Tuning structure and magnetic correlation in Si-Fe multilayers

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  - Magnetic measurements
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  - Specular and off-specular scattering
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Applications

Neutron guides

Polarizing and focussing devices (lenses, benders)

Data storage devices

Motivation

Increase of critical angle

Preparation of high quality multilayers (low stress and roughness, thin interface layers, high saturation and low coercivity fields)

Focus

Optimization of properties of Si-Fe multilayers by variation of substrate Bias voltage

Characterization of stress, structure, magnetic properties and neutron scattering

Preparation of Si-Fe multilayers

System:

10(10nm Si+10nm Fe)+10nm Si

Substrate:

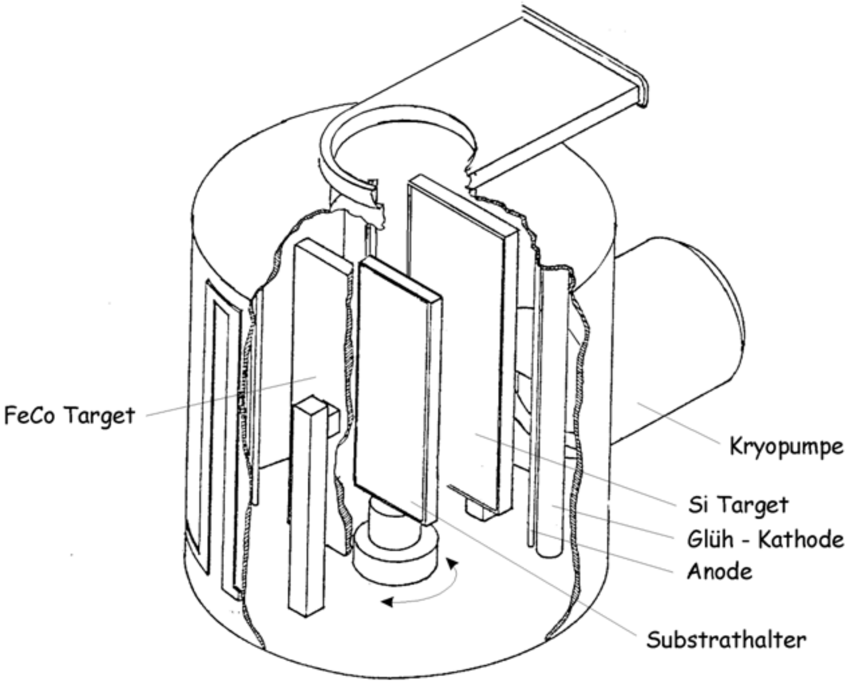
0.5mm thick (100)Si,

3mm thick Floatglass

Triode sputter machine:

p_{Ar}= 0.65×10^{-4} mbar; P= 0.32kW

10V≤ Bias voltage ≤ 65V



Characterization

- Talystep device: Layer stress σ_{St}

$$\boxed{\sigma_{St} = \frac{E}{1-v}\frac{D^2}{6d}\left(\frac{1}{R_1}-\frac{1}{R_0}\right)}$$

E, v: Elastic modules, Poisson constant

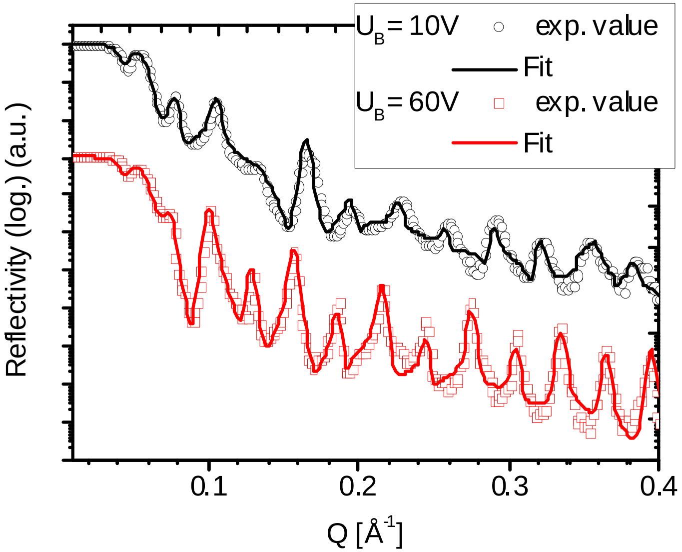
D, d: substrate and film thickness

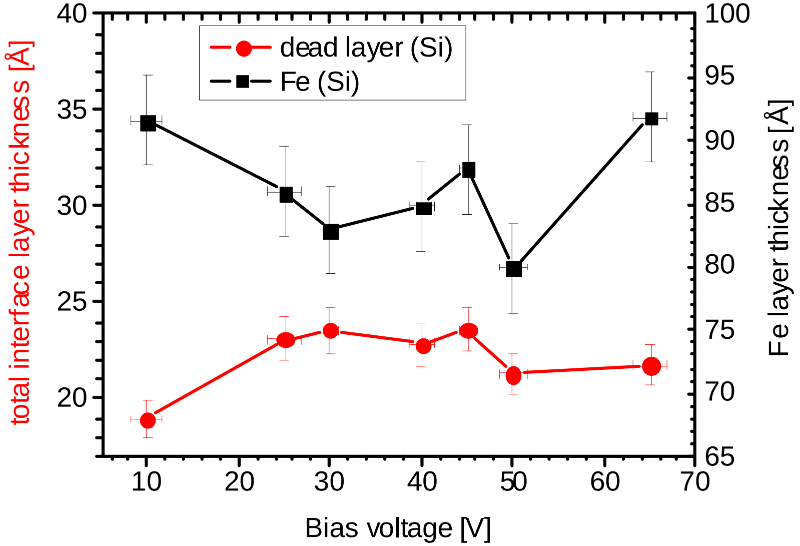
R_1, R_0: bending radii after and before sputtering

