Strain induced magnetic anisotropy in thin $Co_2Fe_{0.4}Mn_{0.6}Si$ magnetic layer

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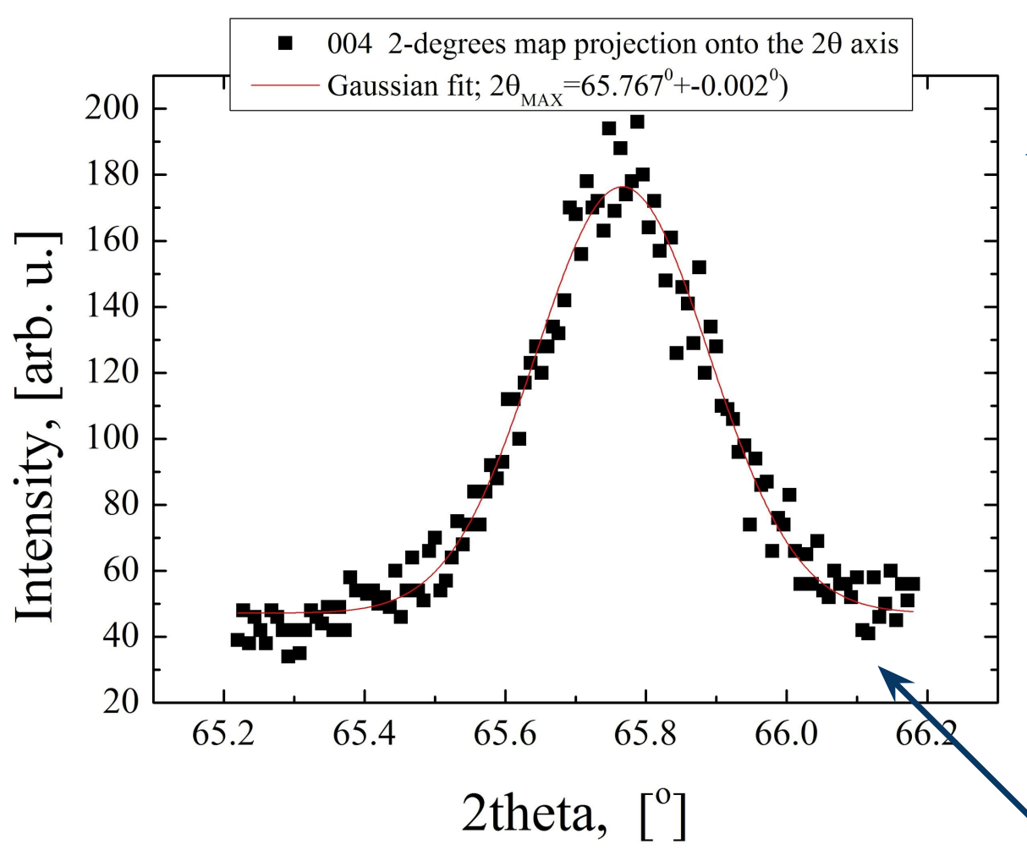
XRD studies

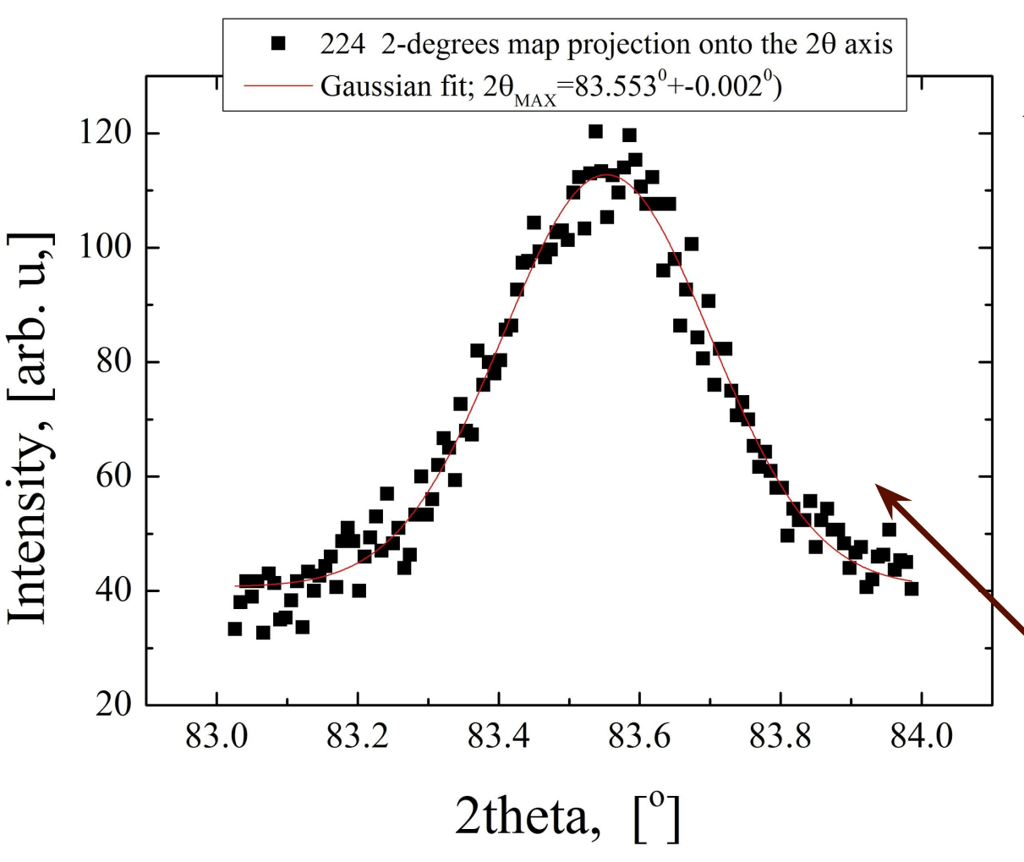
$$\begin{cases} a_{\parallel} = a_0 + a_0\varepsilon'_{11} \\ a_{\perp} = a_0 + a_0\varepsilon'_{33} = a_0 + a_0\left(-2\dfrac{c_{12}}{c_{11}}\right)\varepsilon'_{11} \end{cases}$$

