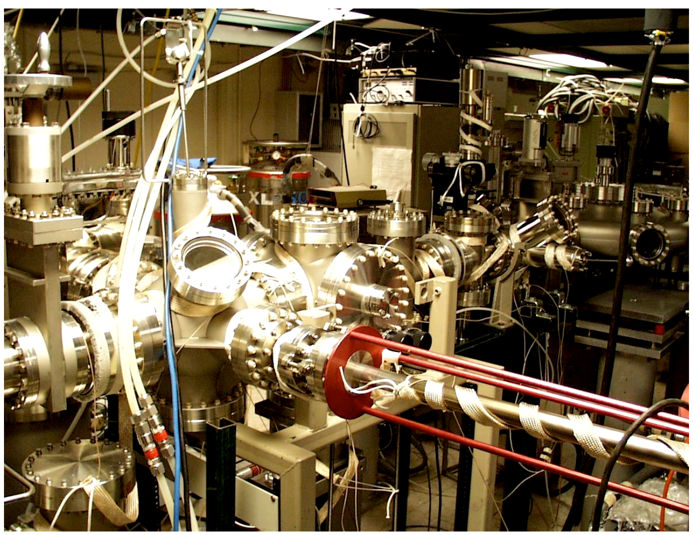
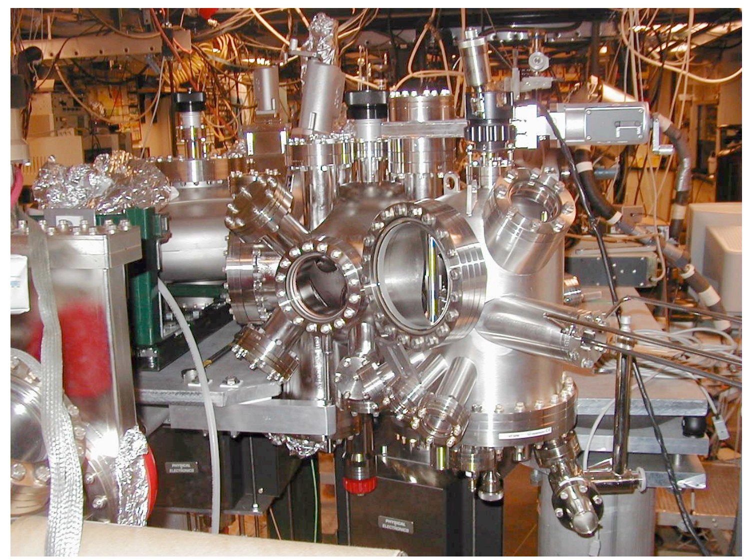
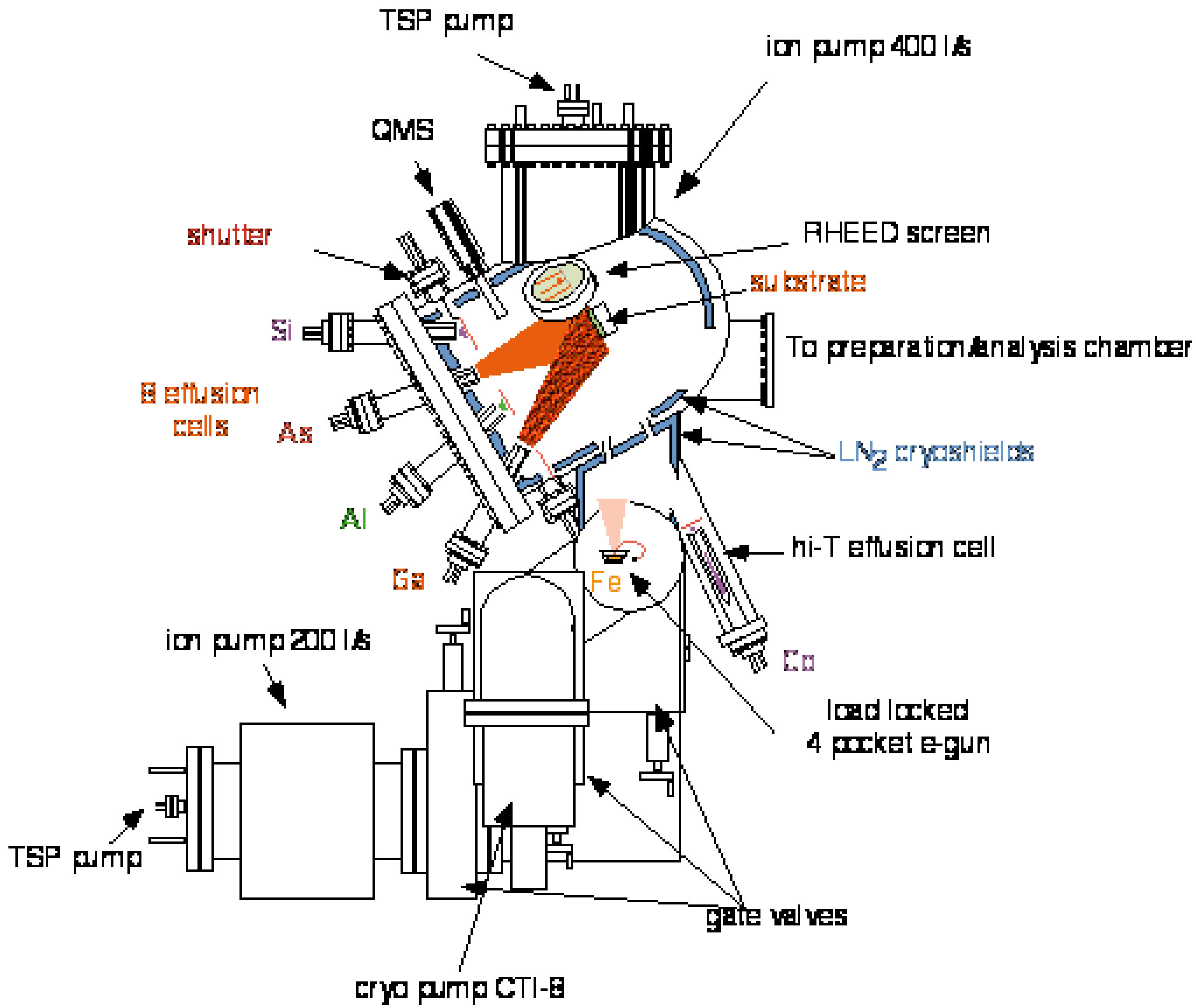