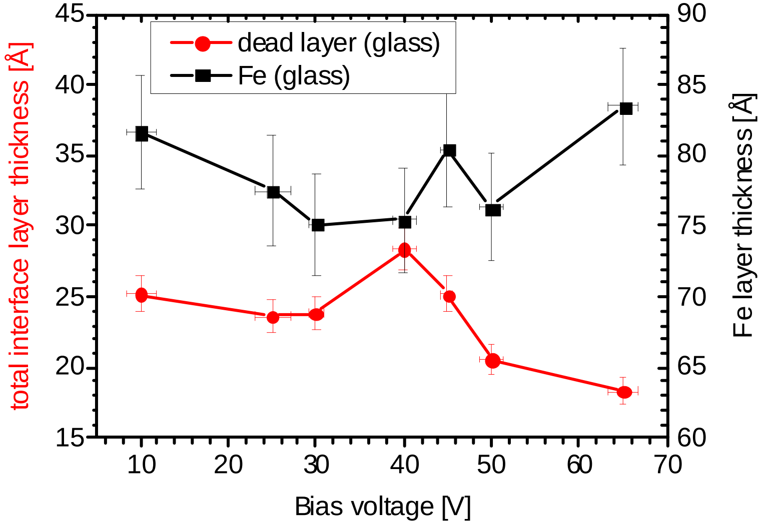
- X-ray scattering : Structure, Crystallinity
- SQUID: magnetic properties
- Polarized neutron reflectometry:

  Specular and off-specular scattering

X-ray reflectometry results from Si-Fe multilayers

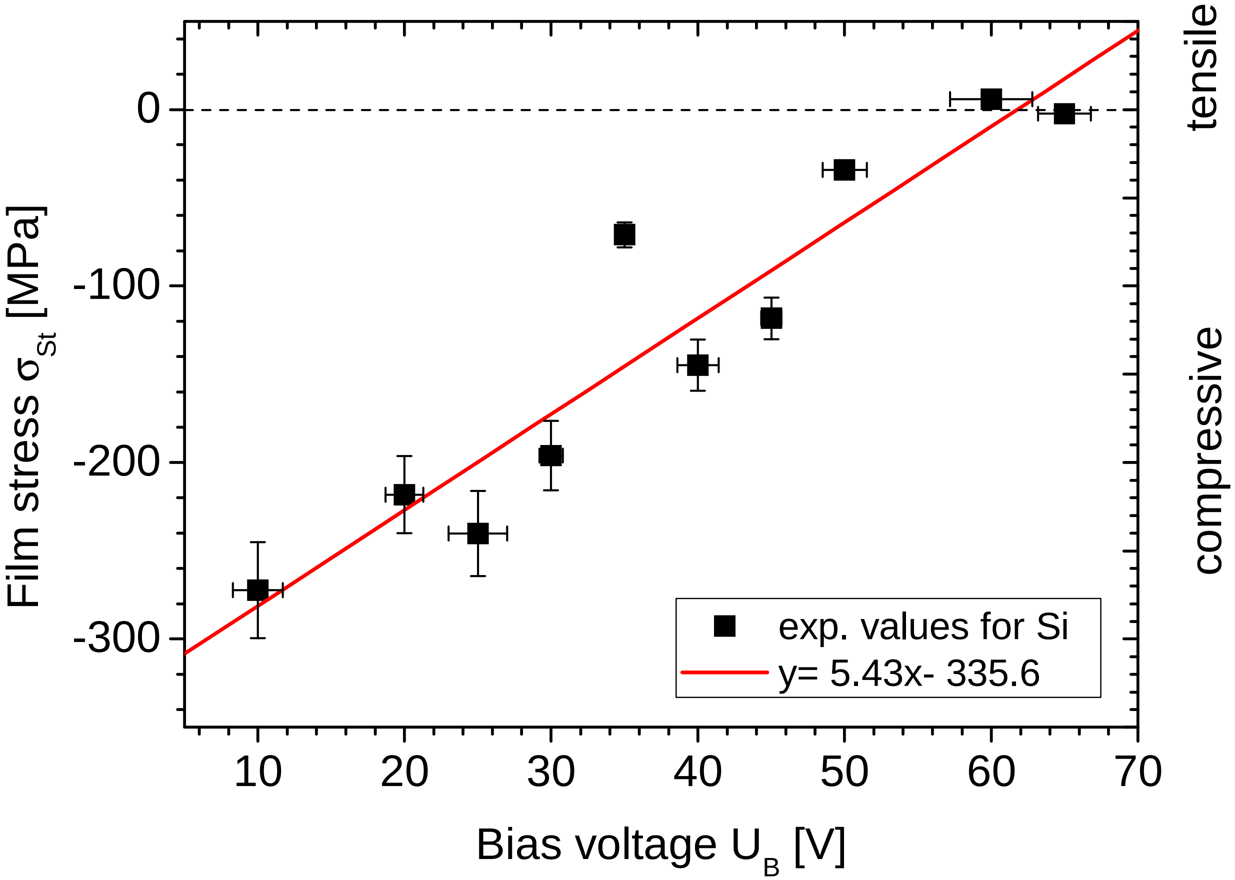


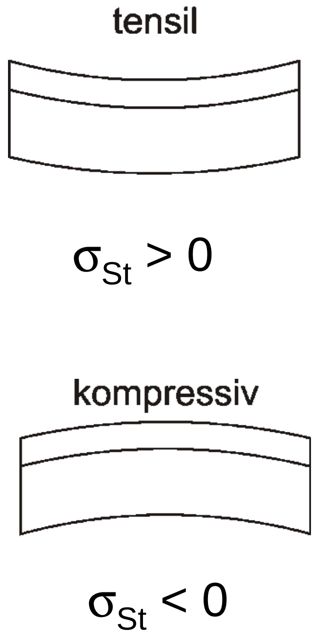




- Total dead layer thickness:
- 18.9 to 23.6Å (Si), 18.3 to 28.4Å (glass)
- Minimal Fe layer thickness at 30V
- Si/Fe ratio: 1.1 to 1.2
- Increasing bilayer thickness