$$a_{\perp} = 5.675 \pm 0.005 Å \qquad \varepsilon_{11} = -2.19 \times 10^{-3}$$

$$a_{\parallel} = 5.645 \pm 0.008 Å \qquad \varepsilon_{33} = 3.10 \times 10^{-3}$$



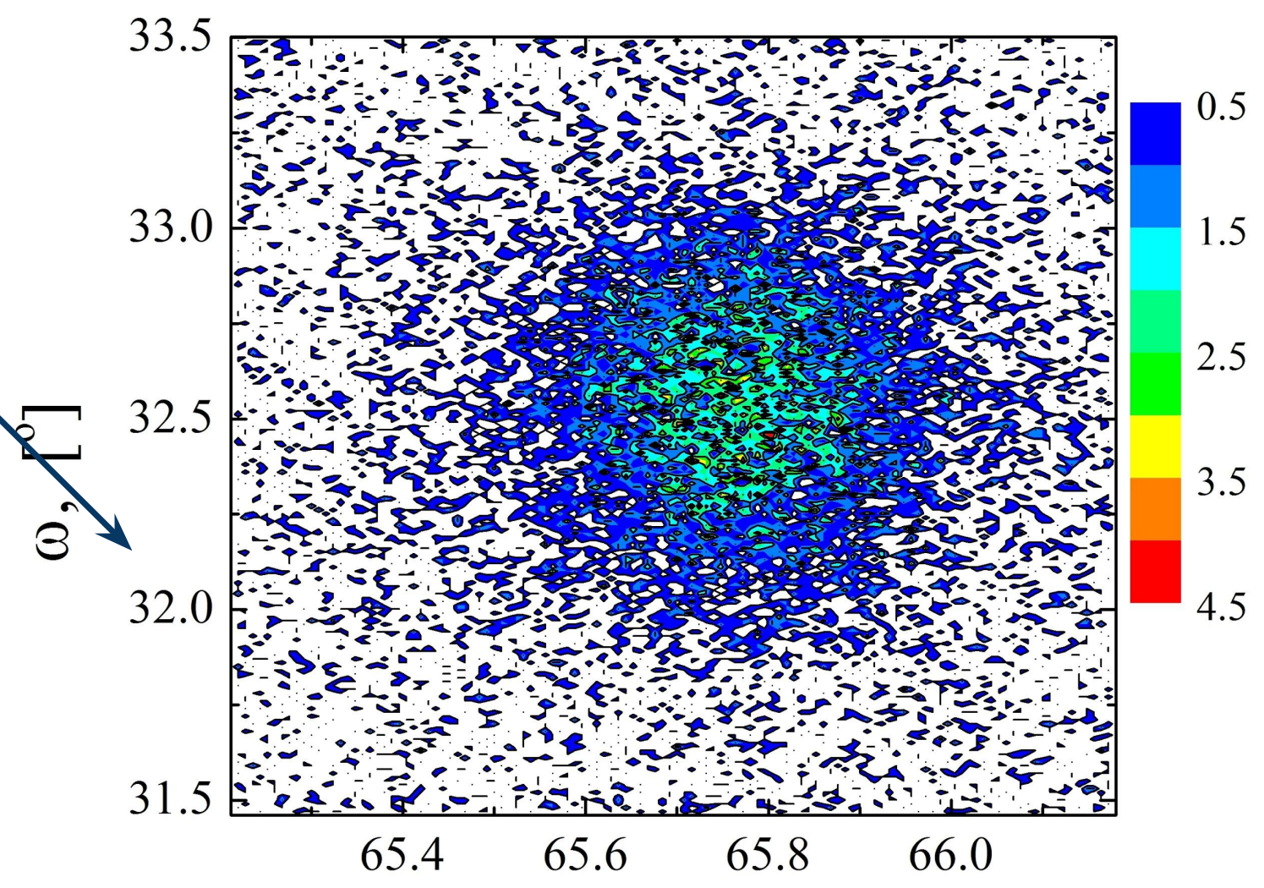
Note projection of the X-ray intensity distribution around the 004 reflection into the 2θ axis