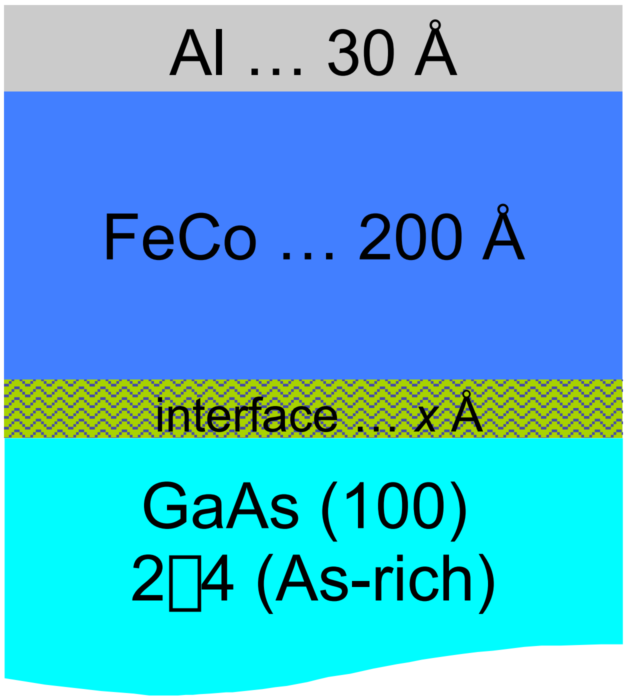




Molecular Beam Epitaxy



Investigated FeCo/GaAs specimens



- Three FeCo single crystal thin film samples were grown by identical conditions.
- substrate temperatures:
  175°C
  95°C
  –15°C

What have been done previously

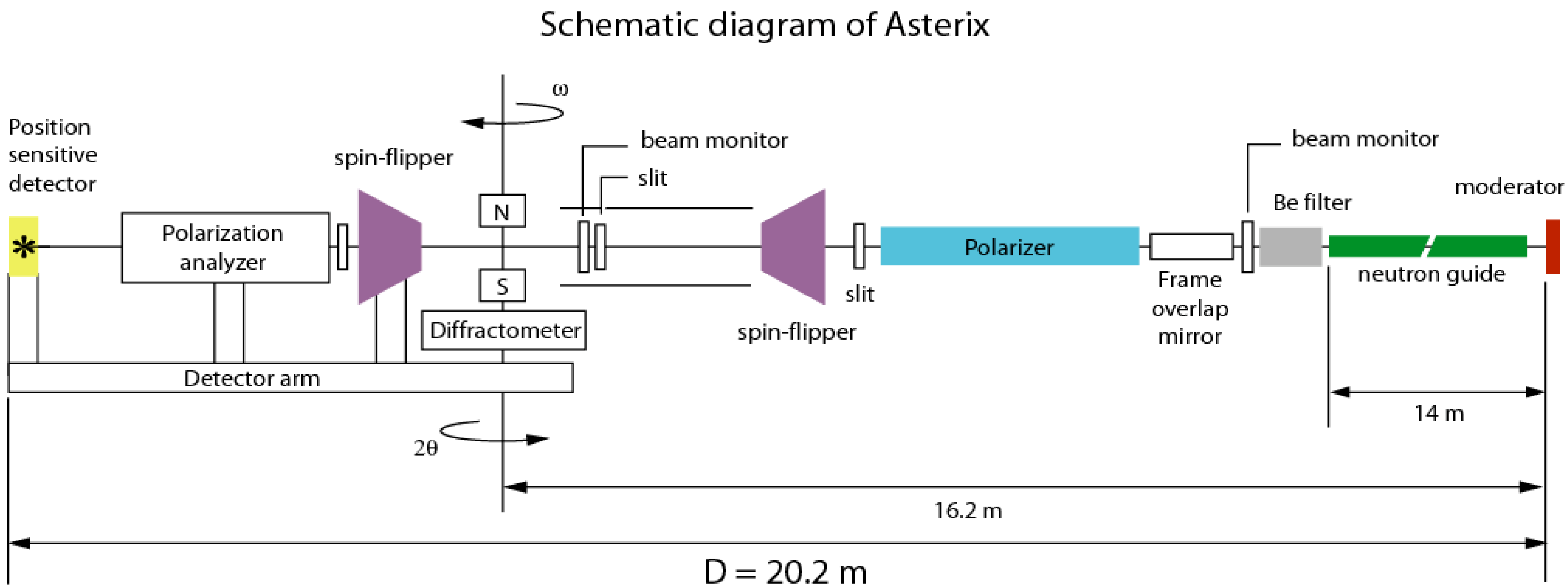
- Structural properties
  - *In-situ* (RHEED, LEED, AES, XPS, and STM)
  - *ex-situ* (RBS, TEM, XRD)
- Magnetic properties (VSM, SQUID)
- MOKE

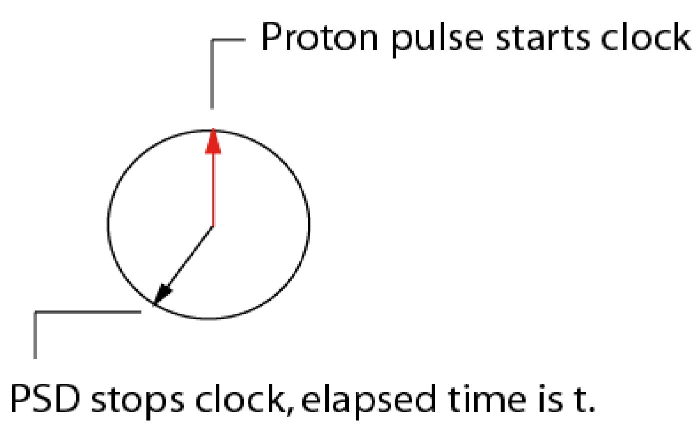
References: 1)L. C. Chen, et al., J. Vac. Sci. Technol. B18, 2057 (2000).
2)A.F. Isakovich, et al., Phys. Rev. B 64 161304 (2001)
3)B. D. Schultz, et al., J. Vac. Sci. Technol. B20, 1600 (2002).

We need to understand the magnetic structure of the as-prepared buried interface.