Stress values in Si-Fe multilayers

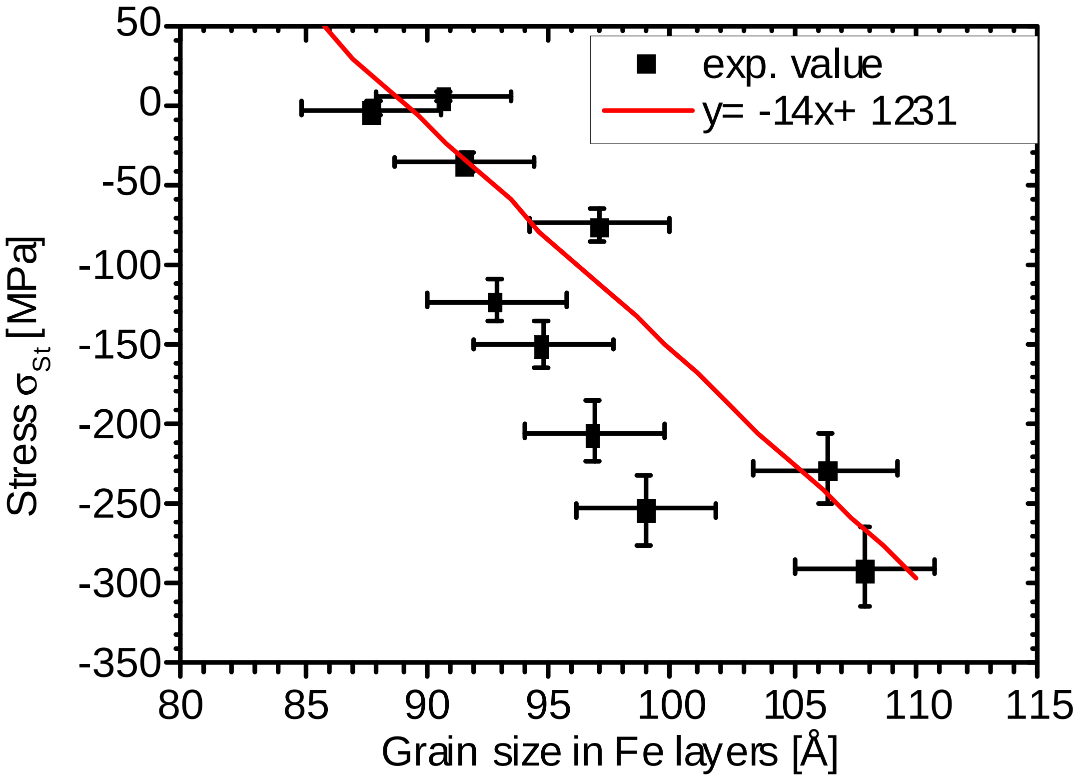




$\sigma_{St} > 0$

$\sigma_{St} < 0$

Structure of Si-Fe multilayers

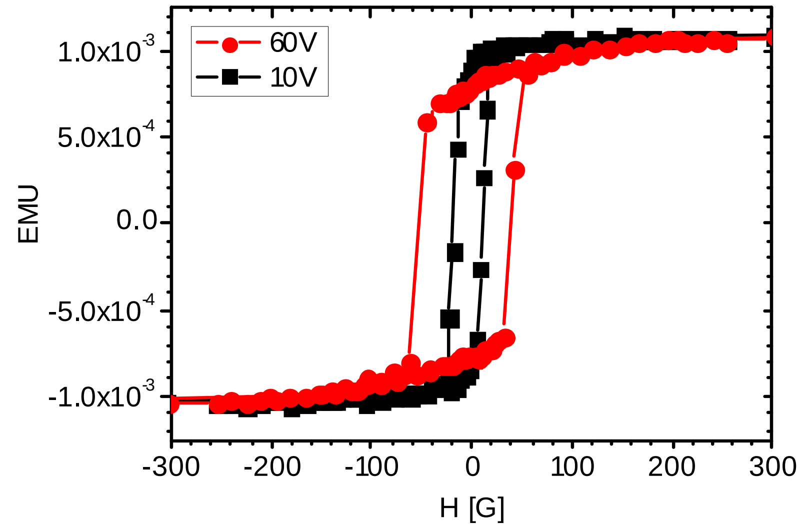


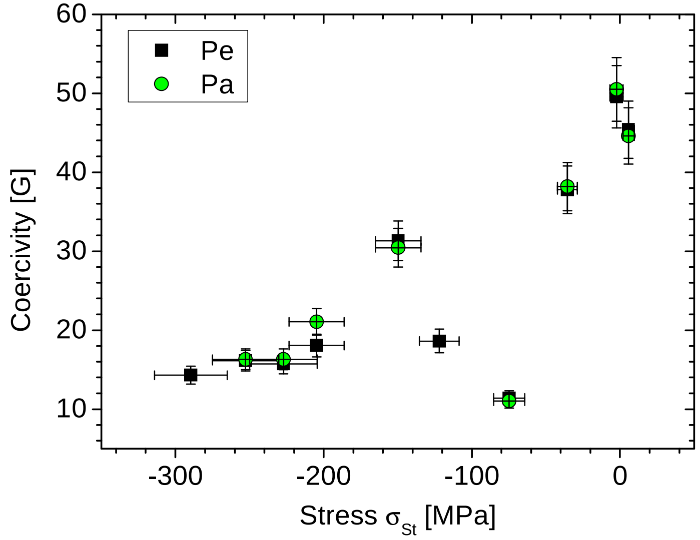
- Si: amorphous
- Fe: (110) orientation

