Standing-wave excited XES and RIXS: new tools for buried interface studies

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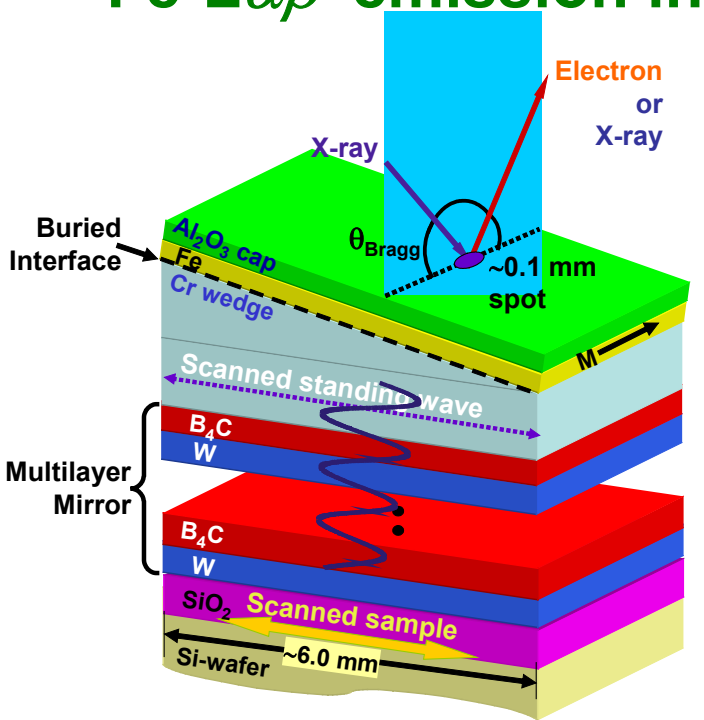
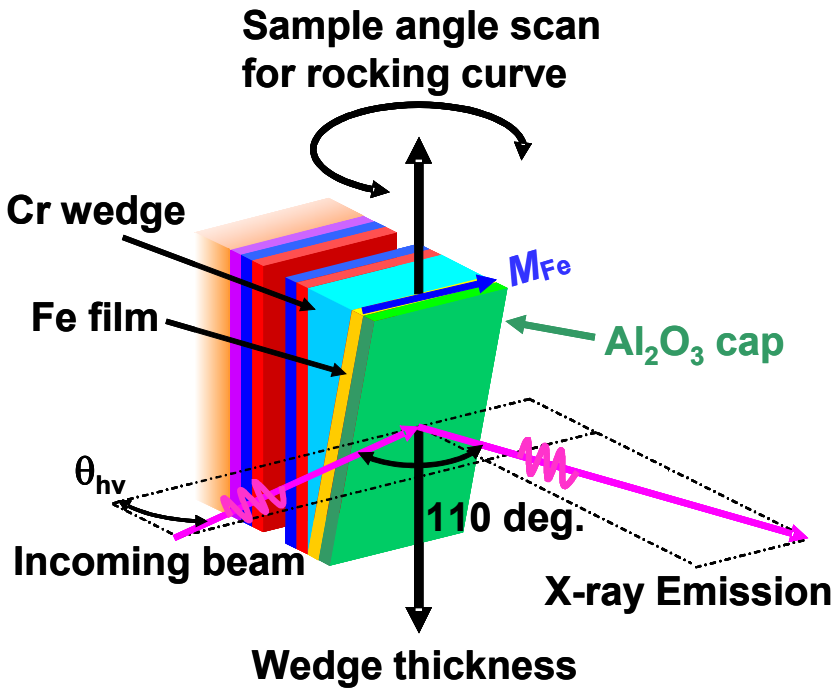
The Advanced Light Source

Outline

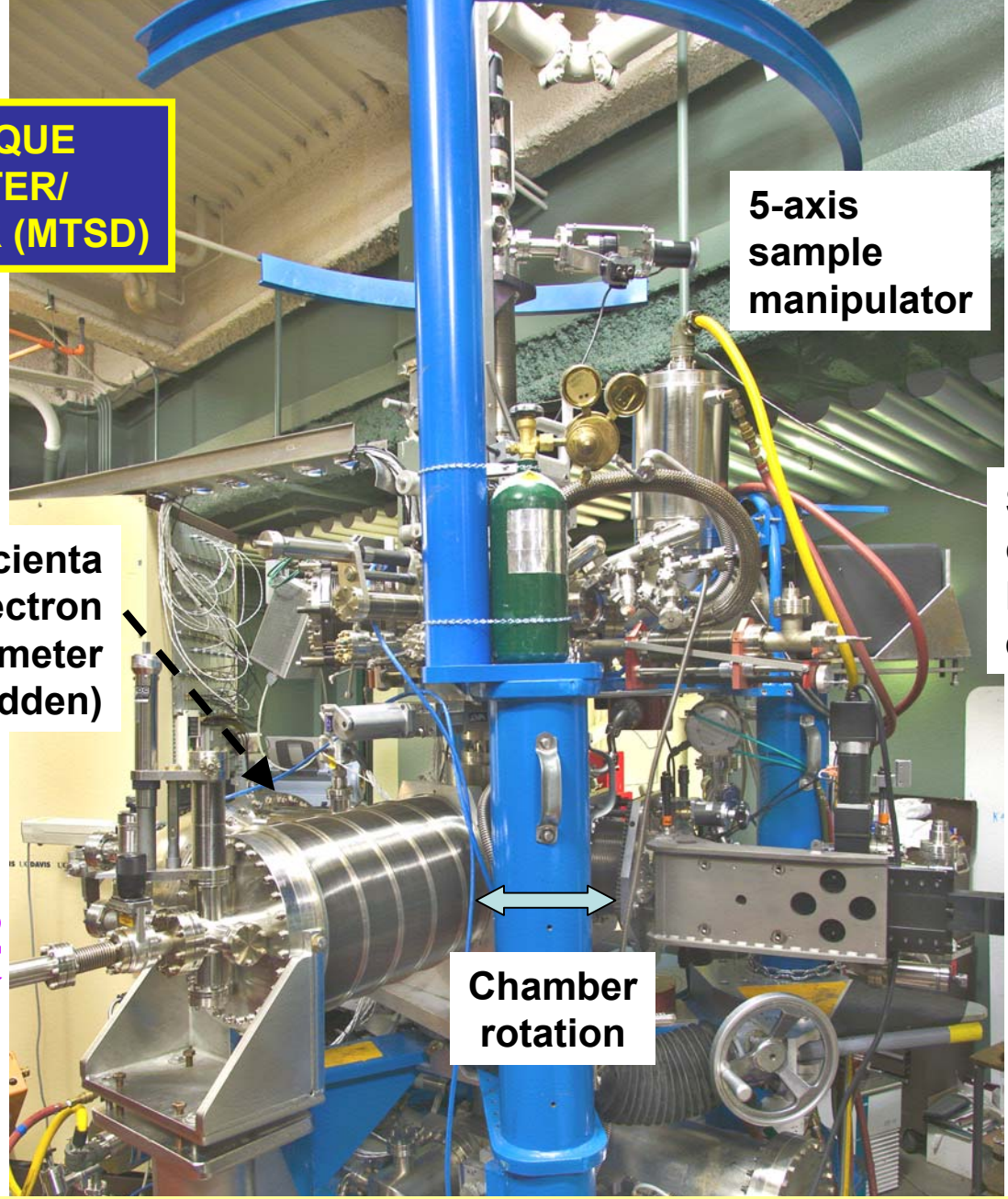
- Intro. to standing wave-wedge technique for probing buried interfaces:
  - Prior example - Photoemission results for Fe/Cr; Fe-2p, -3p, Cr-2p, -3p photoemission, incl. MCD

- New results: XES/RIXS for Fe/Cr:
  - Fe-L$\alpha\beta$ emission intensities, incl. MCD