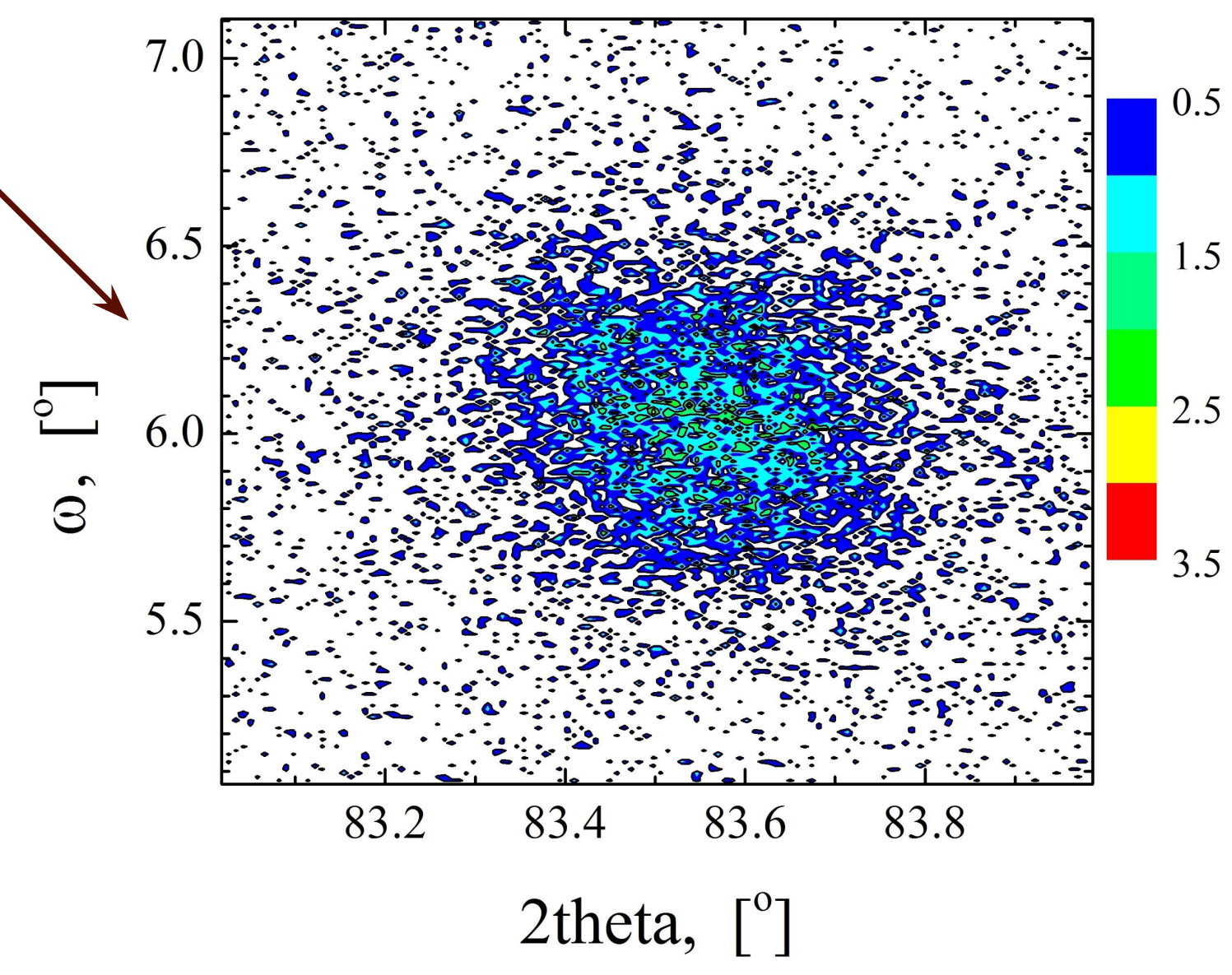


Note projection of the X-ray intensity distribution around the 224 reflection into the 2θ axis

a high-resolution X-ray diffractometer with a 4-reflection Ge (220) monochromator and X-ray mirror, radiation – $Cu_{K\alpha 1}$ and an analyzer in front of a proportional detector

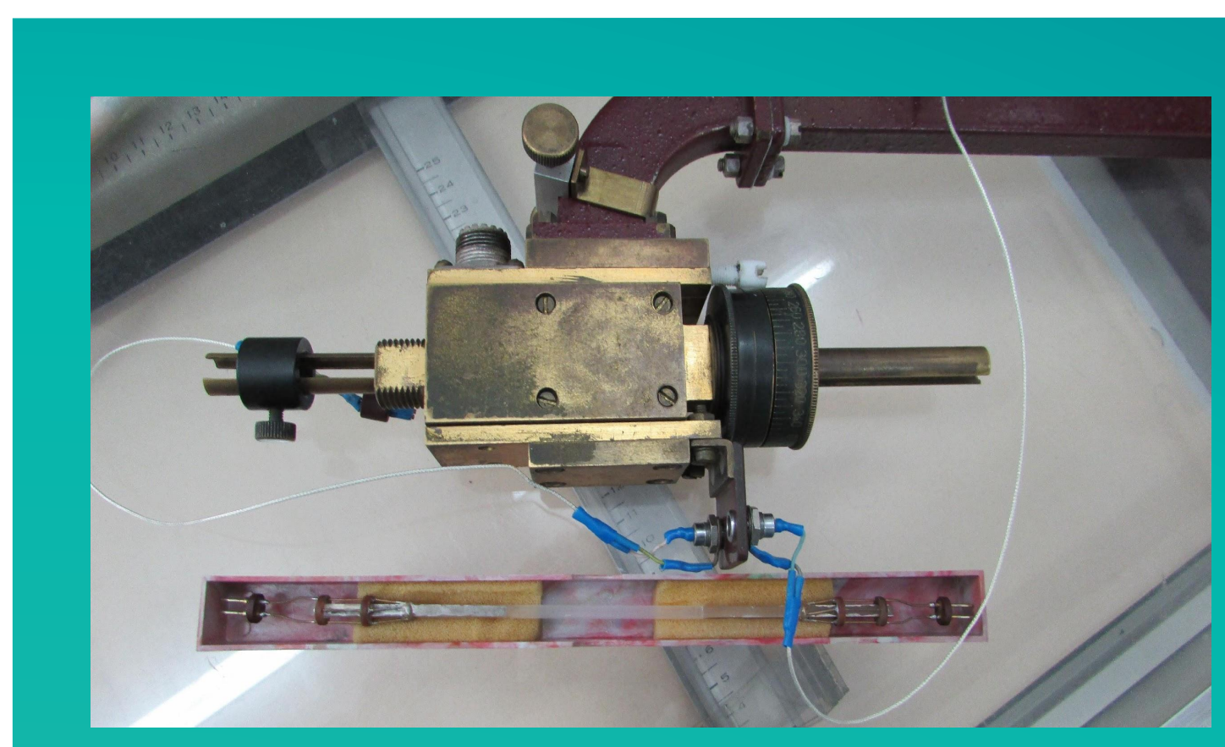
The X-ray intensity distribution around the 004 reflection





