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Study of Buried Interfaces in Fe/Si Multilayer by Hard X-ray emission spectroscopy

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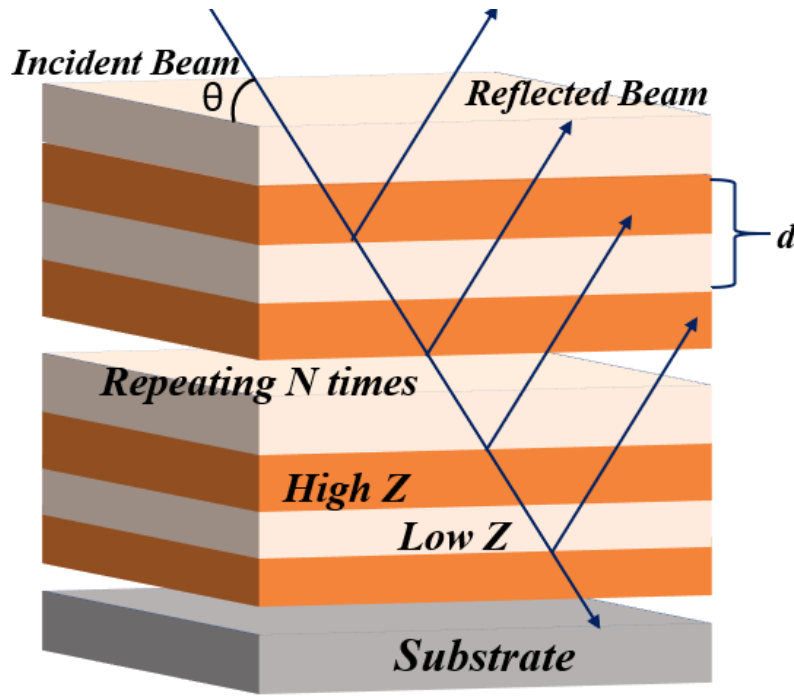
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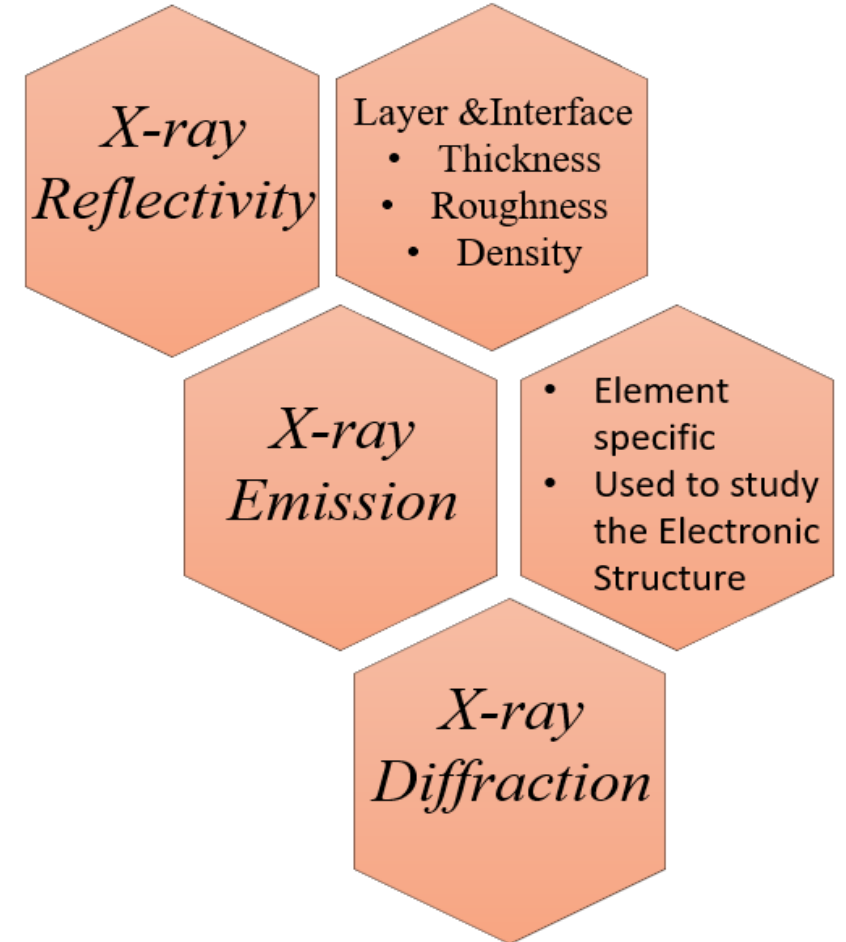
Introduction