→ Polarized Neutron Reflectometry

Measurement of Polarized Neutron Reflectivity





wavelength:

$\lambda = 3956/v = 3956\ t\ /\ D$

λ in Å

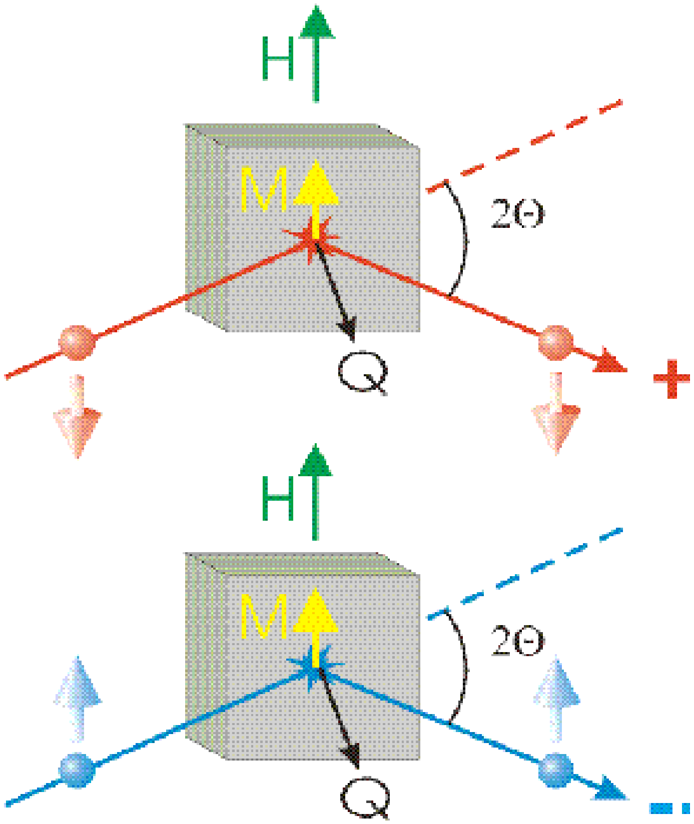
v in m/s

wavelength resolution:

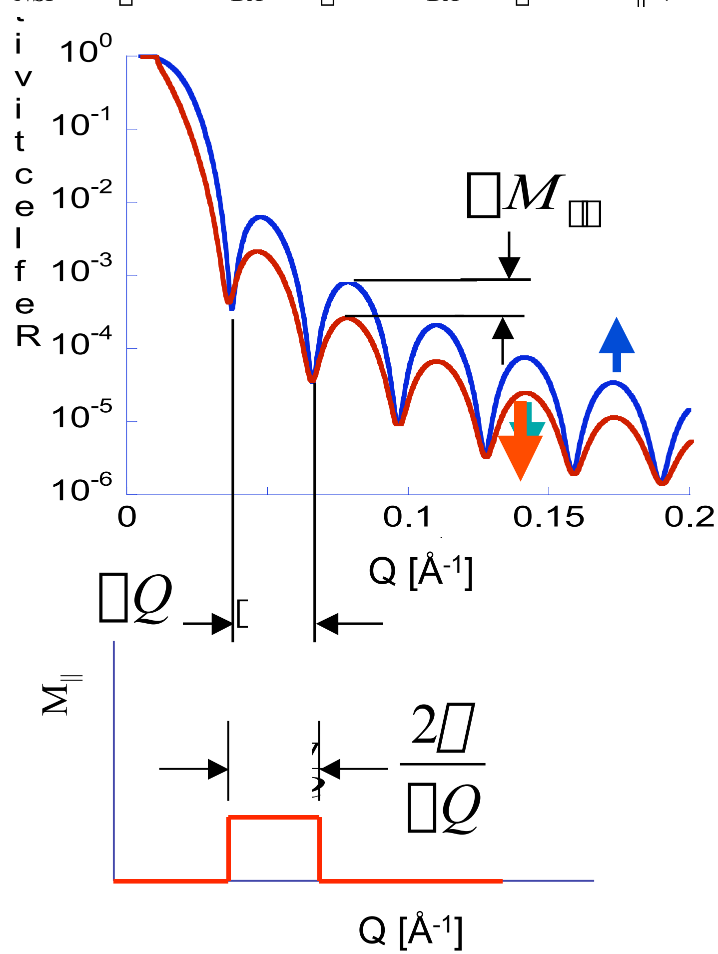
$d\lambda/\lambda = dt/t \sim 300\mu s/30ms\ (1\%)$

PNR-Non spin flip

Neutron has spin !



$$\Delta_{NSF}(Q_z) = R^{++}_{BA}(Q_z) - R^{--}_{BA}(Q_z) \quad m_{\|}(1 - \cos Q_z d)$$



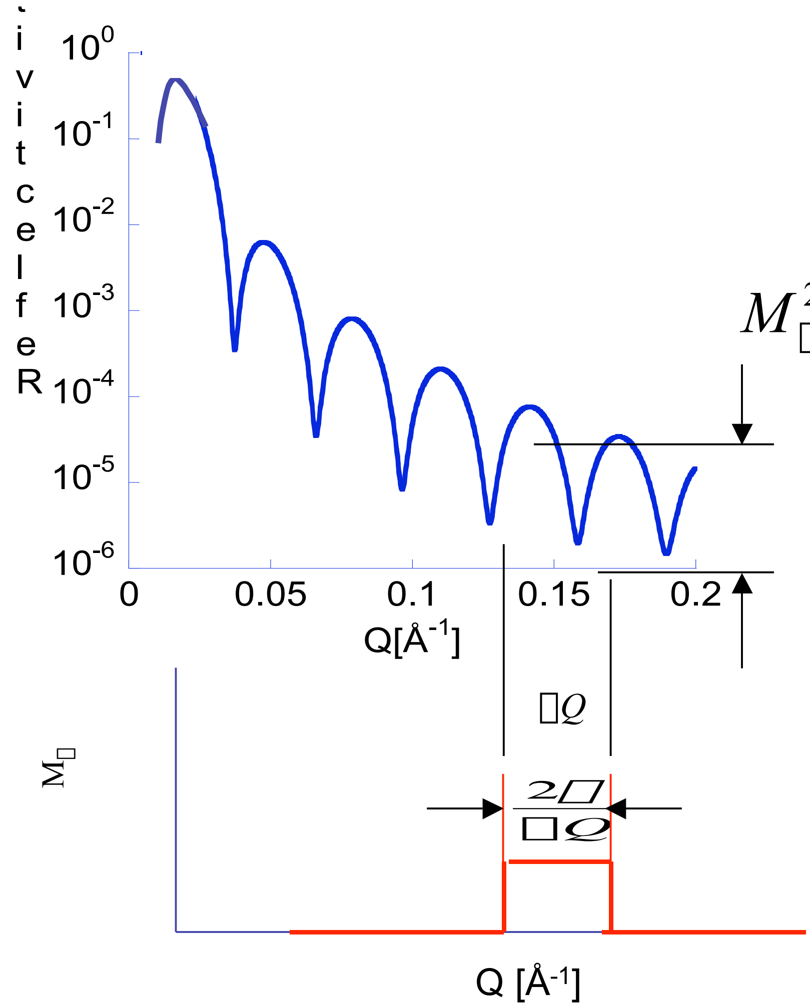
Non spin-flip cross-sections yield: $M_{||}$ as a function of Q .