The X-ray intensity distribution around the 224 reflection

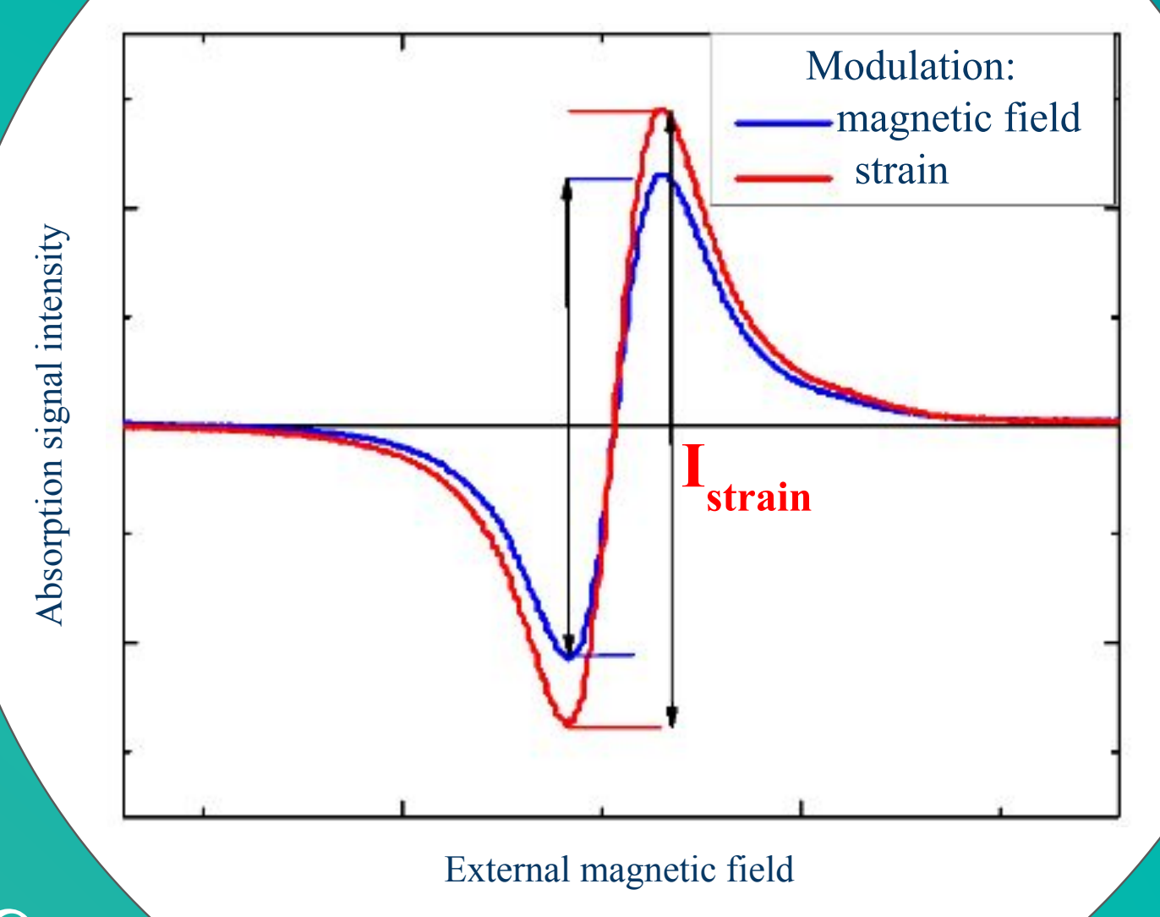
Magnetoelastic properties



Polycrystalline quartz rode with glued thin film driven to oscillations

$$F = -\sum_{i=1}^{3} M_i H_i + 2\pi M_S^2 \alpha_3^2 + K\left(1-\alpha_3^2\right) + \boxed{\sum_{i,j,k,l=1}^{3} B_{ijkl}\alpha_i\alpha_j\varepsilon_{kl}}$$

magnetoelasticity



$$m_\sigma = m_0 \frac{G_0}{G_\sigma}\frac{I_{strain}}{I_{magnet}}$$

$$\Downarrow$$

$$m_\sigma = \Delta H_\sigma = H_{strain} - H_{magnet}$$

$$\Downarrow$$

$$\boxed{\textit{magnetoelastic}\ \text{constant}\ B}$$

$$\lambda_S = -\frac{B_{11}}{c_{11} - c_{12}}$$

The values of magnetoelastic tensor components B_{11} and corresponding saturation magnetostriction λ_S for CFMS