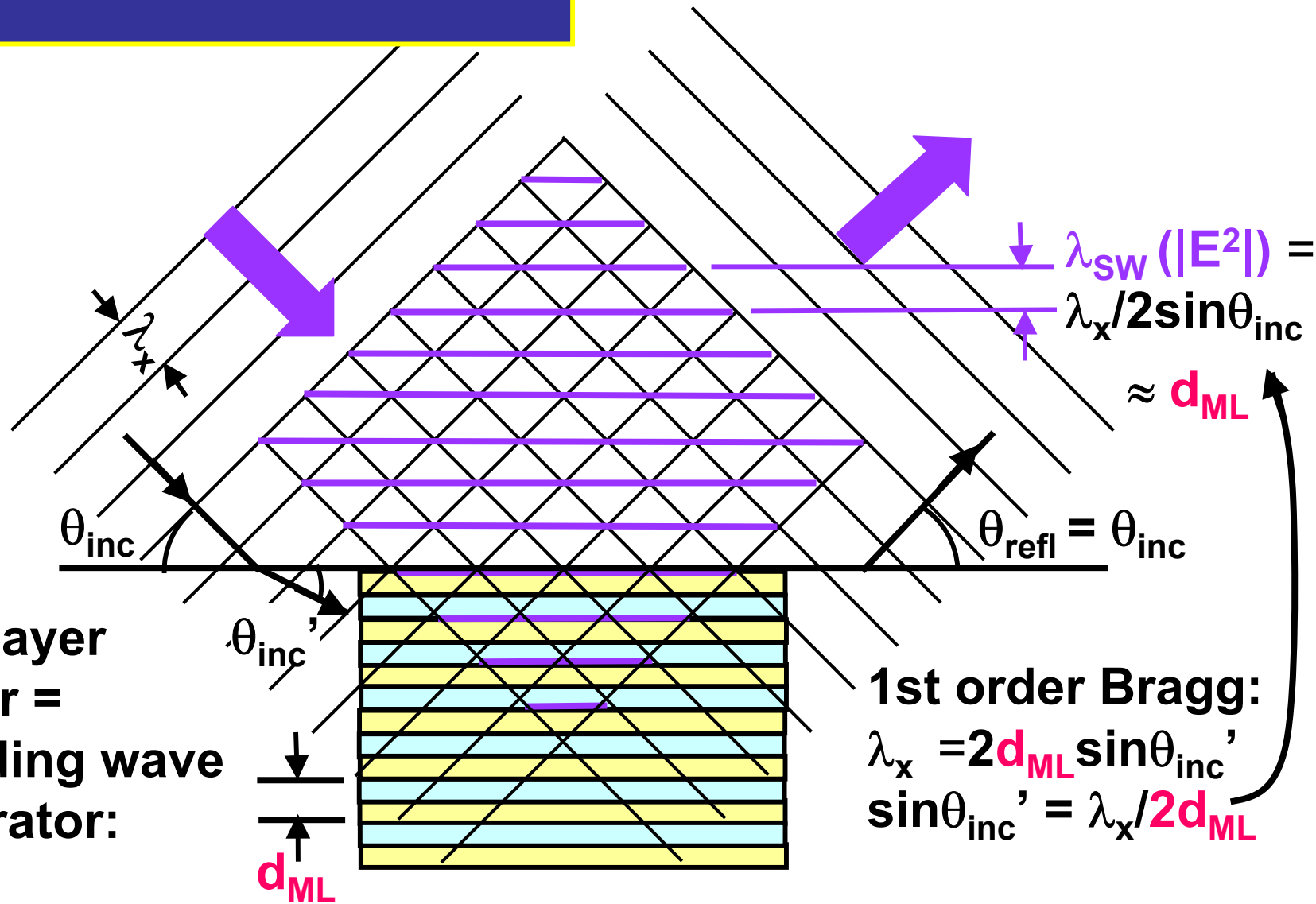




MULTI-TECHNIQUE SPECTROMETER/ DIFFRACTOMETER (MTSD)



Permits using all relevant soft x-ray spectroscopies on a single sample: PS, PD, PH; XAS (e^- or photon detection), XES/RIXS in MCD, MLD



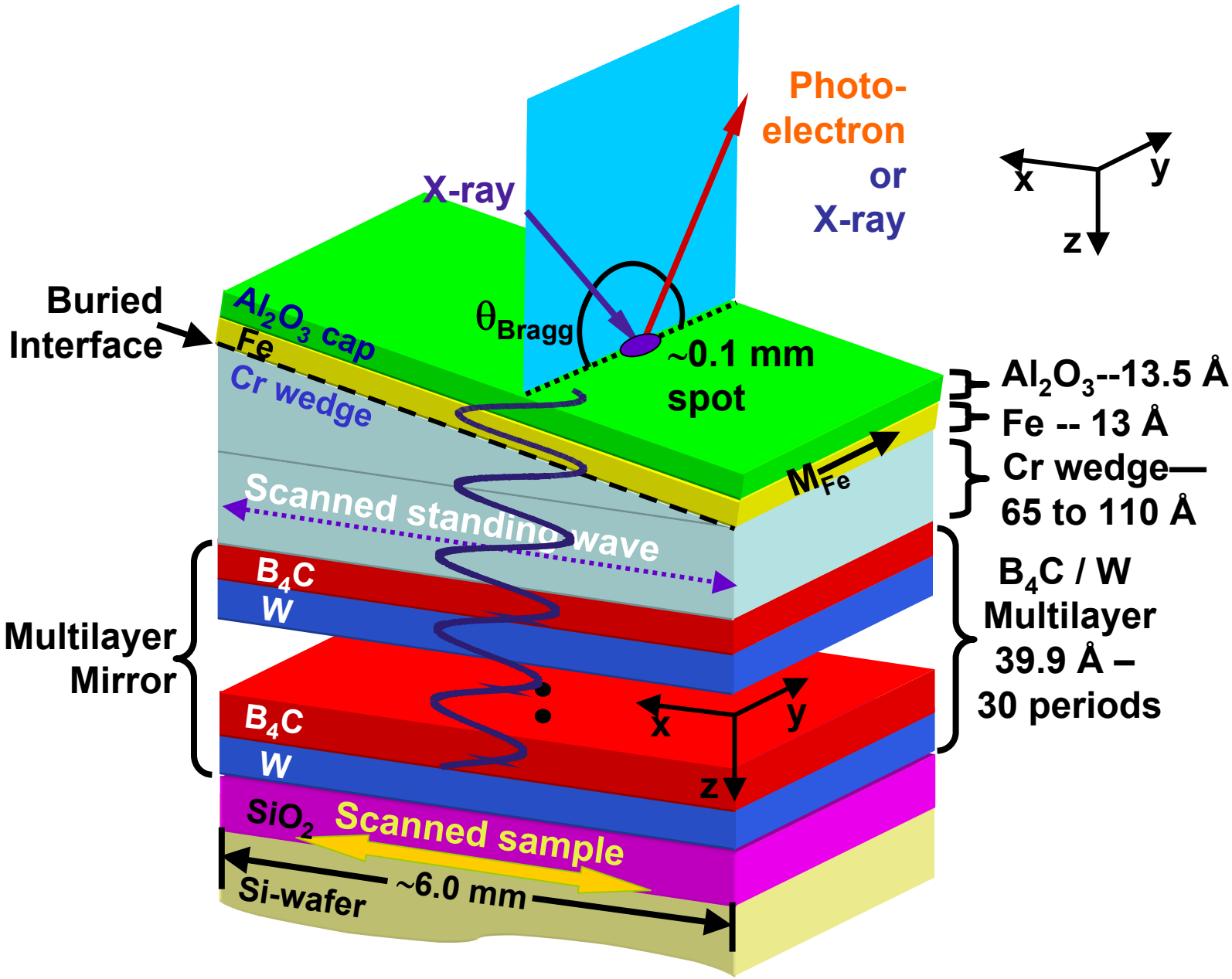
Multilayer mirror = Standing wave generator:

1st order Bragg:

$\lambda_x = 2d_{ML}\sin\theta_{inc}'$

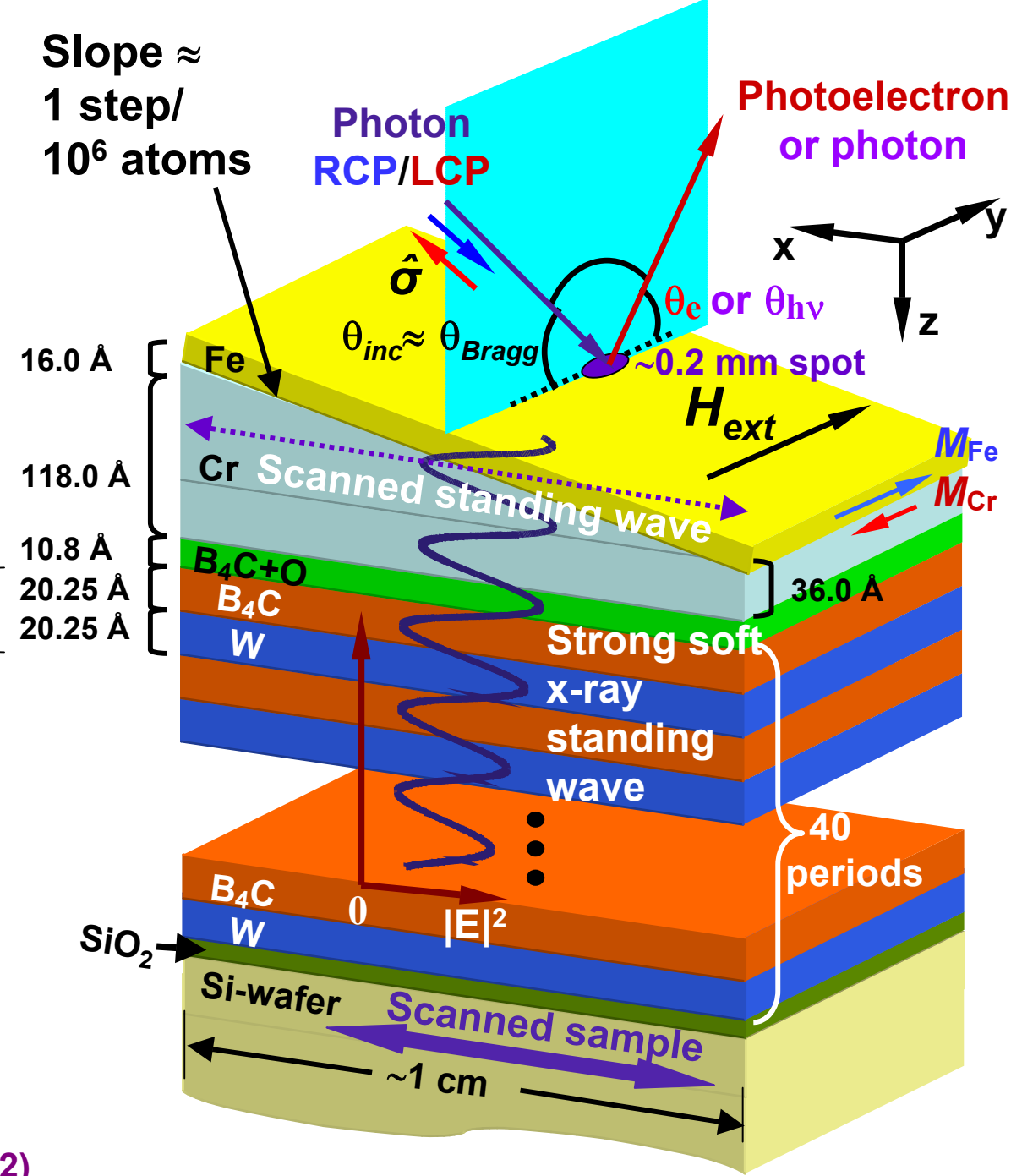
$\sin\theta_{inc}' = \lambda_x/2d_{ML}$

The Standing Wave-Wedge Method



Probing Buried Interfaces with Soft X-ray Standing Waves: Core PS Spectra

Fe/Cr: a prototypical system for giant magneto-resistance



S.-H. Yang. B.S. Mun et al., Surf. Sci. Lett. 461, L557 (2000); Phys. Cond. Matt. 14, L406 (2002)

X-ray Optical Calculations :

Calculating XRO effects on spectroscopy--Yang

- $n(h\nu) = 1 - \delta(h\nu) + i\beta(h\nu)$

-variable polarization

-multiple reflection/ refraction

-exact treatment of interlayer intermixing a/o roughness

-electric field at i-th layer:

$$I_i(z) = |E_i^+(z) + E_i^-(z)|^2$$

Photoemission:

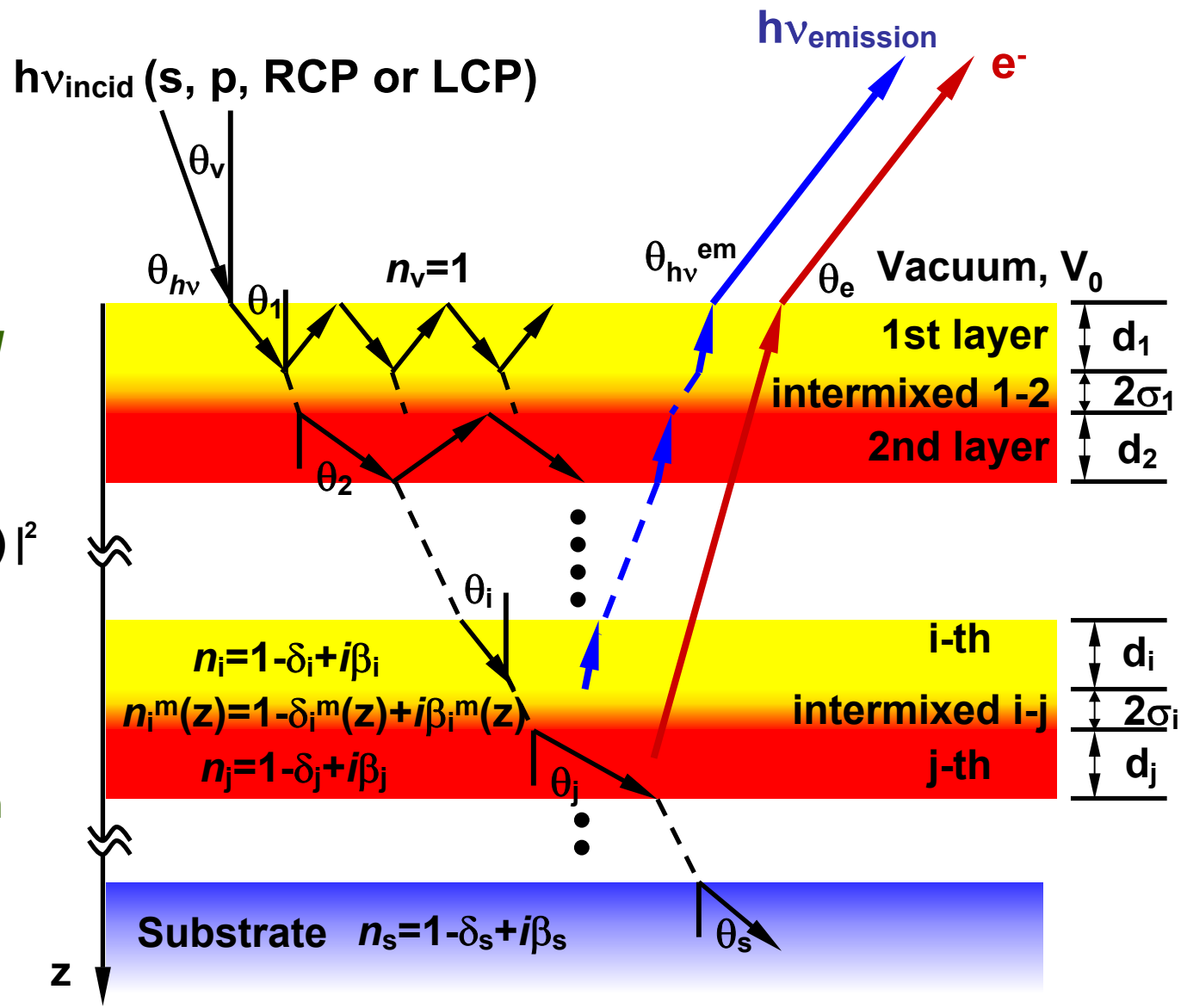
-differential cross section

-inelastic attenuation

-surface refraction

X-ray emission:

-fluorescence yield

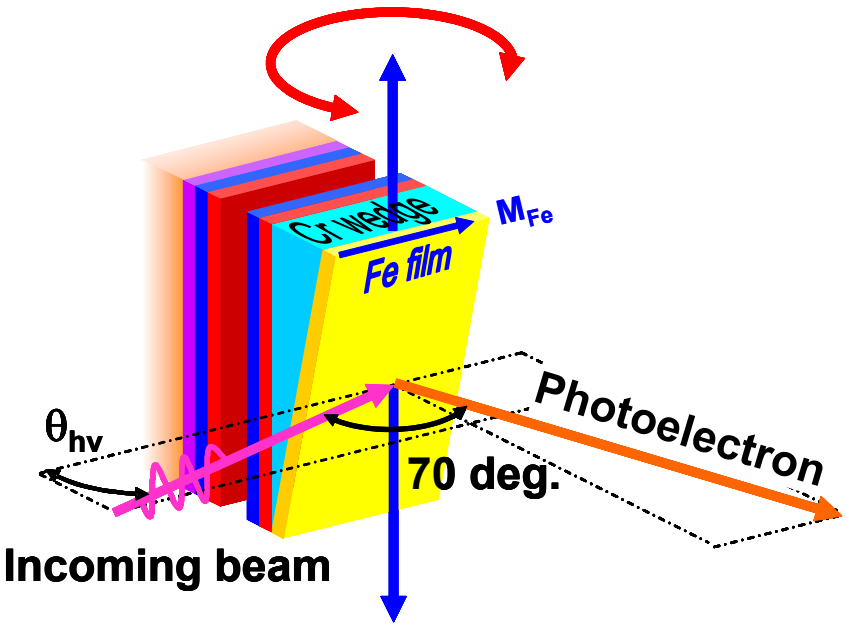


Multilayer PS, XES--S.-H. Yang et al., Surf.Sci.Lett. 461, L557 ('00); J.Phys.C.M. 14, L406 ('02)

Experimental + Calculated Photoemission Yield Ratio I(Fe 3p)/I(Cr 3p) from Fe/Cr wedge on standing-wave multilayer

Incidence Photon Angle Scan

Sample angle scan for rocking curve



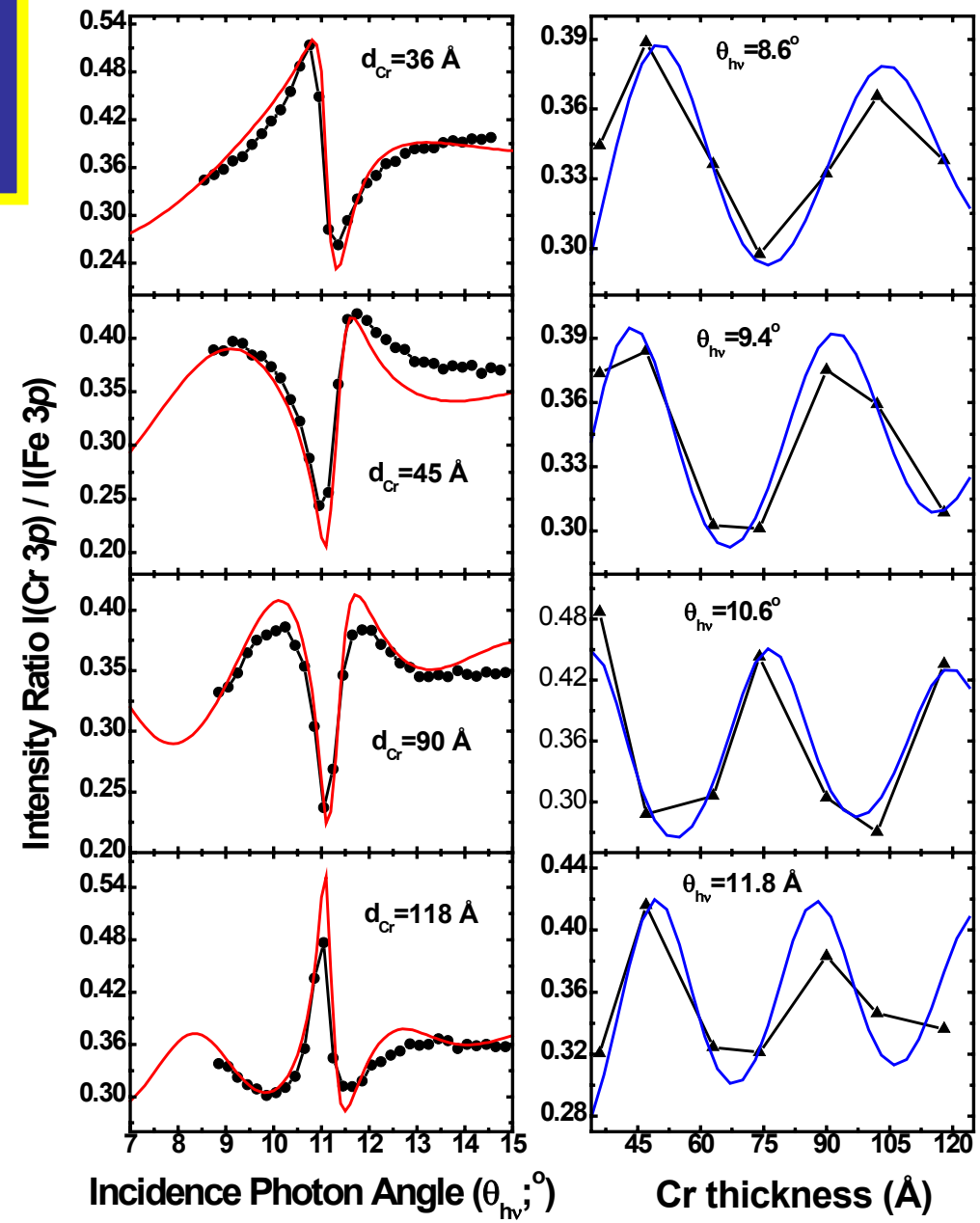
Wedge thickness

Cr Thickness Scan

S.-H. Yang. B.S. Mun et al.,
Surf. Sci. Lett. 461, L557 (2000);
Phys. Cond. Matt. 14, L406 (2002)

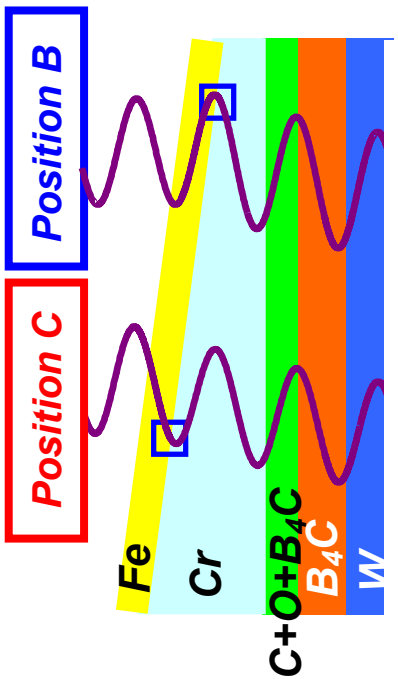
Rocking curves

Sample scan = Cr thickness depend.