- Absorbing material (high Z element e.g. Fe, Cu etc.)
- Spacer material (low Z element e.g. Si, C etc.)

$$\text{Bragg's Law, } 2d \sin\theta = n\lambda$$

Characterisation of Multilayers



Soft X-ray Telescopes for Solar Imaging

Microscopy in Water Window Range

Extreme Ultra Violet Applications



State of the Art & Motivation

➤ Multilayers studied by X-ray emission in the soft X-ray range ($E \leq 2\text{keV}$)

Extent the Methodolgy in
Hard X-ray range ($E \leq 5\text{keV}$)

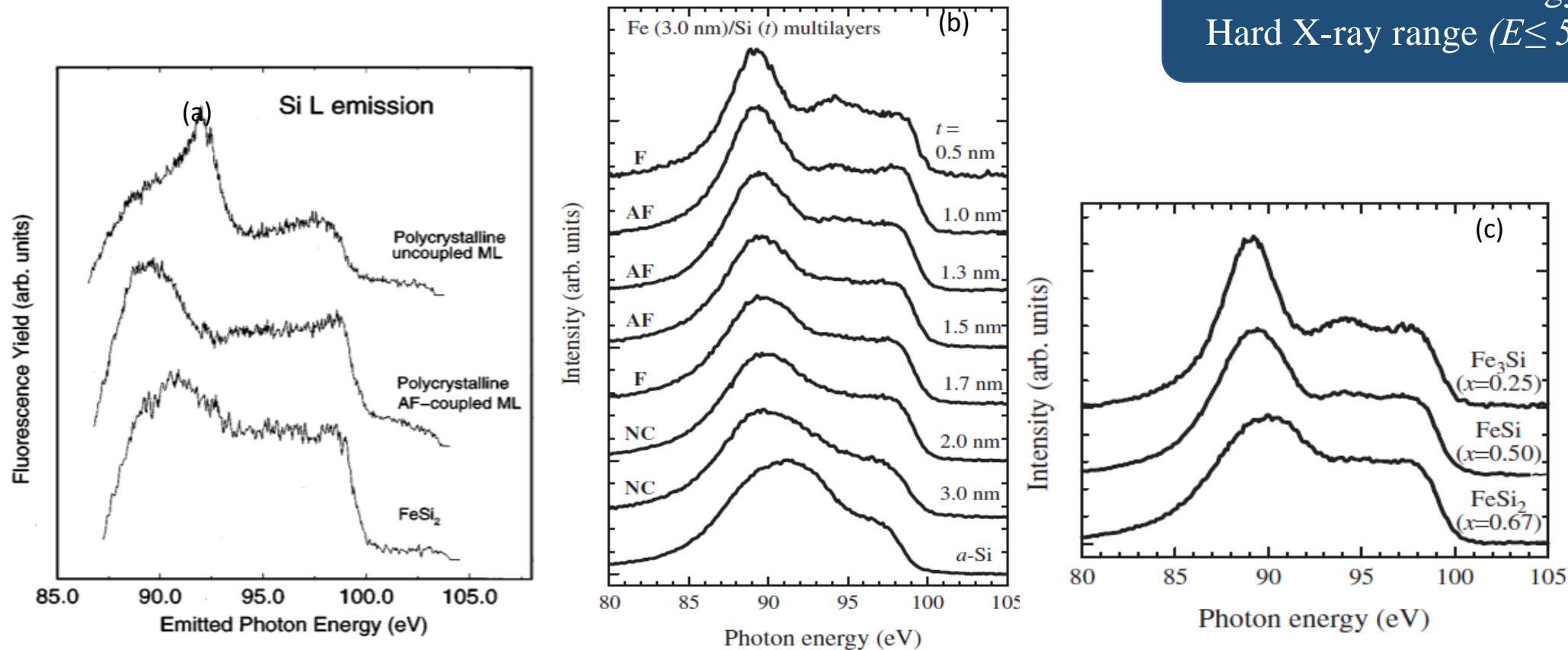


Figure 1 – (a) *XRF Si L emission spectra for an FeSi₂ ref. & two Fe/Si multilayers (b) & (c) **Si L_{2,3} XRF spectra measured for the [Fe/Si(t)] multilayer.