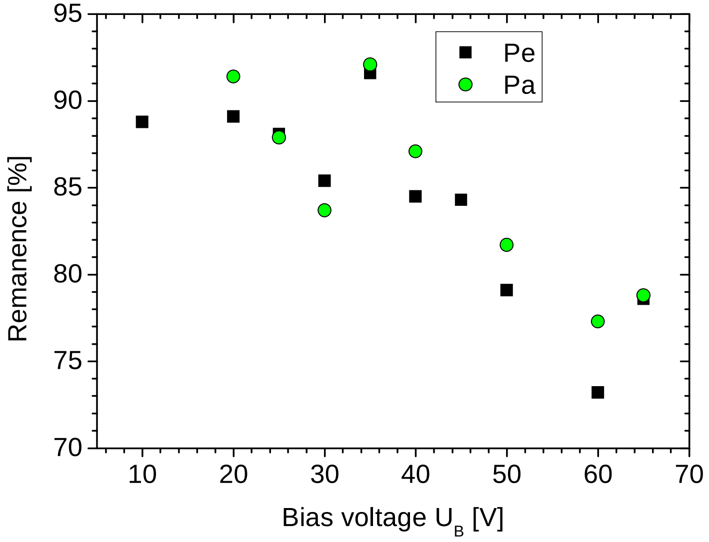
➢ **10V → 65V**

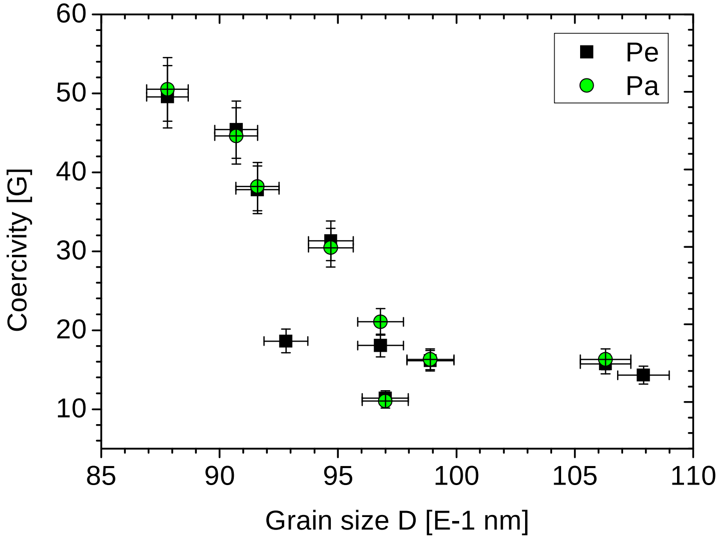
- enhanced island growth and lower mobility of atoms on the surface
- smaller grains
- Reduction of compressive film stress
- Increase of layer thickness