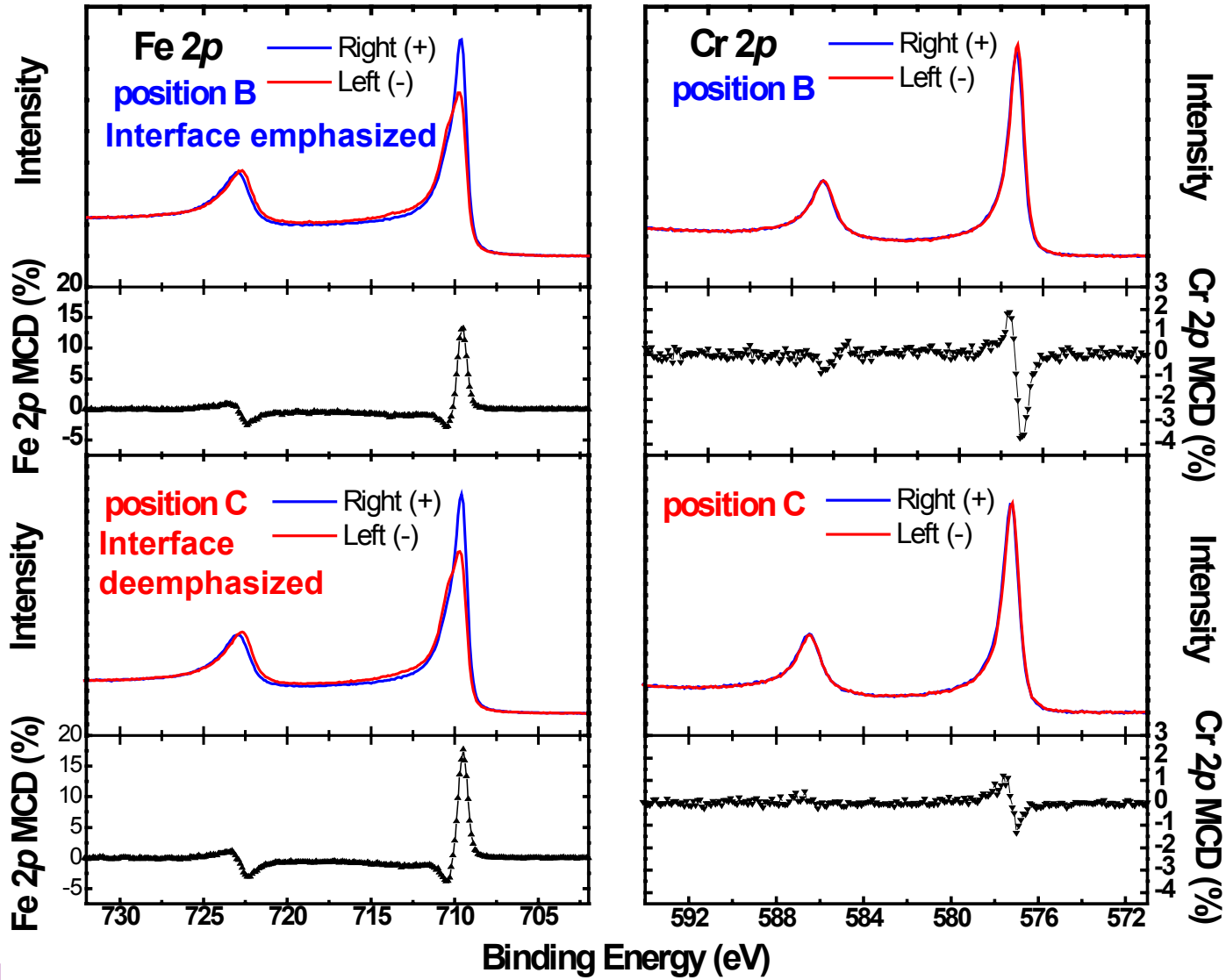


Fe and Cr 2p magnetic circular dichroism--probe of y-axis magnetization

Cr magnetization Is antiparallel to Fe; systematic variation of MCD strengths vs d_{cr}



Fe and Cr 2p MCD data from Fe/Cr wedge/multilayer



S.-H. Yang. B.S. Mun et al.,
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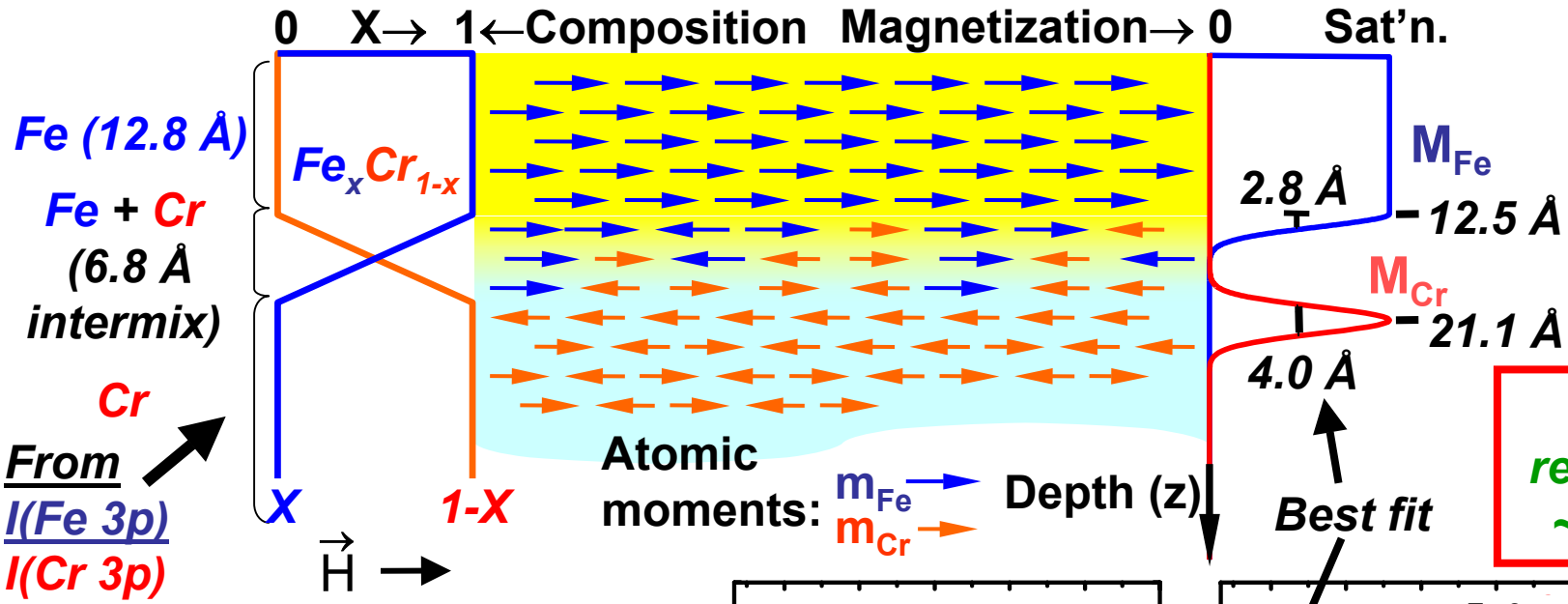
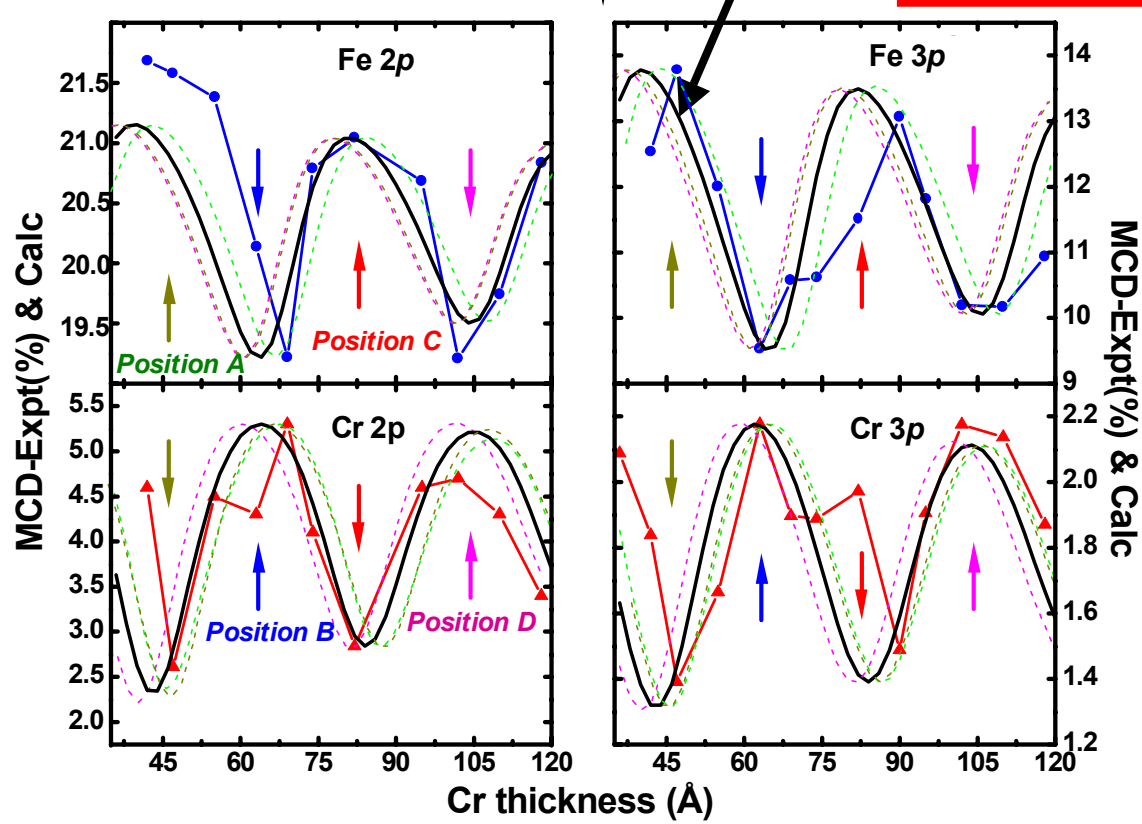
Plus similar results for Fe 3p and Cr 3p