	$Co_2Fe_{0.4}Mn_{0.6}Si$			
	with Ag		without Ag	
d, nm	B_{11}, 10^6 erg/cm^3	λ_S, 10^{-5}	B_{11}, 10^6 erg/cm^3	λ_S, 10^{-5}
15	-	-	-6.67	0.54
30	-13.10	1.08	-12.90	1.06
50	-17.50	1.44	-13.20	1.08

Strain induced magnetic anisotropy

$$K_{si} = 1.39 \pm 0.43 \quad 10^5\ \text{erg/cm}^3$$

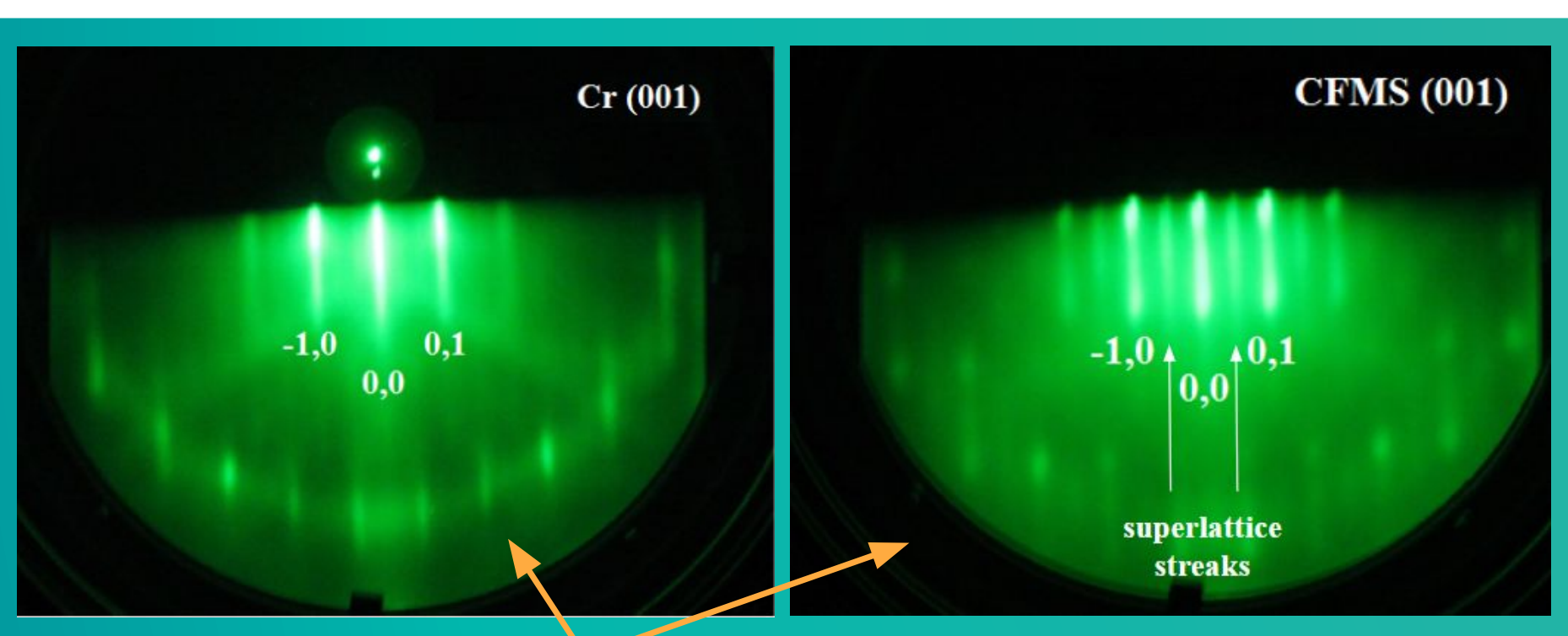
$$\varepsilon'_{11min} = \frac{4\pi c_{11} M_S^2}{3B_{11}(c_{11}+c_{12})} \approx -0.07$$

Minimal tetragonal distortion to switch the magnetic layer anisotropy from an easy-plane to an easy axis type