Correlation between structure and magnetic properties

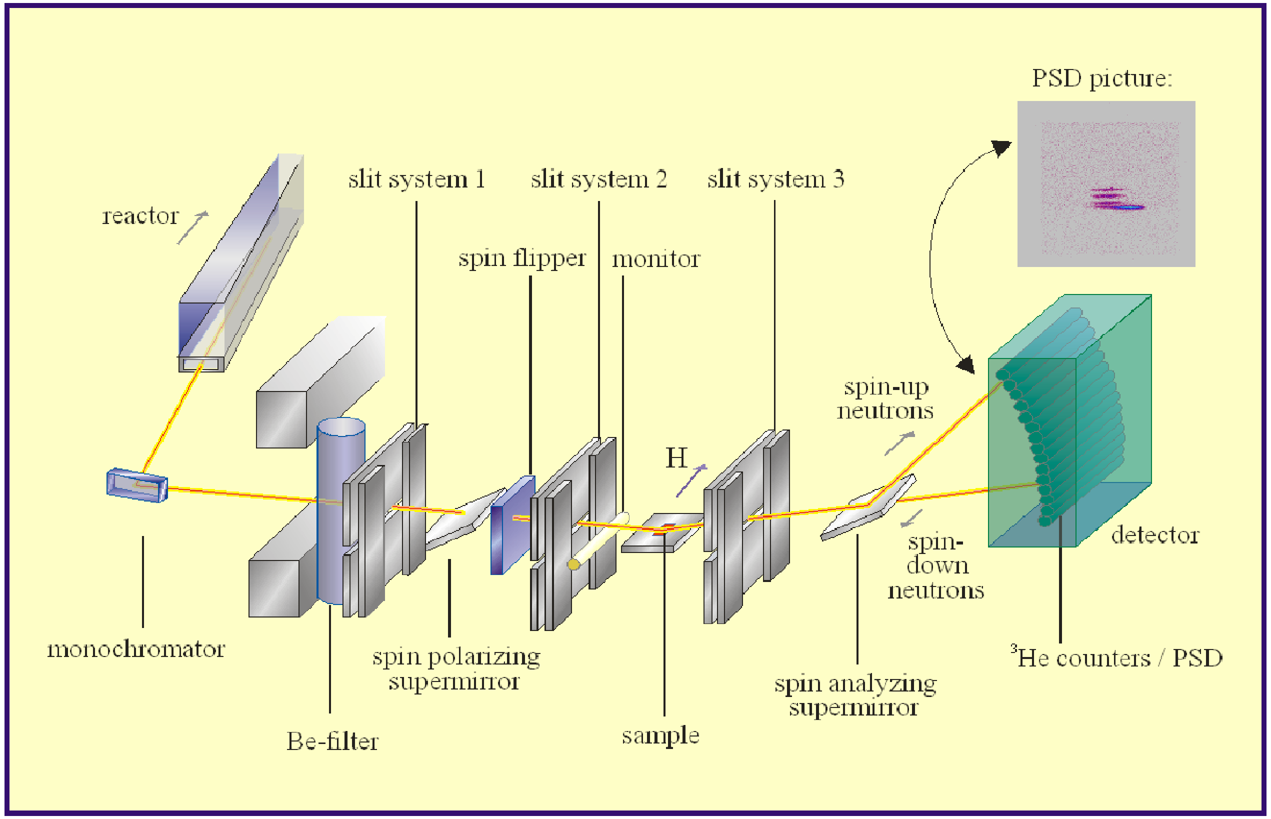






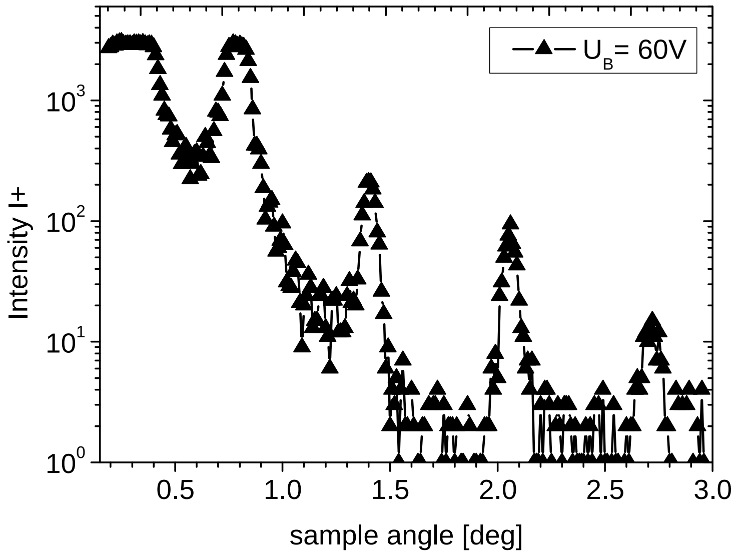


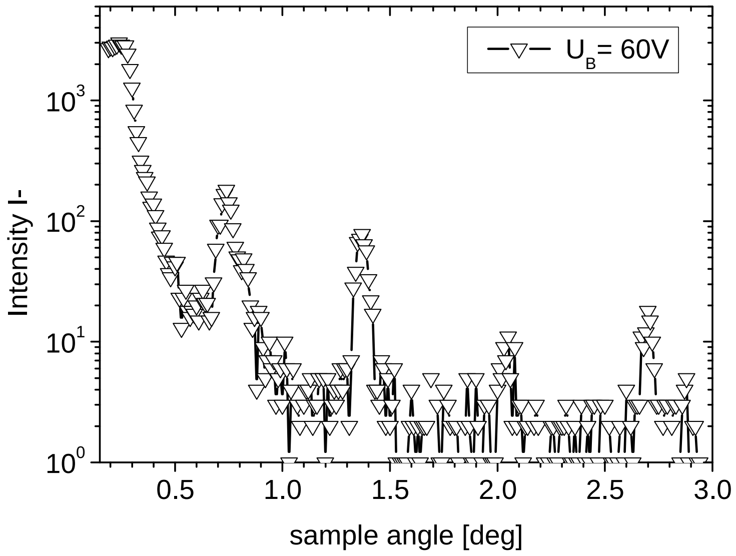
Setup of neutron reflectometer V6



Equipment: Si/Fe analyzer, $\alpha_f = \pm 7.2°$,
magnetic field B: 20G, 200G, 300G, 1030G