*J. A. Carlisle et al 1996 Phys. Rev. B 53, R8824(R), **Takashi Imazono et al 2004 Jpn. J. Appl. Phys. 43 4327



Samples Studied



Figure 2 - Magnetron Sputtering Chamber at LCPMR

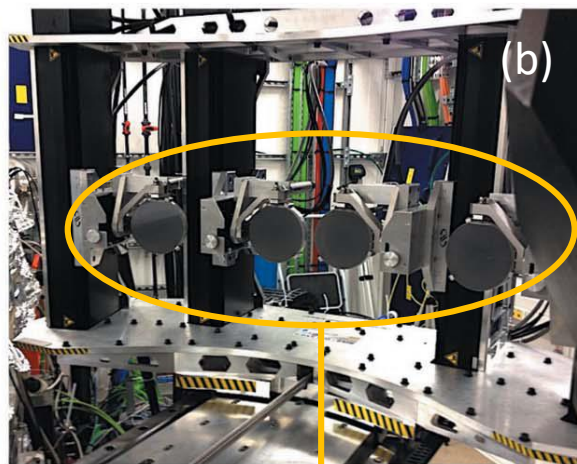
Fe ref. – Thin Film of 20nm Fe on Si Substrate

*FeSi₂ ref. – [Fe(3.6nm)/Si(4.5nm)]_{x13} multilayer sample
annealed at 675°C for 2 hours in vacuum*

[Fe(2.5nm)/Si(2.5nm)]_{x40} Multilayer

Spectrometer

- **RIXS** (resonant inelastic x-ray spectrometer) multi analyser spectrometer was used to obtain the emission spectra of Fe at GALAXIES beamline installed at synchrotron SOLEIL, Paris.



Ge (620) analyser crystals

Sample kept under He

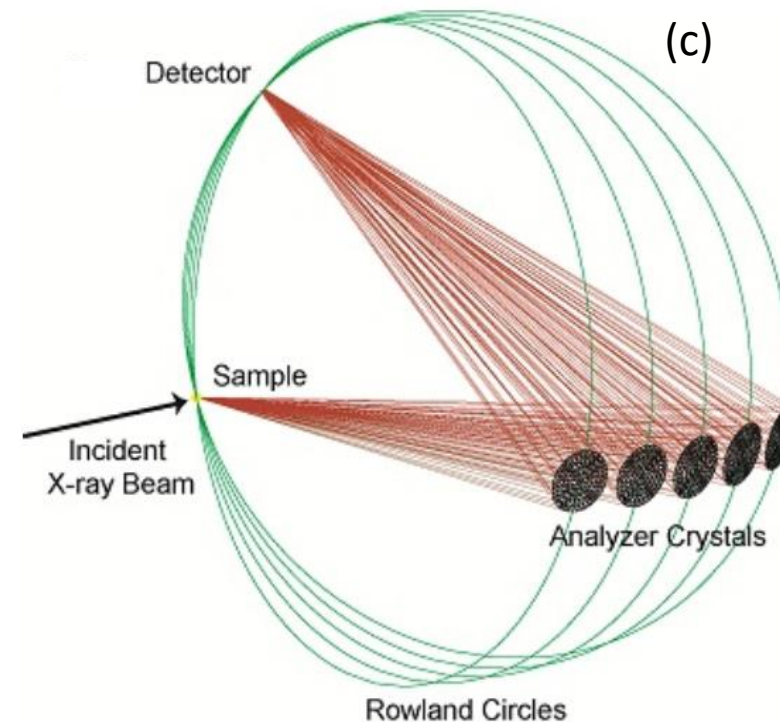


Figure 3 - (a) RIXS set up (b) Multi-analyser arranged in the RIXS in the scanning 4x1 configuration at GALAXIES beamline, Soliel (c) Rowland Circle Geometry