$$K_{si} = \frac{3}{2}B_{11}\left(\varepsilon'_{11} - \varepsilon'_{33}\right)$$

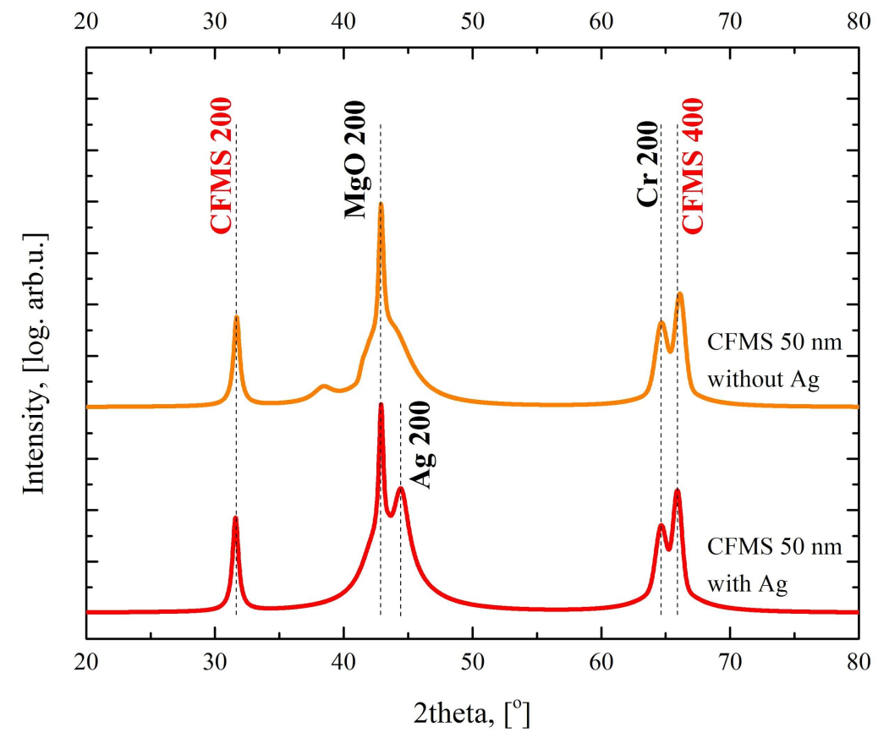
$$U_{ME} = -K_{si}\cos^2\theta$$

Samples information



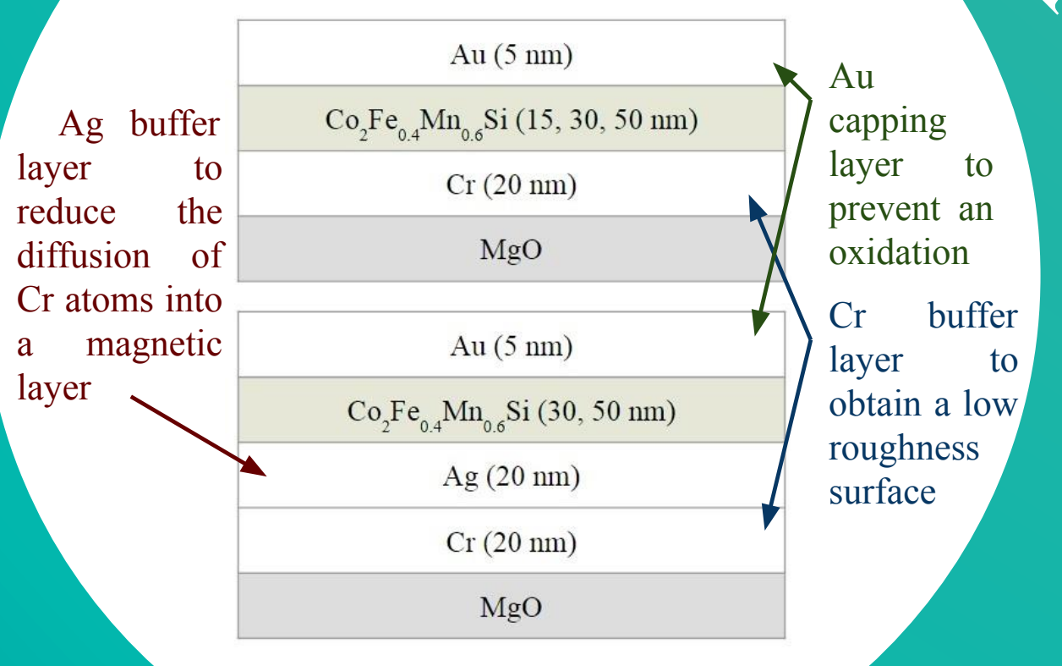
flat surface with epitaxial relationships:
MgO (001) ‖ Cr (001) ‖ CFMS (001) or
MgO (001) ‖ Cr (001) ‖ Ag (001) ‖ CFMS (001)

well crystalline with cubic symmetry; at least B2 ordered structure



XRD scan patterns

Samples



Au (5 nm)
$Co_2Fe_{0.4}Mn_{0.6}Si$ (15, 30, 50 nm)
Cr (20 nm)
MgO

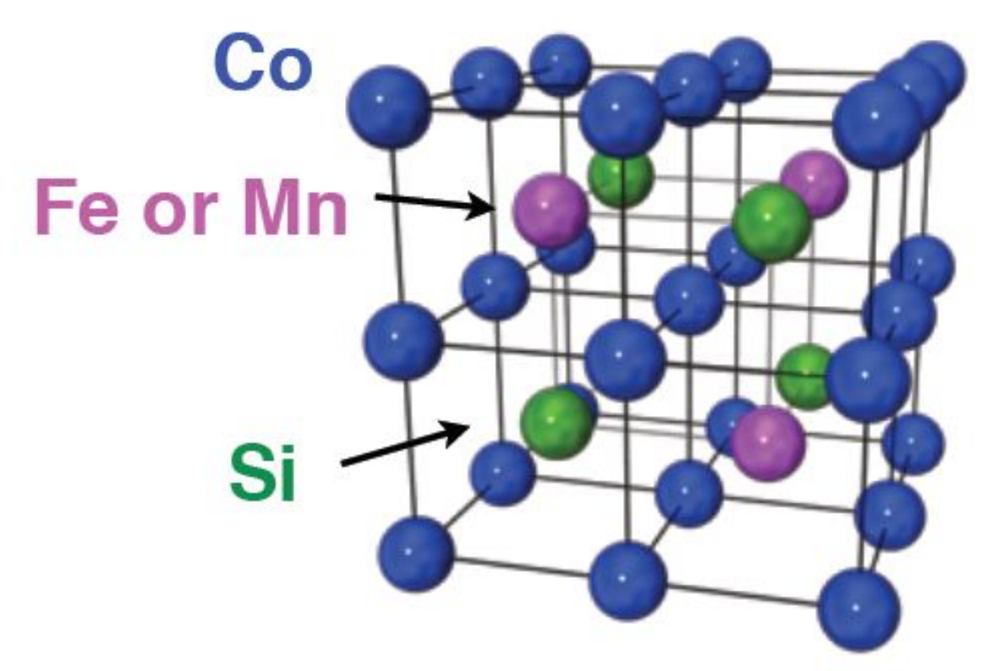
Au (5 nm)
$Co_2Fe_{0.4}Mn_{0.6}Si$ (30, 50 nm)
Ag (20 nm)
Cr (20 nm)
MgO