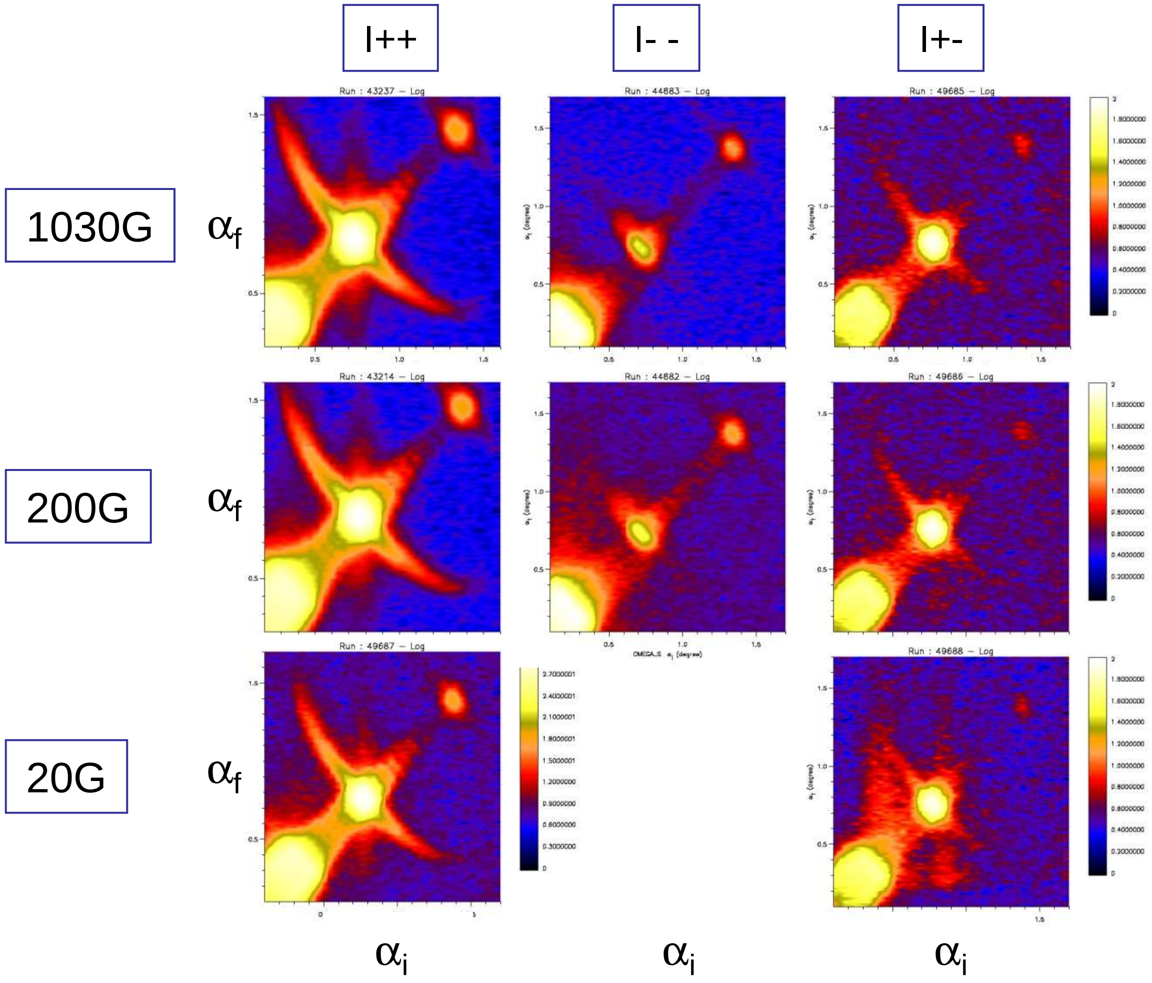
PNR measurements at a stress-free ML on Si at 300G

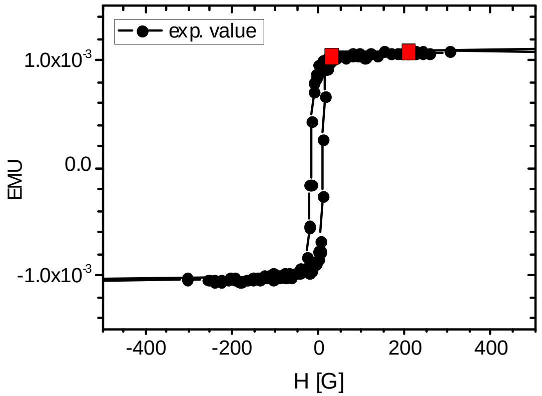




- Layer thickness similar to XRR results
- Calculation of flipping ratio at first Bragg order
- flipping ratio= I^+/ I^-
- Average flipping ratio: ML on Si: 38.1; ML on glass: 52.4