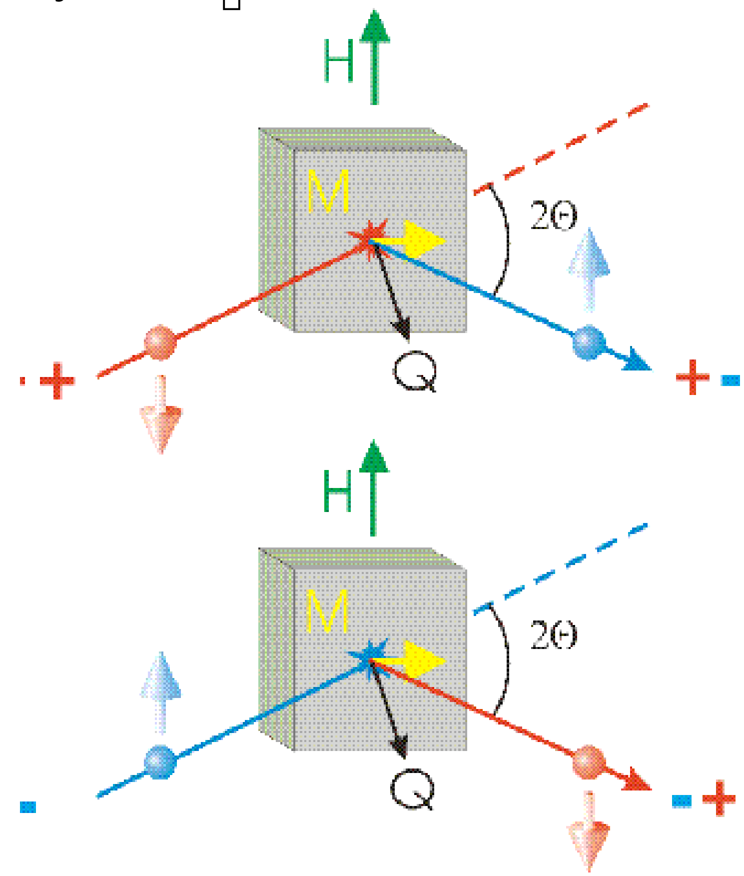
- Magnetic moment parallel to neutron spin
- Magnetic layer thickness, roughness

PNR-Spin flip

$$R_{BA}^{SF}(Q_{\square}) \quad m_{\square}^{2}\left(1 \square \cos Q_{\square} \square\right)$$

Spin-flip cross-sections yield M□ as a function of Q.

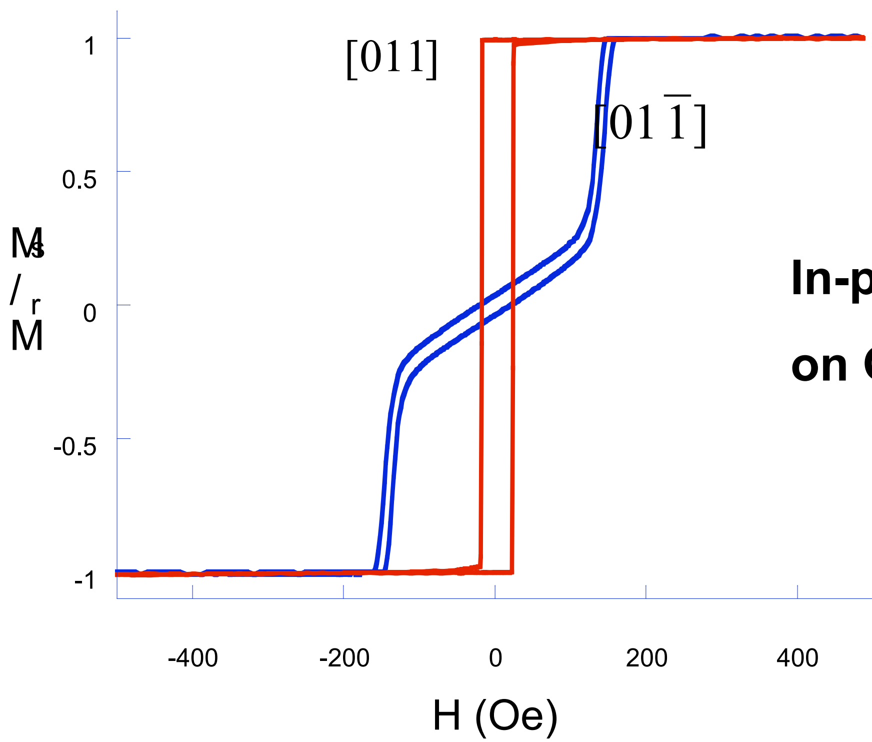




- Magnetic moment perpendicular to neutron spin
- Magnetic layer thickness, roughness

Chemical profile vs. Magnetic profile ?