X-ray emission spectra

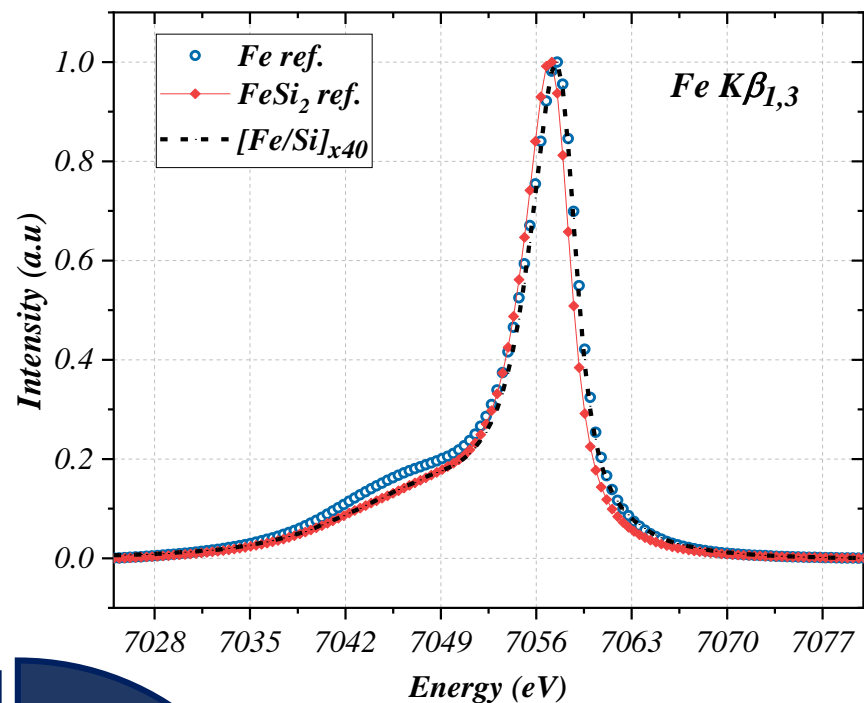


Figure 4 - Normalised Fe $K\beta_{1,3}$ emission curves plotted for an incident photon energy of 7250 eV.