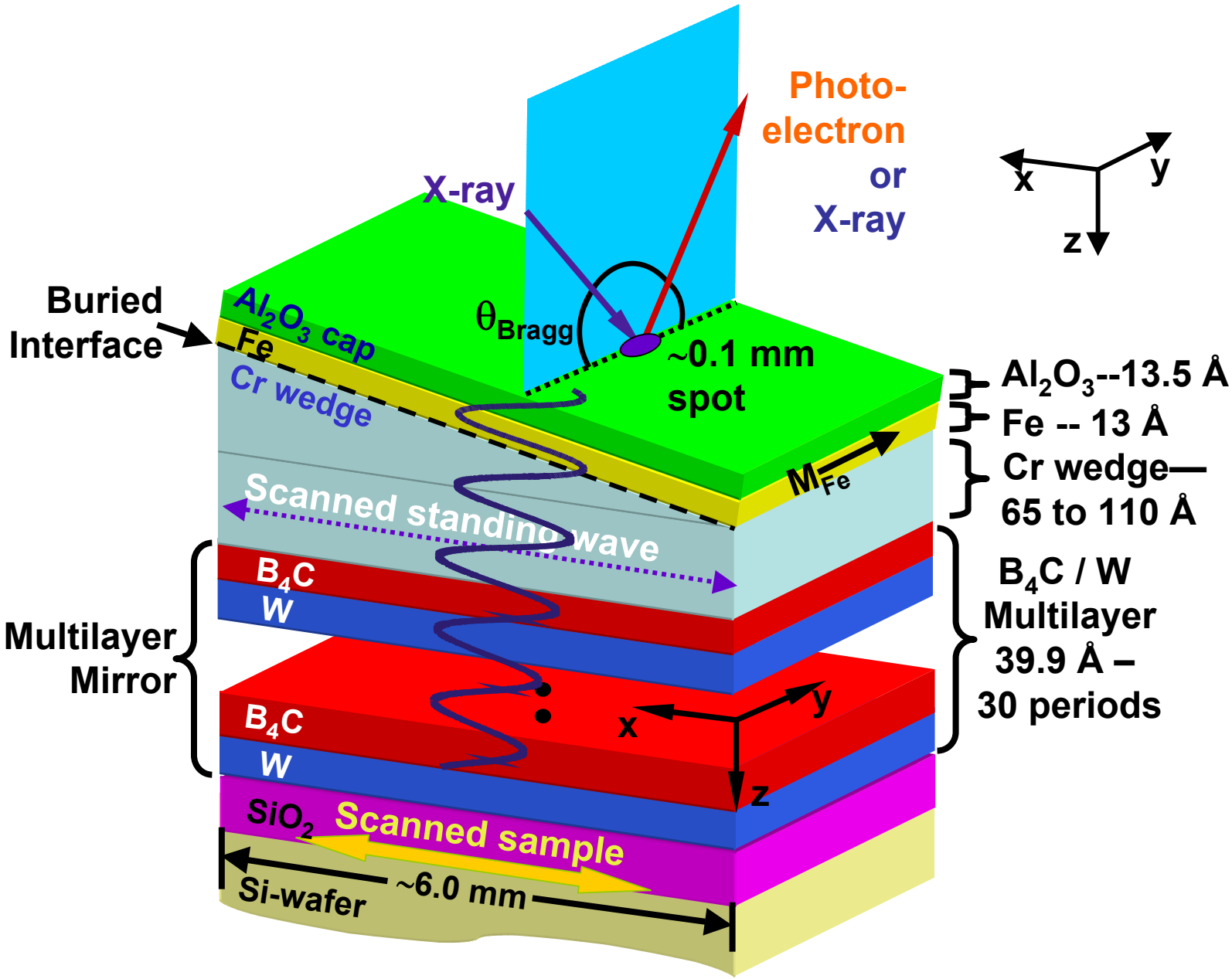
Depth-resolution ~± 2-3 Å

Fitting core PS experiment to XRO theory: non-destructive, depth-resolved determination of composition and magnetization profiles

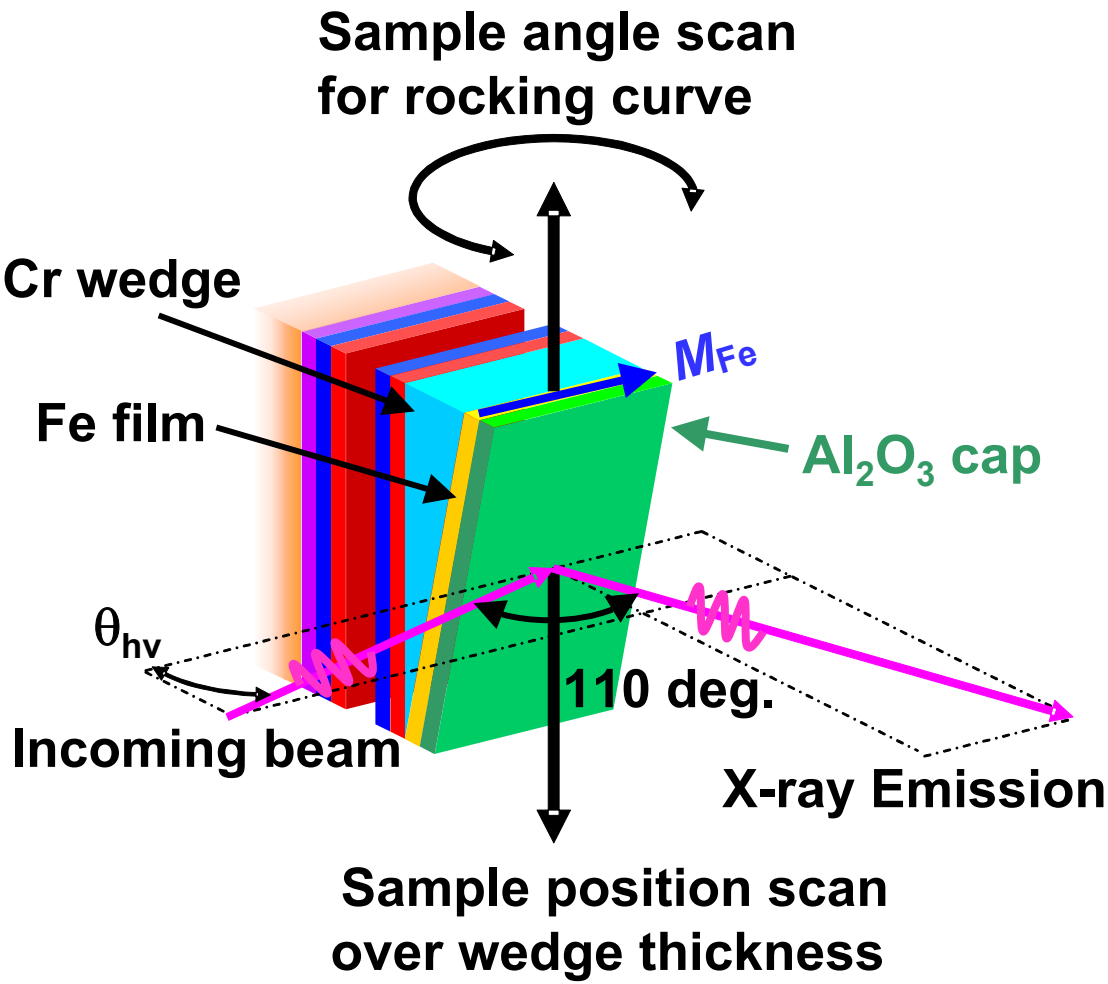


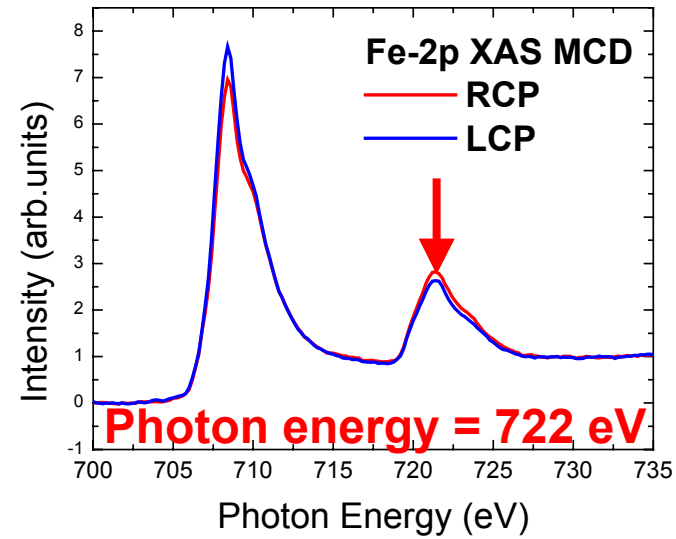
S.-H. Yang. B.S. Mun et al., Surf. Sci. Lett. 461, L557 (2000); Phys. Cond. Matt. 14, L406 (2002)