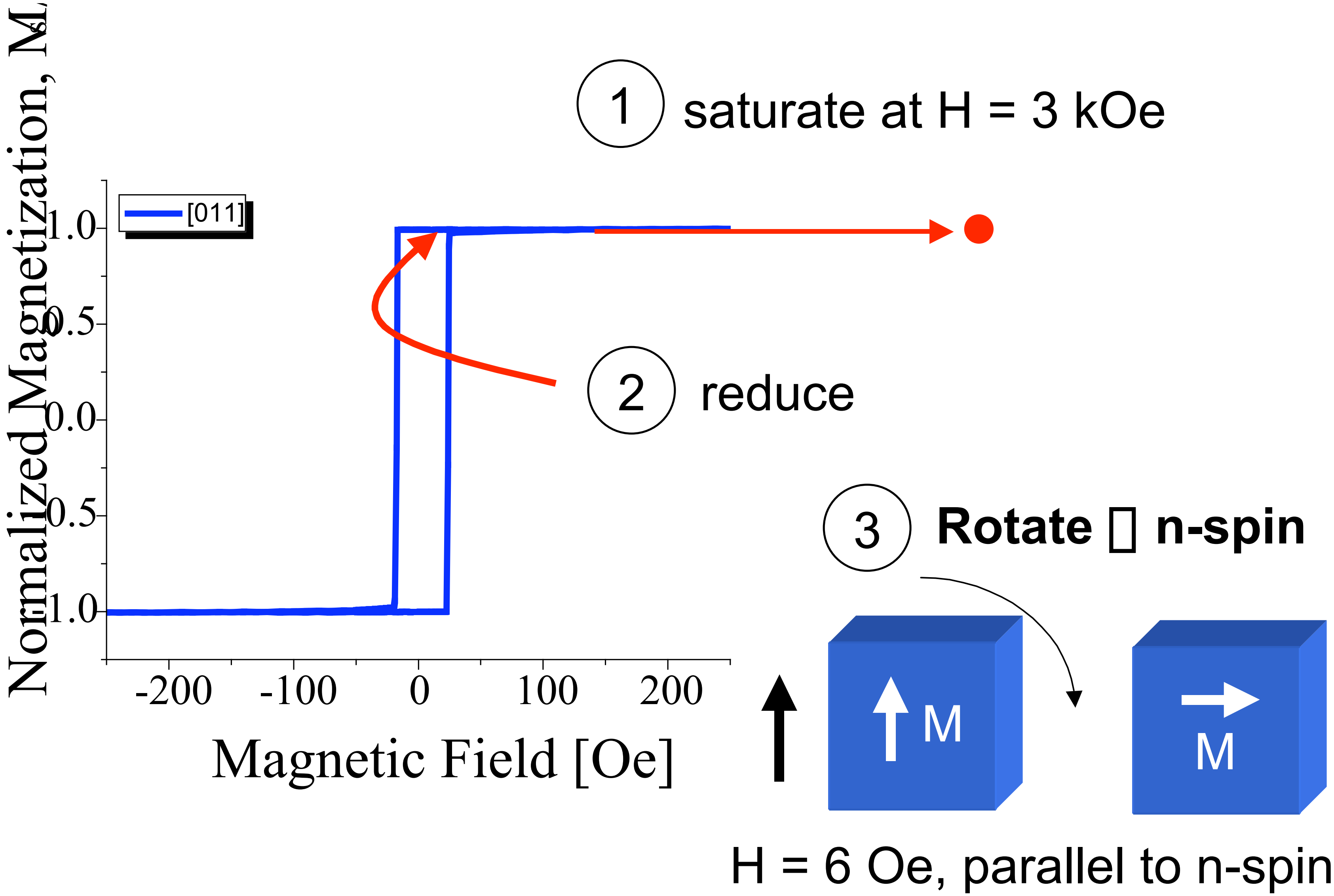
- **Neutron spins and sample magnetic moment need to be perpendicular to each other .**
  - **+-, -+ give magnetic profile**
  - **++, -- give chemical profile only**



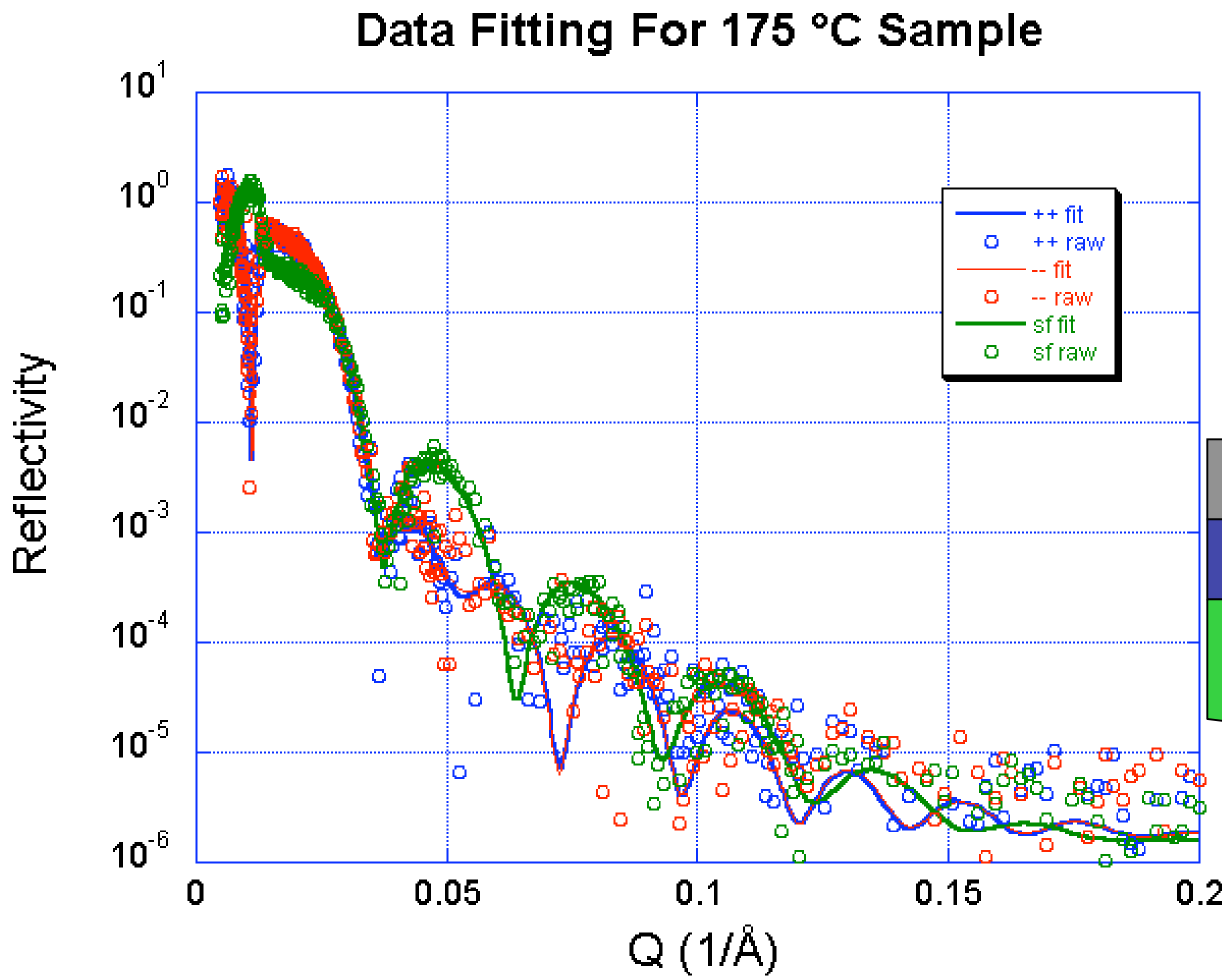
In-plane magnetization of $Fe_{48}Co_{52}$ grown on GaAs(100) surface.