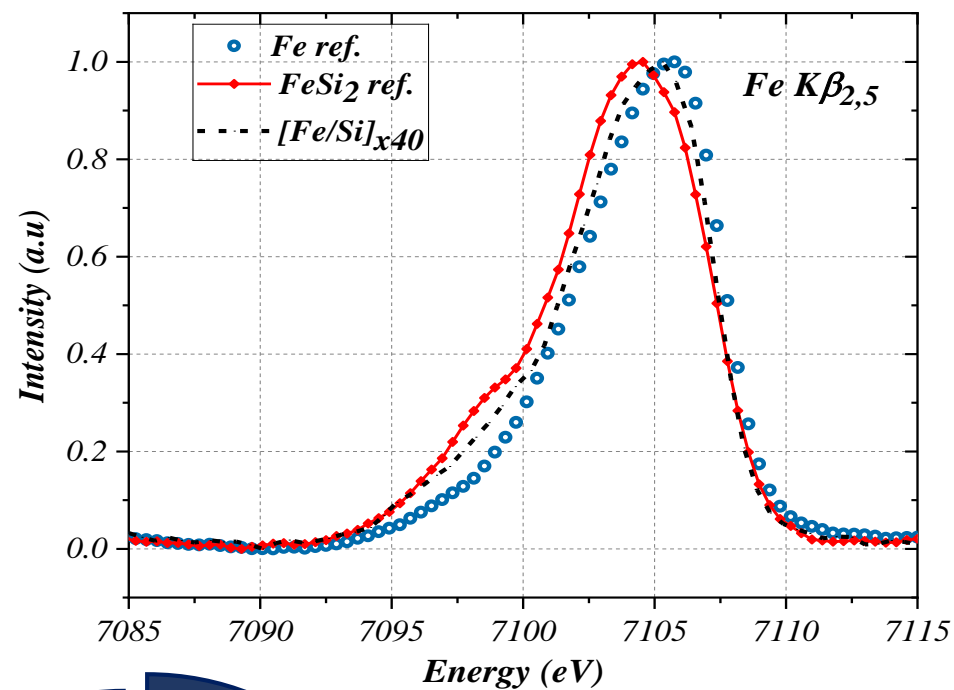
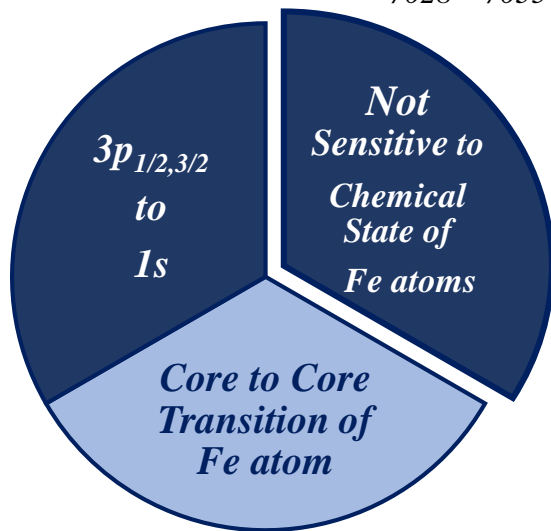
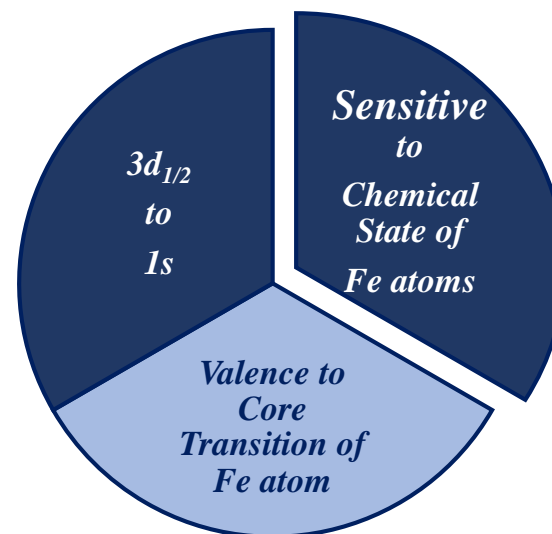
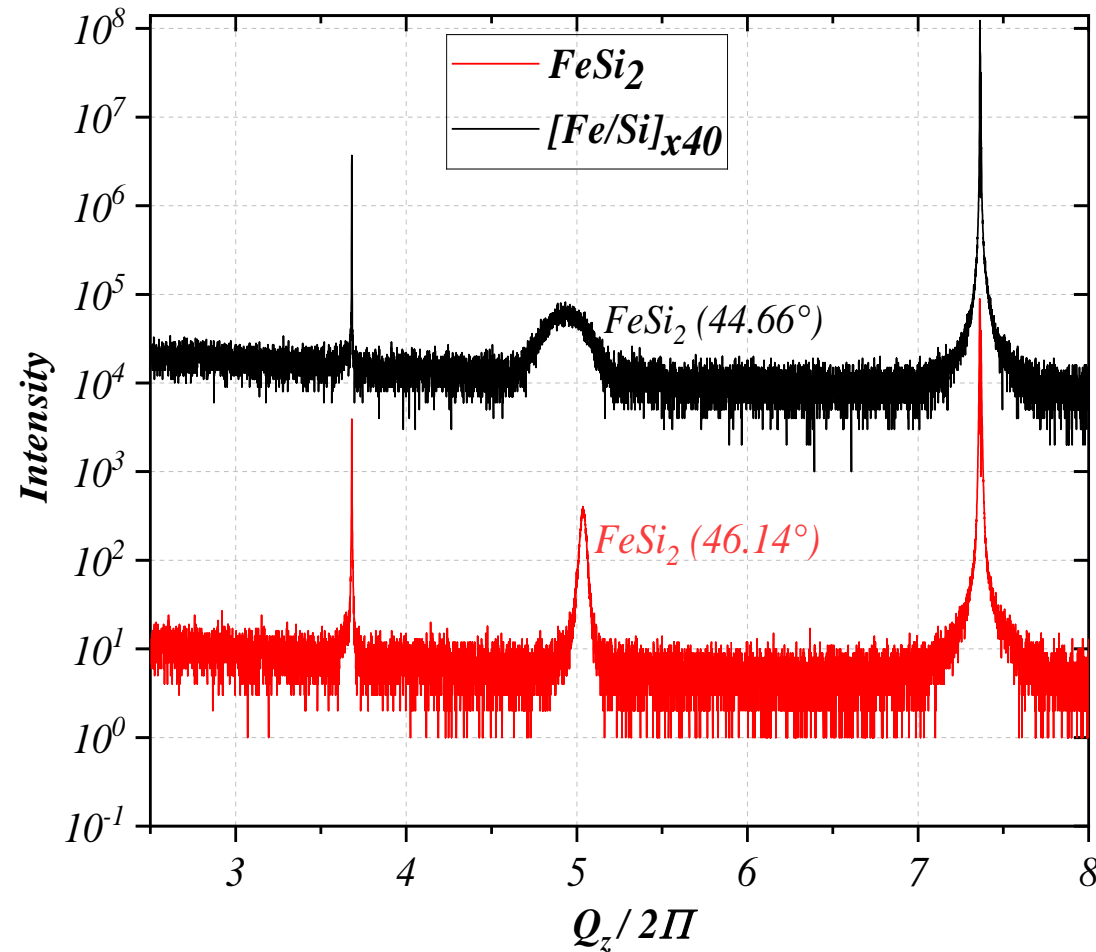


Figure 5 - Normalised Fe $K\beta_{2,5}$ emission curves plotted for an incident photon energy of 7250 eV.