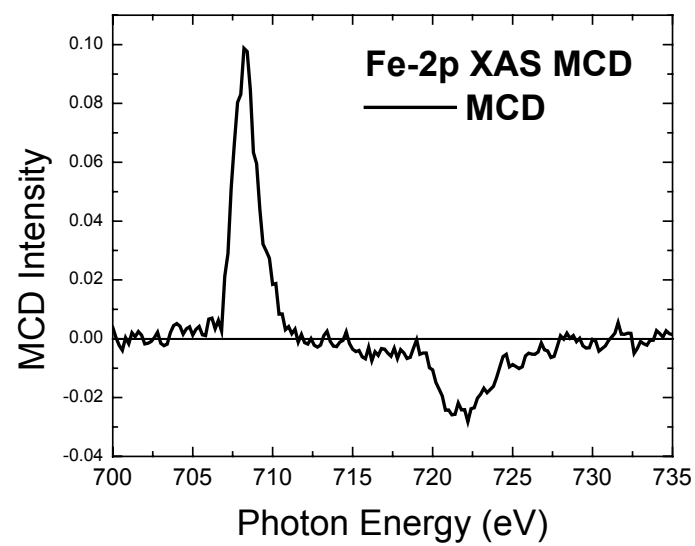
The Standing Wave-Wedge Method



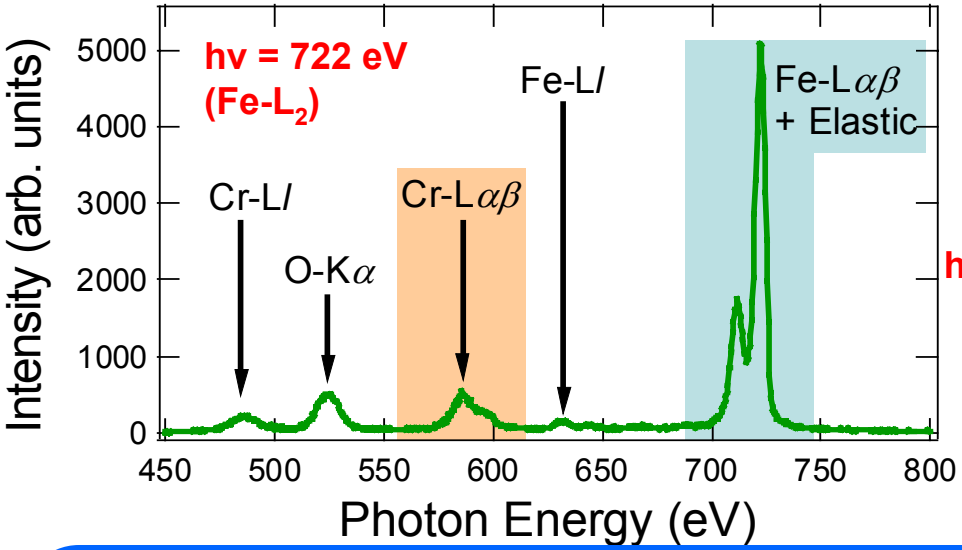
Standing wave excitation of x-ray emission/RIXS in a multilayer magnetic structure



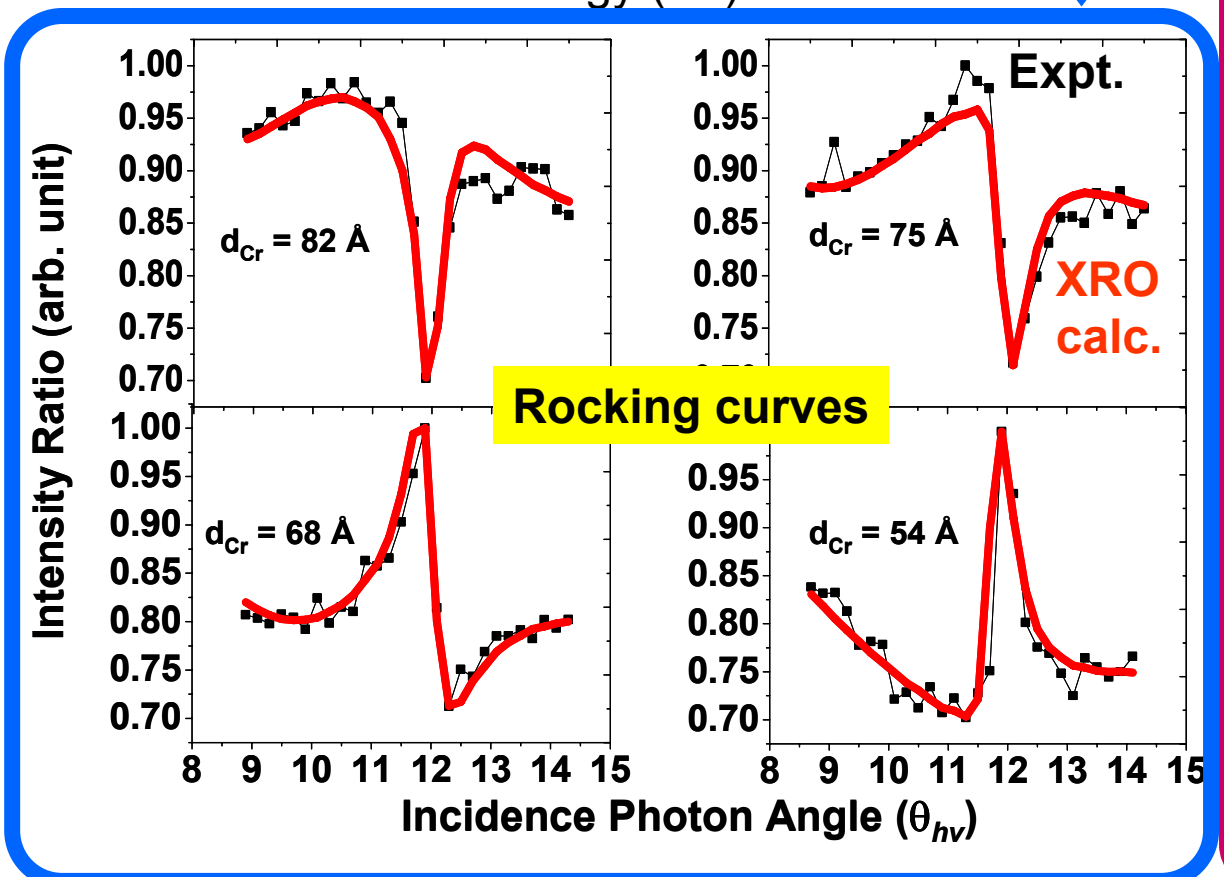


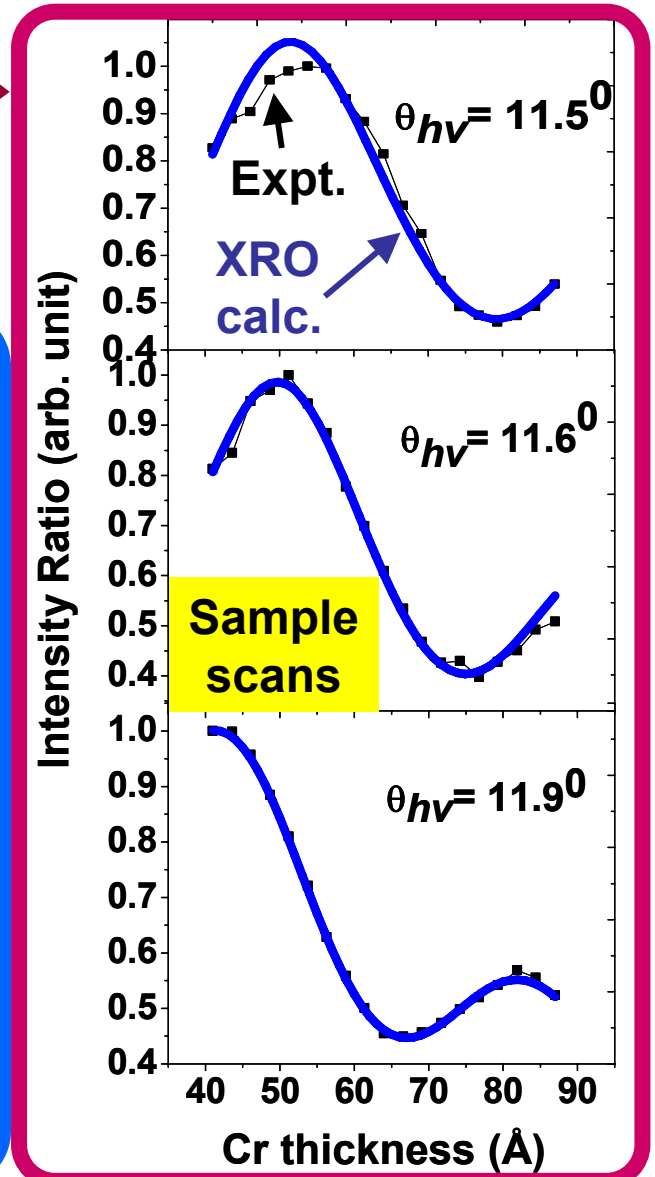


Experimental + Calculated X-Ray Emission Yield Ratio I(Fe Lαβ)/I(Cr Lαβ) from Fe/Cr wedge on standing-wave multilayer