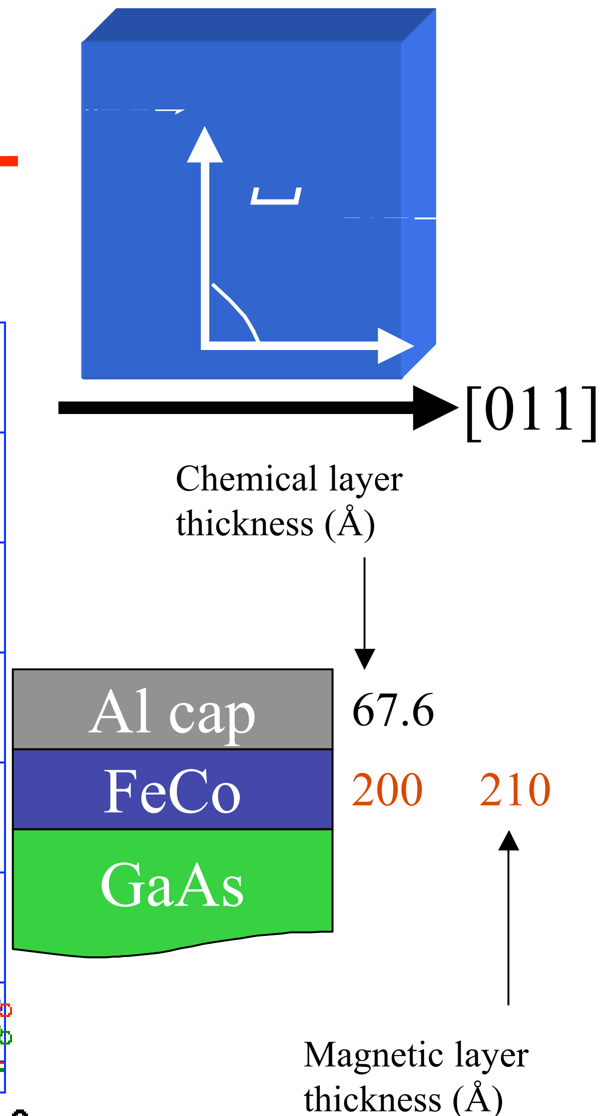
- **large uniaxial anisotropy offers a solution**

Orientation Procedure



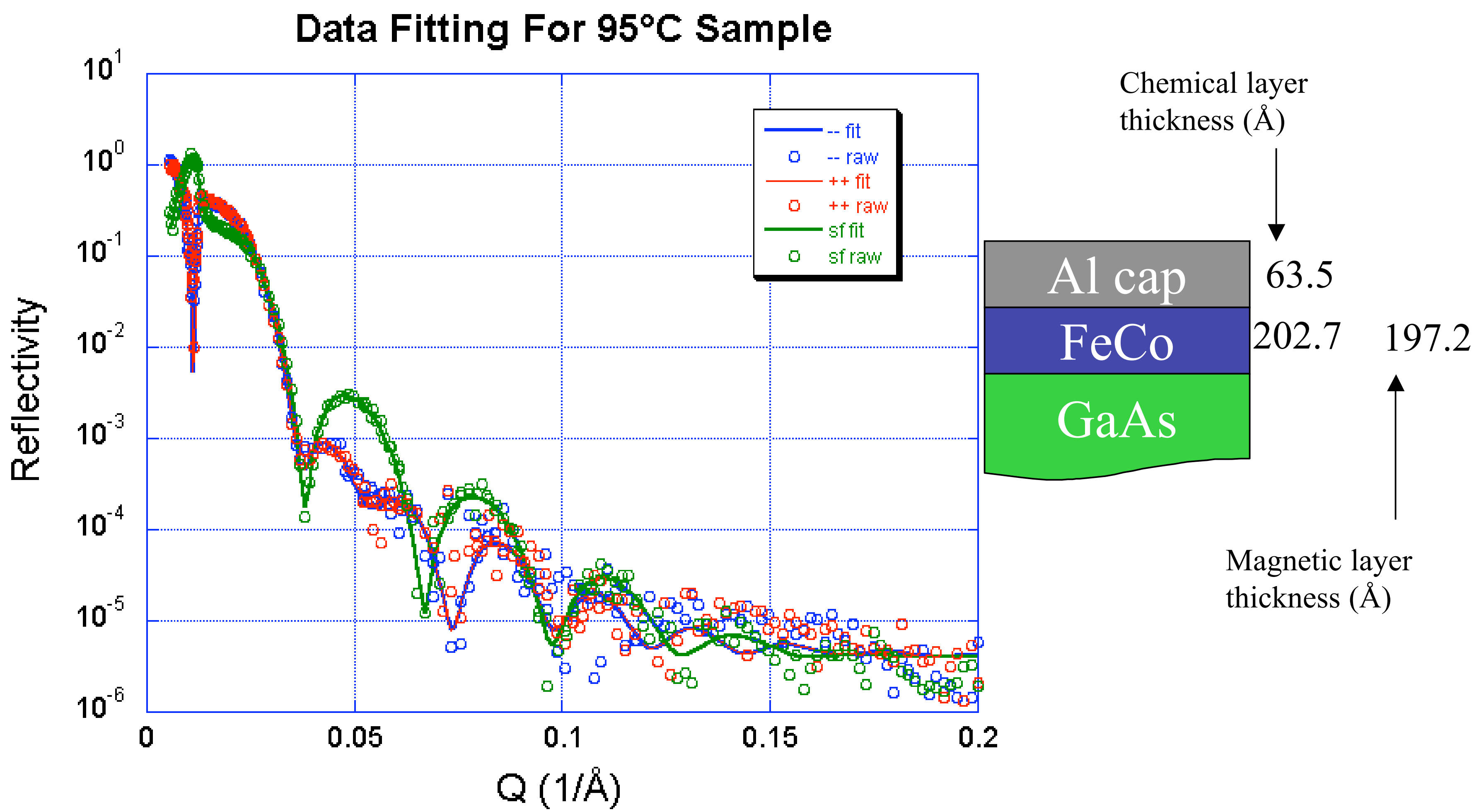
Data Fitting (175°C)