Ag buffer layer to reduce the diffusion of Cr atoms into a magnetic layer

Au capping layer to prevent an oxidation

Cr buffer layer to obtain a low roughness surface

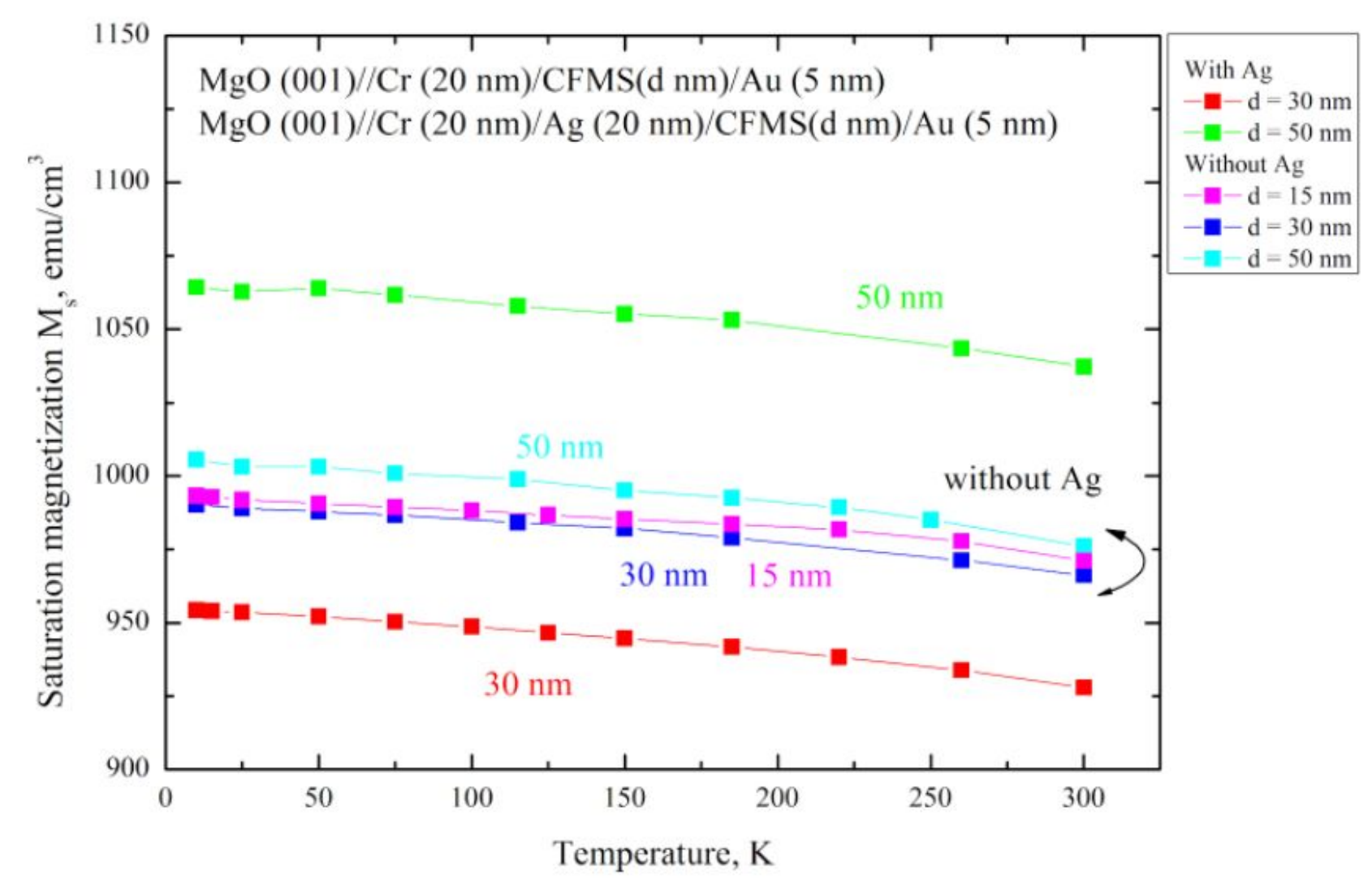
$L2_1$-CFMS



Ultrahigh-vacuum (UHV)-compatible magnetron sputtering deposition:

Buffer layer deposition T_R
⇓
Annealing 600° C
⇓
Magnetic layer deposition T_R
⇓
Post-annealing 500° C
⇓
Cover layer deposition T_R