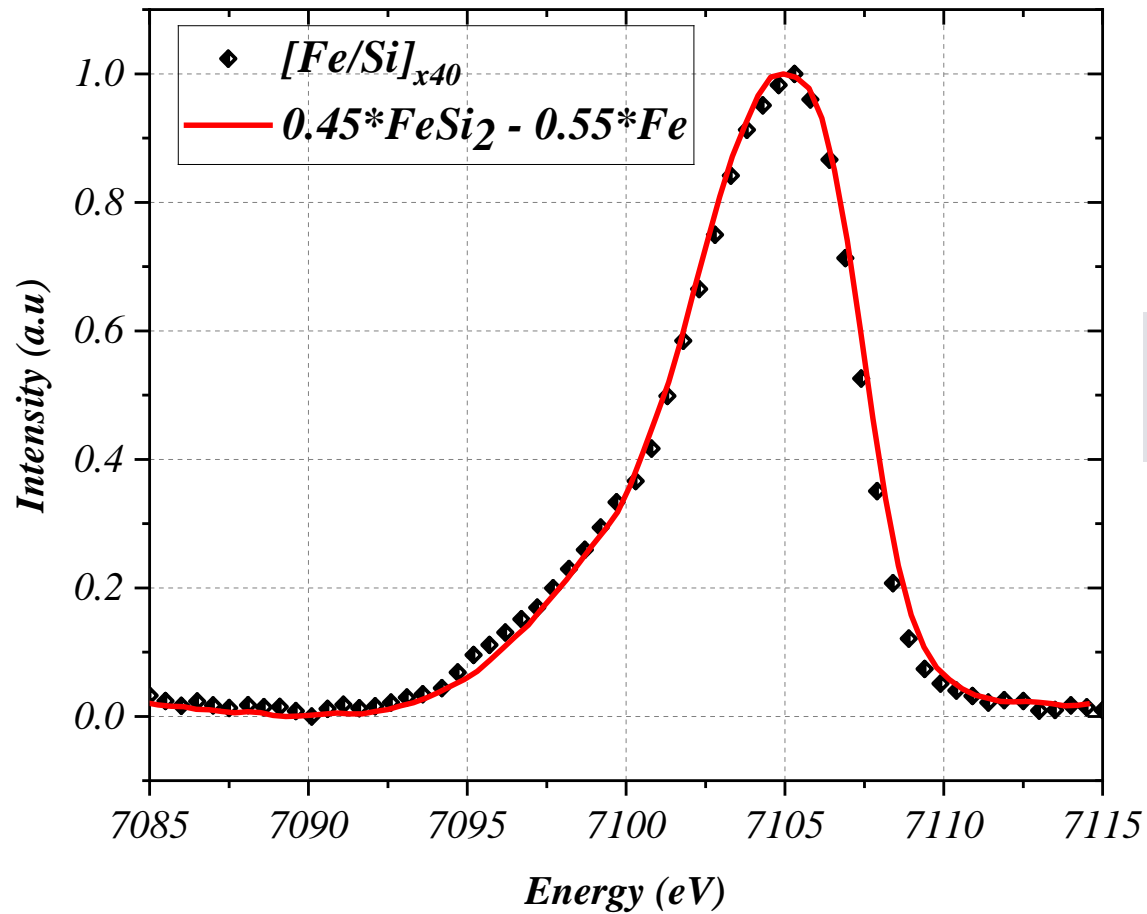
X-Ray Diffraction Analysis



- Peak Width --- Vertical Coherence Length – 3.8nm in Fe/Si Multilayer
- *Presence of $FeSi_2$ at the interface between Fe and Si layers in the $[Fe/Si]_{x40}$ multilayer*
- *$FeSi_2$ grains in the multilayer are too large & distort the structure of the multilayer*

Figure 6 - X-ray diffraction patterns of the Fe/Si multilayer and the $FeSi_2$ reference