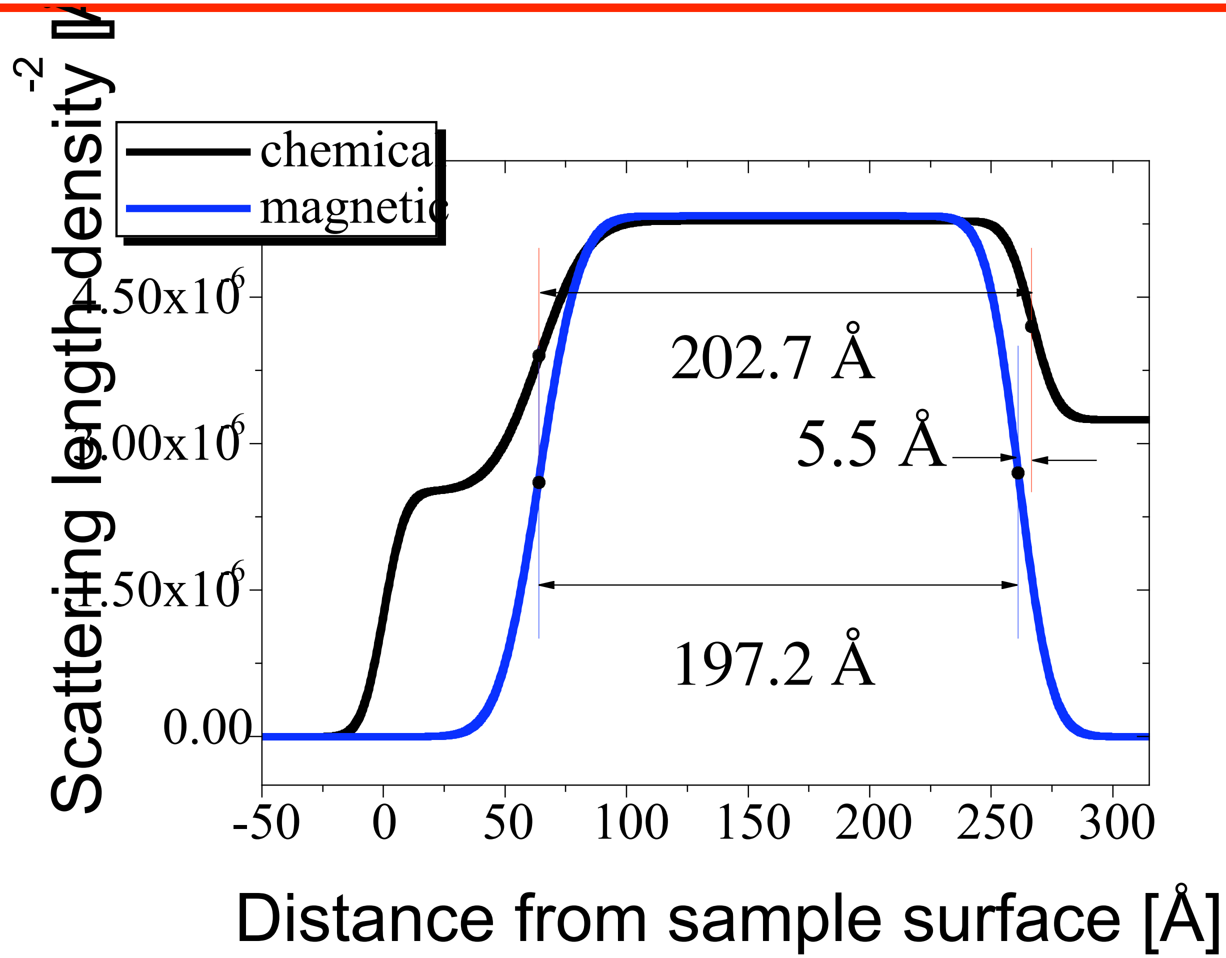


- **+-, -+ give magnetic profile (magnetic moment, magnetic thickness, roughness)**
- **++, -- give chemical profile only (Chemical thickness, roughness)**

Data Fitting (95°C)