Magnetocrystalline anisotropy



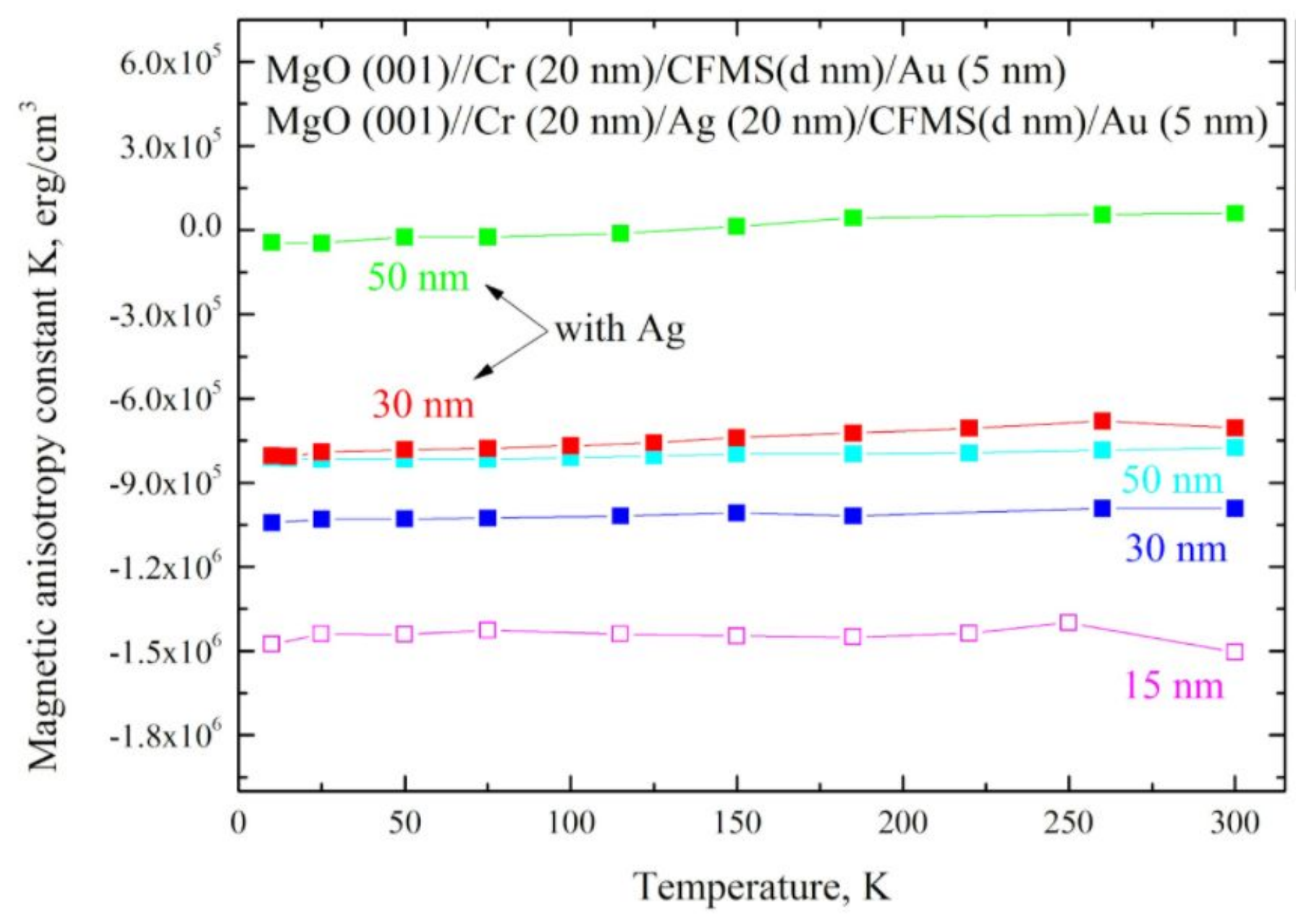
Saturation magnetisation

$$F = -\sum_{i=1}^{3} M_i H_i + 2\pi M_s^2\cos^2\theta - K\cos^2\theta = $$

$$= -\sum_{i=1}^{3} M_i H_i + 2\pi M_s M_{eff}\cos^2\theta$$

$$M_{eff} = M_s - \frac{K}{2\pi M_s}$$

$$\begin{cases} \left(\dfrac{\omega_{res\parallel}}{\gamma}\right)^2 = H_{\parallel}\left(H_{\parallel} + 4\pi M_{eff}\right) \\ \dfrac{\omega_{res\perp}}{\gamma} = H_{\perp} - 4\pi M_{eff} \end{cases}$$



Magnetocrystalline anisotropy

- Magnetoelastic properties of quaternary $Co_2Fe_{0.4}Mn_{0.6}Si$ Heusler alloy thin magnetic films were determined by the Strain Modulated FMR method; the magnetoelastic constants were found to have relatively small and negative values while saturation magnetostriction for all the studied samples was positive.
- Tetragonal deformation in the layer was observed by high-resolution X-ray diffractometry, which resulted in the appearance of the strain induced anisotropy, which was calculated. Strain causes an increasing of the overall anisotropy constant and reduces its absolute value.
- The minimal tetragonal distortion value, which is necessary to switch the magnetic layer anisotropy from an easy-plane to an easy axis type, was estimated to be at least $\varepsilon_{11\text{-}min} \approx -0.07$; such a large strain is not likely to be obtained.