Calculation of Interface Thickness – Weighted Fit

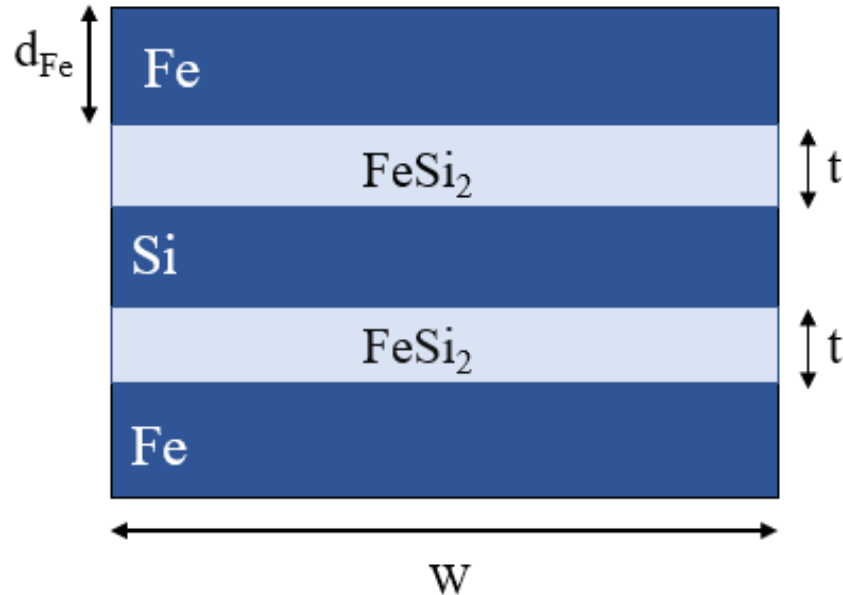


*Best Fit is obtained for $0.45 * \text{FeSi}_2 - 0.55 * \text{Fe}$ weights with 0.20 uncertainty*

Figure 7 - Fit of Fe K-beta5 emission band of the multilayer with a weighted sum of Fe ref and FeSi₂ ref spectra.

Calculation of Interphase Thickness

*Interdiffusion Model
(Miyata et al.)*



$$I_{ML} = xI_{Fe} + yI_{FeSi_2}$$

$$\frac{I_{Interface}}{I_{Fe}} = \frac{\text{No. of emitting Fe atoms from the FeSi}_2 \text{ interface}}{\text{No. of emitting Fe atoms from the Fe layer}}$$

$$= \frac{y}{x} = R$$

$$\frac{I_{Interface}}{I_{Fe}} \sim \frac{(\rho/M)_{Interface} \times N \times 2t \times w}{(\rho/M)_{Fe} \times N \times (d_{Fe} - t) \times w} \sim R$$