2D plot from a bent Si-Fe ML at different magnetic fields

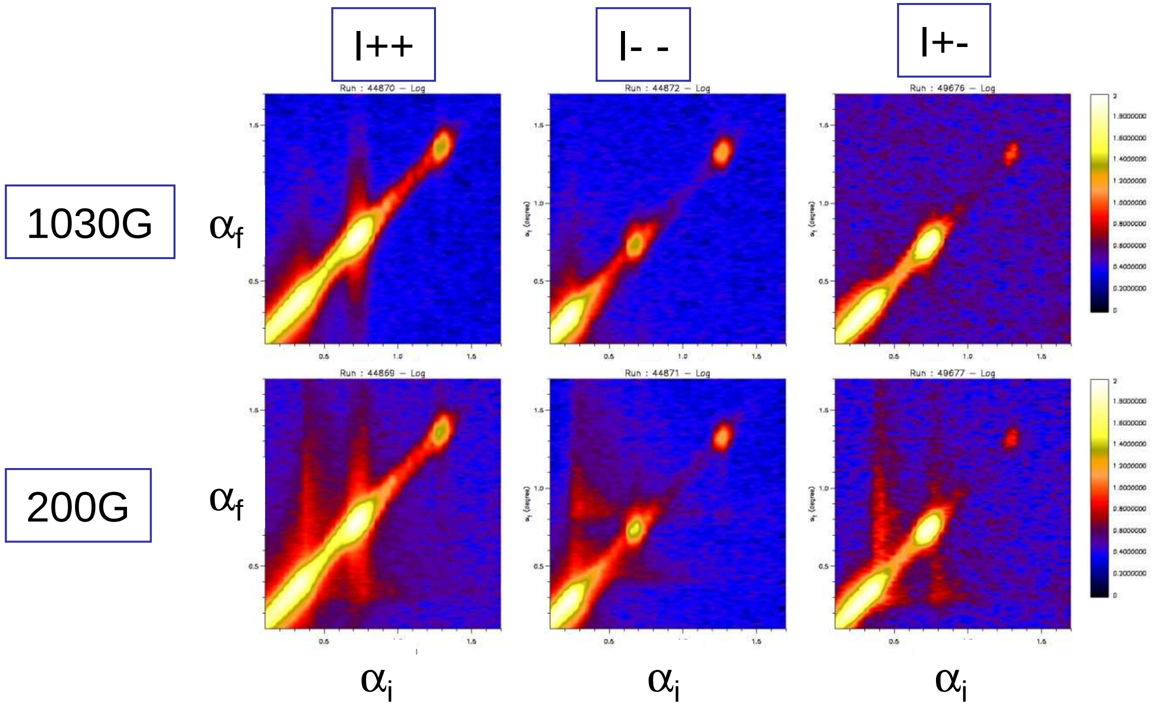


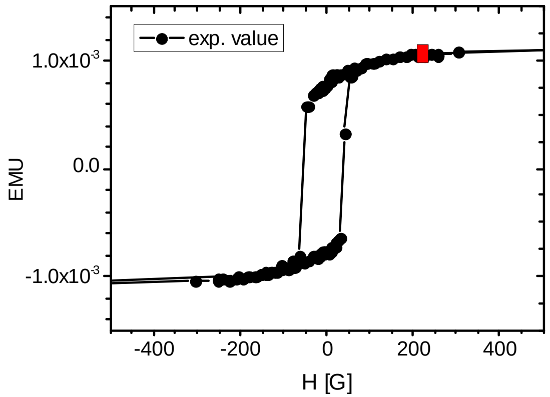


- Vertically correlated interface structure: associated domains of ~500 nm of lateral correlation

- additional diffuse streaks *independent of stress within the sample* caused by longitudinal and transverse fluctuations from uncorrelated portion of the domains

2D plot from a stress-free Si-Fe ML at different magnetic fields





- additional diffuse streaks *independent of stress within the sample* caused by longitudinal and transverse fluctuations from uncorrelated domains

- No vertical correlation of structure or of domains

Results of PNR measurements

Bent multilayer (10V)

- high NSF and SF diffuse scattering from vertically correlated structure and associated domains (streaks caused by magnetic fluctuations of vertically uncorrelated magnetic domains)
- Increase of magnetic field – vertically correlated part remains similar while the uncorrelated part gradually disappears

Stress-free multilayer (60V)

- shows diffuse scattering at 200G (streaks caused by magnetic fluctuations of vertically uncorrelated domains)
- Higher magnetic field – Reduction of SF diffuse scattering

Comparison to other Bias values

- half width w of Bragg peaks drops with lower compressive film stress
- No correlation between film stress and off-specular scattering

Summary

- **Increase of Bias voltage**
  - lower compressive stress
  - smaller grains
- **Lower compressive stress**
  - higher coercivity
  - lower remanence

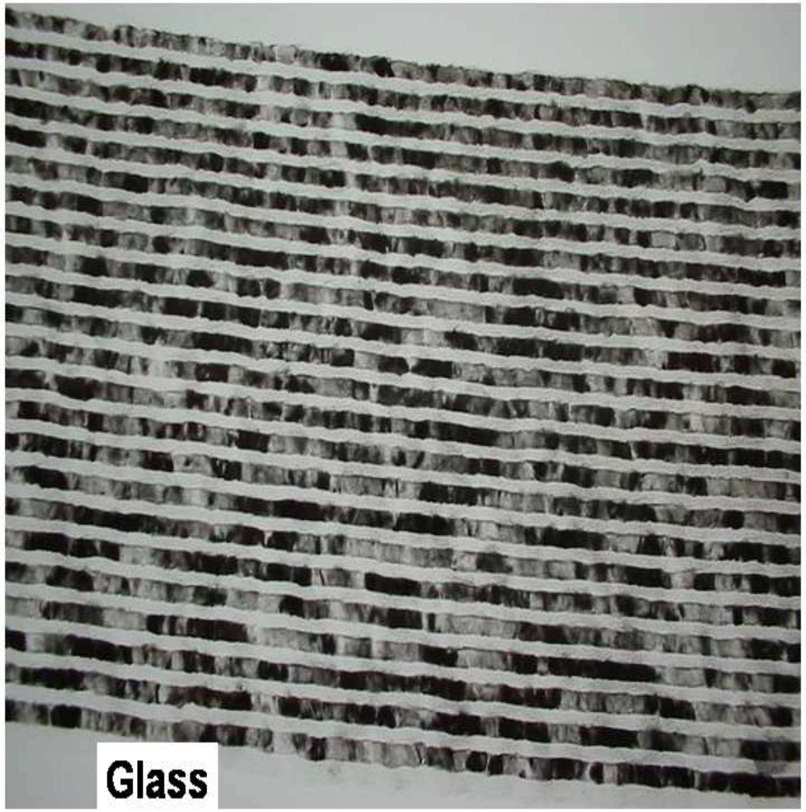
- maximal interface layer and minimal Fe layer around 30V
- saturated from 300G

- Reduction of diffuse scattering by higher magnetic field for stress-free multilayer

- **Best performance:**
  - Multilayer with low film stress, small grains, minimal interface layer thickness, low diffuse scattering at small magnetic fields