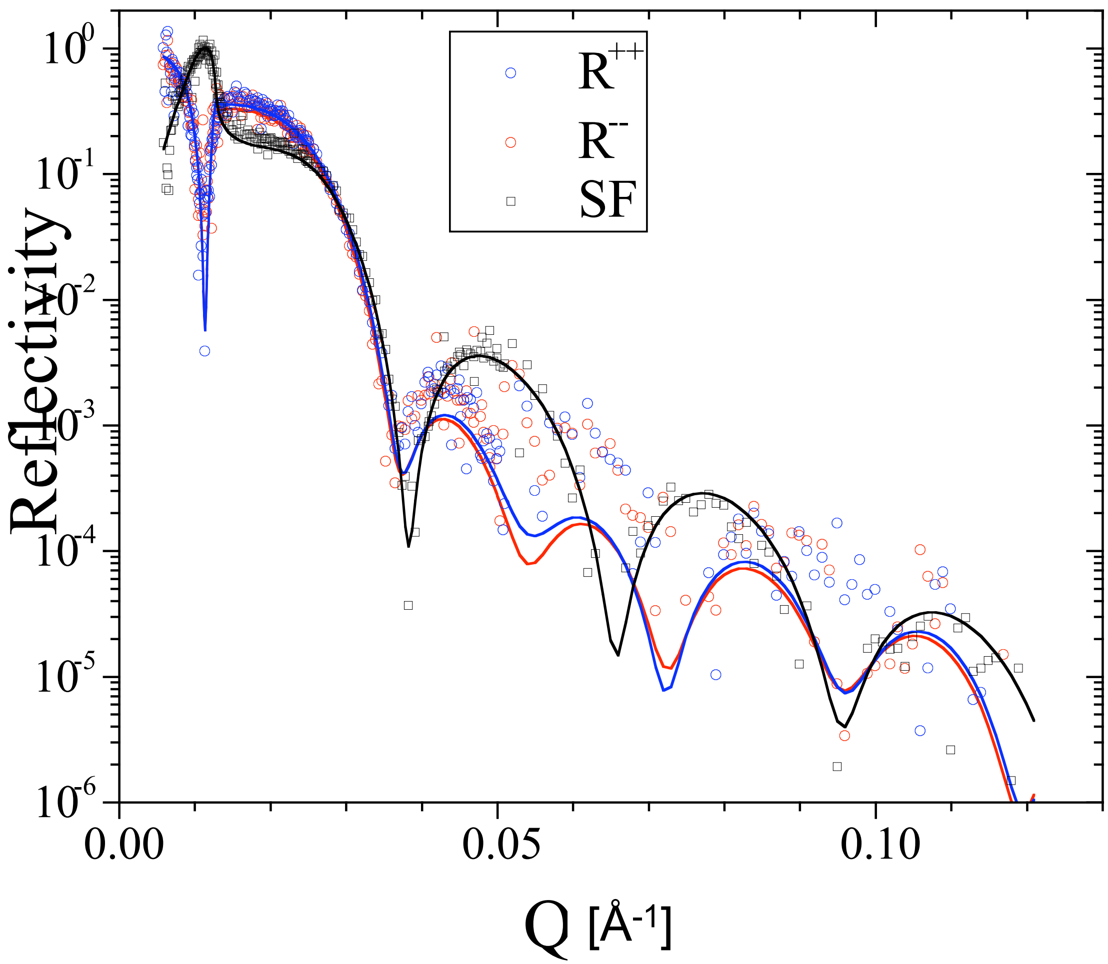


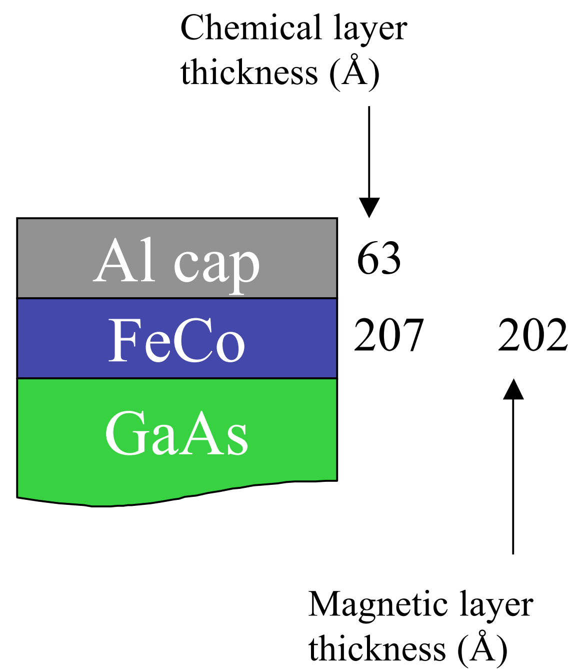
Magnetic ≠ chemical thickness



The FeCo/GaAs(100) 2x4 interface is not ferromagnetic at 300 K (for this sample grown at 95ºC).

Data Fitting (-15°C)





Summary

Sample Growth temperature (ºC)	**Thickness** of the FeCo layer		**Roughness** of the interface FeCo/GaAs	
	Chemical	Magnetic	Chemical	Magnetic
175	200	210	5	15
95	202	198	9	12
-15	206	202	7	12

- By orienting neutron spins perpendicular to the magnetic moment in the film, Chemical profile and magnetic profile were split and detected at the same time.

- It was observed that the chemical profile of the FeCo layer is different from the magnetic profile for all three samples.
  - Sample grown at 175ºC °˙magnetic layer is thicker than chemical layer °˚FeCo might diffuse into Semiconductor.
  - Sample grown at 95ºC °˙magnetic layer is thinner than chemical layer °˚This difference (~5 Å) might be related to the magnetic dead layer at the FeCo/GaAs interface.
  - Sample grown at -15ºC

  - When growth temperature increases, chemical interface roughness decreases, while magnetic interface roughness increase with increasing growth temperature.

• Magnetization of the FeCo films

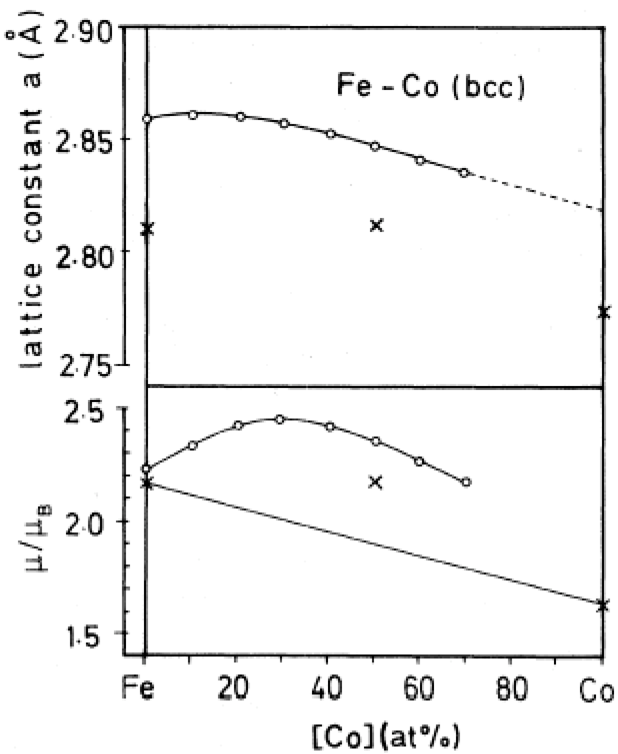


FIG. 1. Fe-Co (bcc) alloy: (a) lattice constant and (b) average magnetic moment. Experimental values (circles) are taken from Ref. 2; present theoretical results (crosses).

Schwartz *et al*.,
Phys. Rev. B**25**, 3427 (1982)

Growth temperature (ºC)	Magnetization (emu/cm^3)
175	1959
95	1861
-15	2080
Calculation in theory	1562

Thank you !_

Spintronics

Semiconductor Devices:
~$120 billion (WW2001)

Magnetic Recording:
~$120 billions (WW2001)

Semiconductor: Charge ⟷ Information technology ⟷ Magnetic materials: Spin

Using charge and spin degrees of freedom

↓

Spintronics

Spin polarization, <u>injection</u>, transport, manipulation, detection

Advantages of Molecular Beam Epitaxy

- Straightforward physical deposition process
  - Good for growing new structures for the first time
- Extremely abrupt changes in composition or doping are possible
- Capable of growing ultra-thin layers
- Ultra-High Vacuum (UHV) - minimal surface contamination
  - Allows for the the use of multiple surface science techniques for analyzing films and growth processes *in-situ*
- Flexibility is limited by the number of sources

If materials growth can be controlled at the atomic level, then their properties can be controlled