$$t = \frac{R (\rho/M)_{Fe} d_{Fe}}{2 (\rho/M)_{Interface} + R (\rho/M)_{Fe}}$$

ρ = density; M = Molar Mass; N = Avogadro's number

With, $x = 0.55$ and $y = 0.45$
Interface Thickness (t) = $1.4\text{nm} \pm 0.2$

Reflectivity Measurements for $[Fe/Si]_{x40}$ multilayer

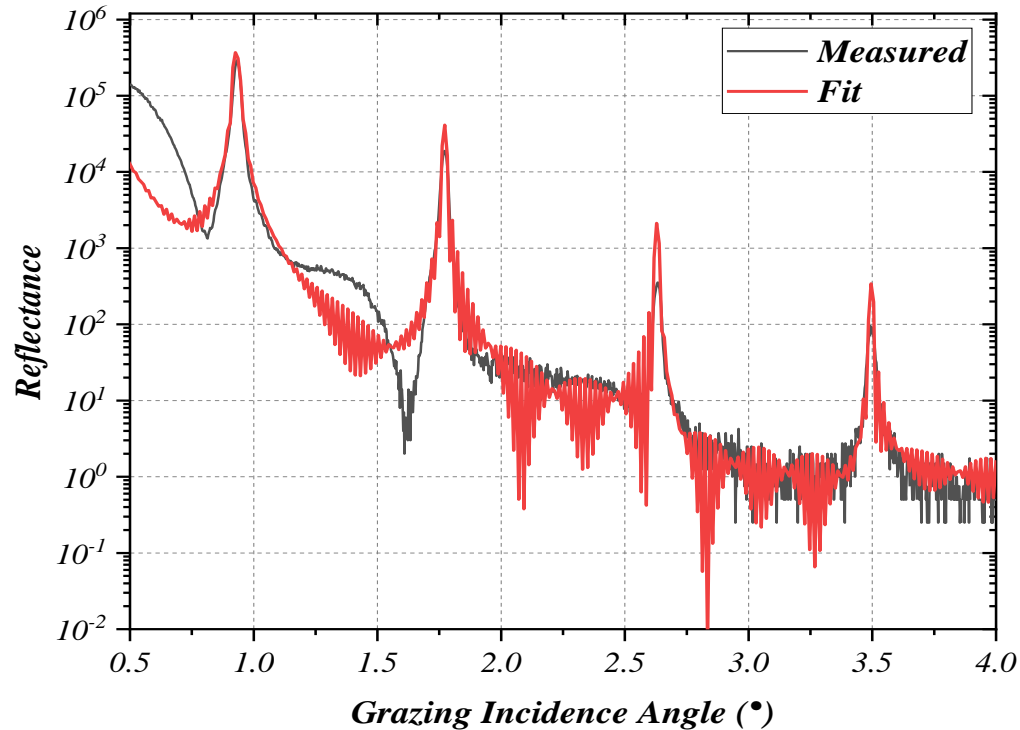


Figure 8 - Reflectivity Fit of $[Fe/Si]_{x40}$ Multilayer.

Layer	Thickness (in nm)	Roughness/Difussenes s (in nm)	Density (g/cm ³)
Fe	1.75	0.72	7.87 (Bulk)
FeSi ₂	1.04	0.22	7.18
Si	1.43	0.27	2.33 (Bulk)
FeSi ₂	0.85	0.23	6.59

- Total FeSi₂ Thickness - (2.8 nm)*Weighted Fit* > (1.9 nm)*XRR*
- Considering mean density of FeSi₂ (6.9 g/cm³) – XRR

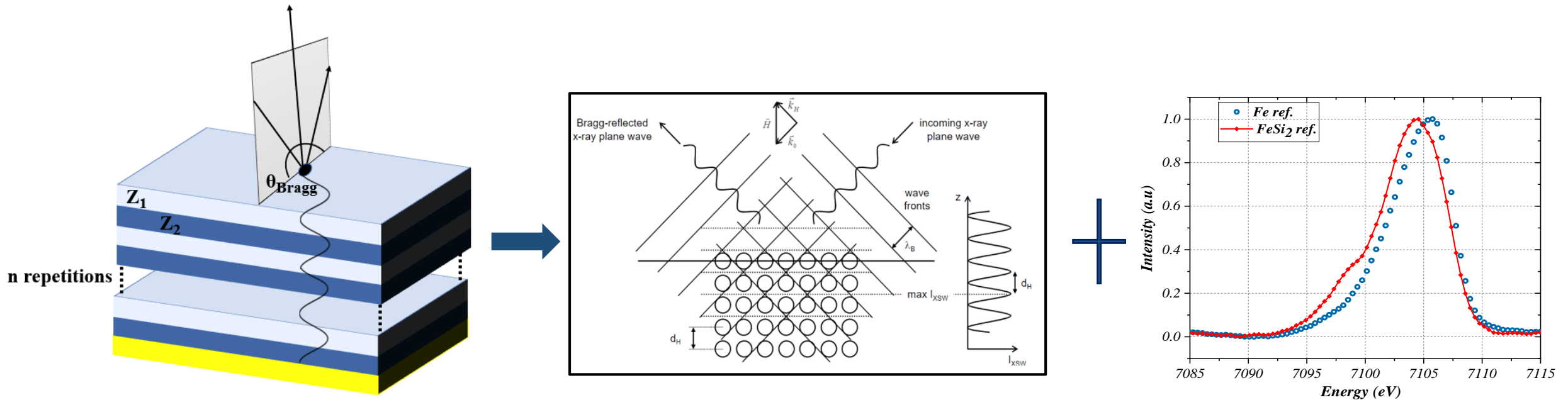
Thickness (Miyata model) = 1.2 ± 0.2 nm at each interface with a total of 2.4nm in one period

The total interfacial thicknesses deduced by XRR and XES can be considered as similar when taking into account the uncertainties

Conclusion & Future Prospects

- XES can be used to study the multilayer systems in the hard x-ray range to get information about the multilayer, qualitatively and quantitatively.
- The interface thickness obtained with XES in hard x-ray range is comparable to that obtained with soft x-rays in Fe/Si Multilayer.
- More precise information could be obtained by coupling X-ray Standing technique (XSW) with high resolution x-ray fluorescence (XRF) at high spectral resolution.

(XSW) Depth-dependent information + Chemical Sensitivity (XES)





Thank you