Thanks for your attention

TEM picture of a Si-Fe multilayer

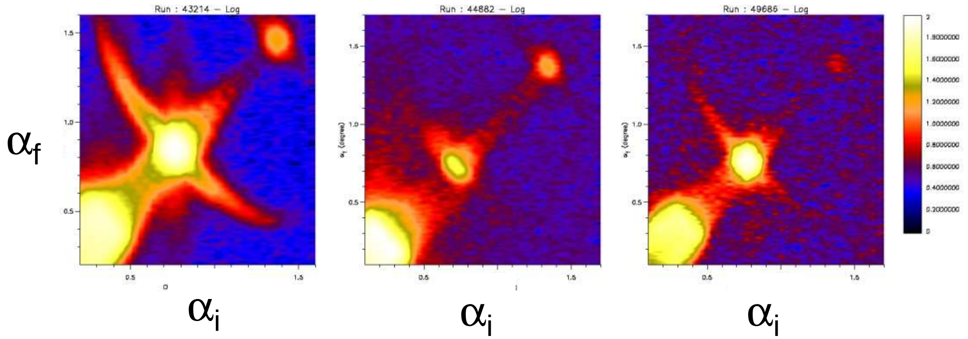


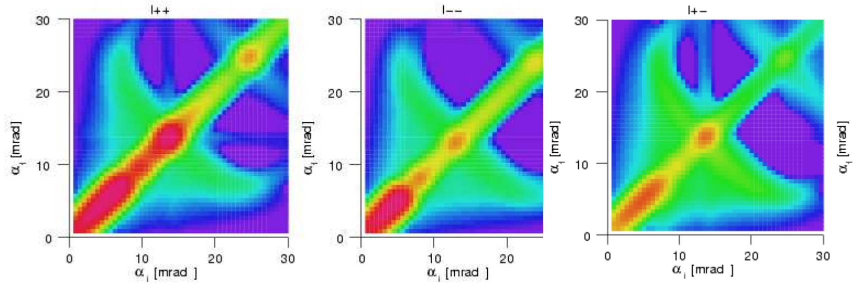
- **Fe: (dark)**
  - – polycrystalline, (110)
  - – Roughness ≈ 10Å
- **Si: (bright)**
  - – amorphous
  - – Roughness ≈ 5Å
- **Substrates**:
  - – Si (0.5mm thick)
  - – Floatglass (3mm thick)
  - – Roughness ≈ 5Å
- Interface layer thickness[1]

[1] S.-J. Cho et al., Thin Solid Films 434 (2003) 136-144

Specular and off-specular scattering from a bent Si-Fe multilayer at 200G

I++ I- - I+-





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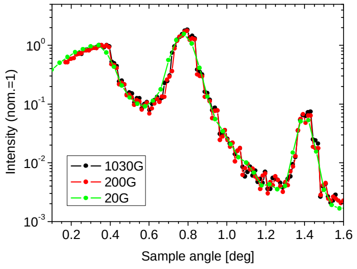

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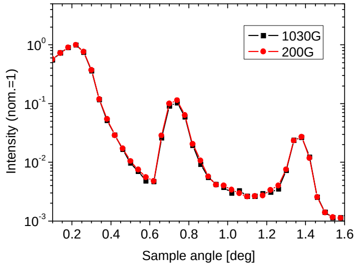

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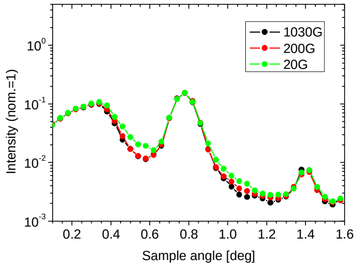

- Vertically correlated interface structure and associated domains with ~500 nm of lateral correlation

Specular and off-specular scattering from a stress-free Si-Fe multilayer at 200G

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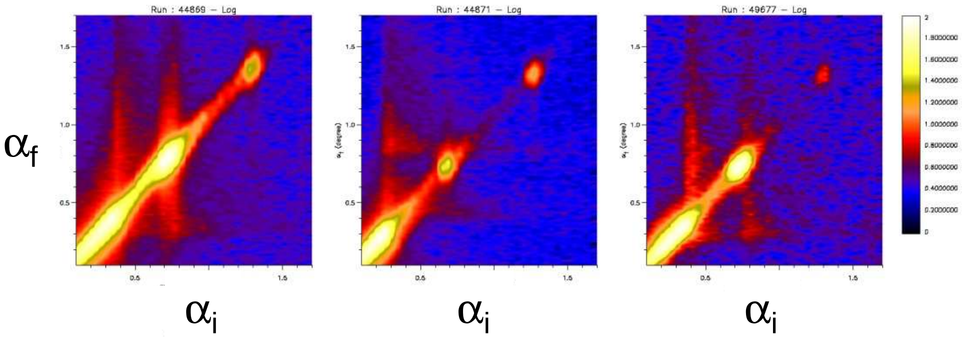

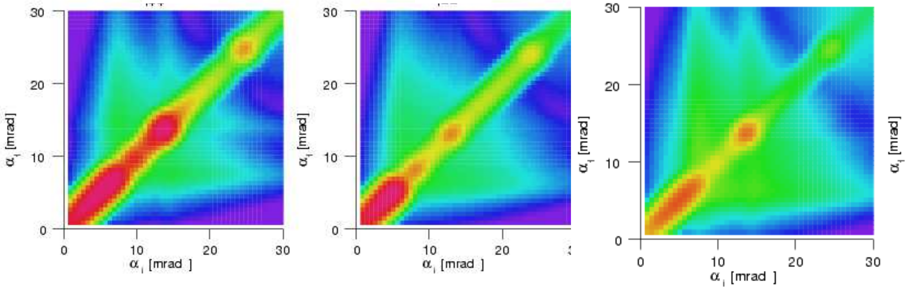

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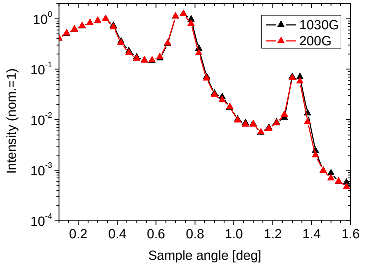

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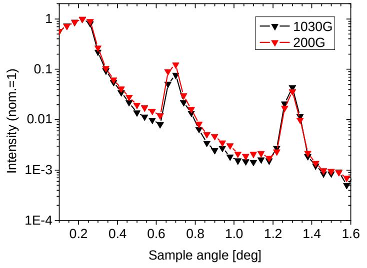

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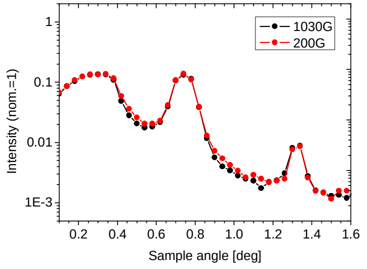

- streaks caused by longitudinal fluctuations