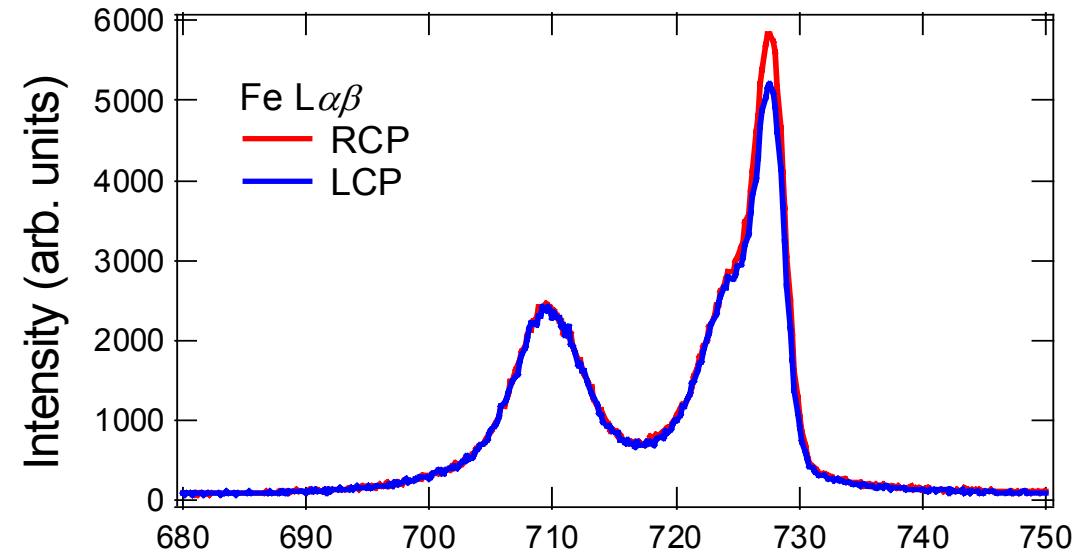


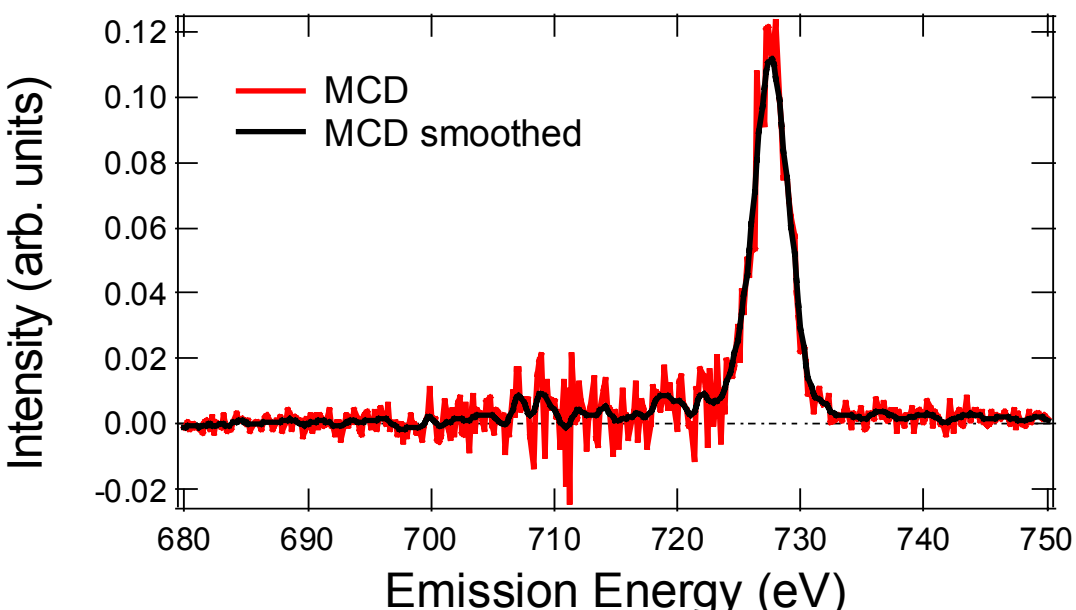
hv = 825 eV



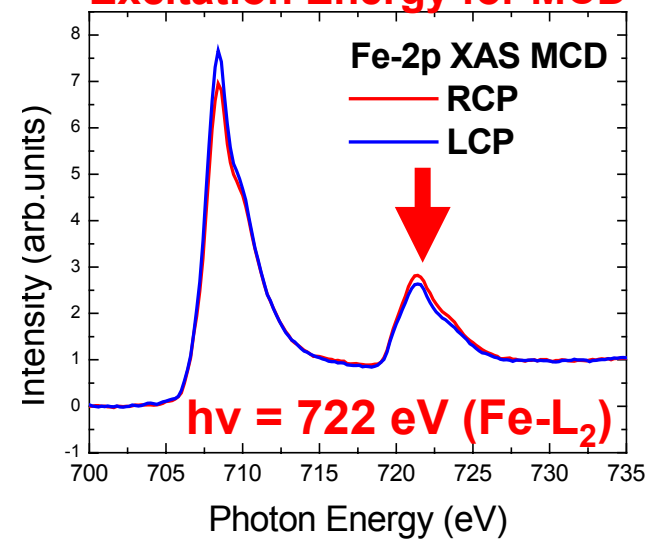


RIXS with Standing Wave Excitation: Fe-L x-ray emission, L2 edge excitation, MCD Z-position dependence



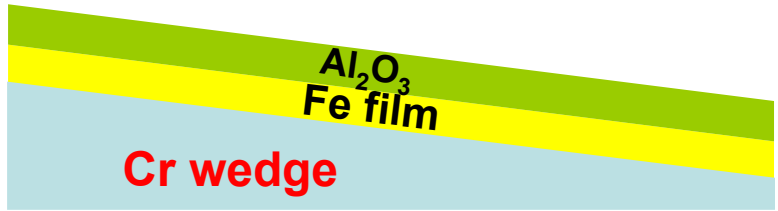


Excitation Energy for MCD

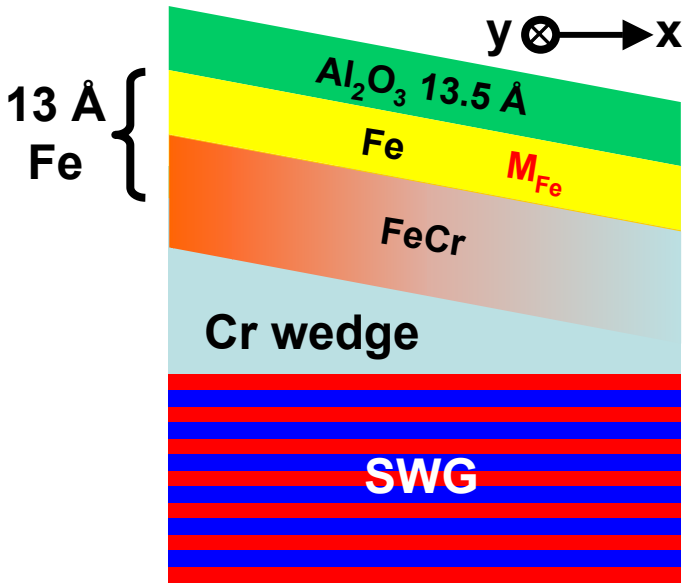


$$\text{MCD} = \frac{2\{I(RCP) - I(LCP)\}}{\{I_{max}(RCP) + I_{max}(LCP)\}}$$

RIXS with Standing Wave Excitation: Fe-L x-ray emission, MCD L2 edge excitation Z-position (Cr-thickness) dependence

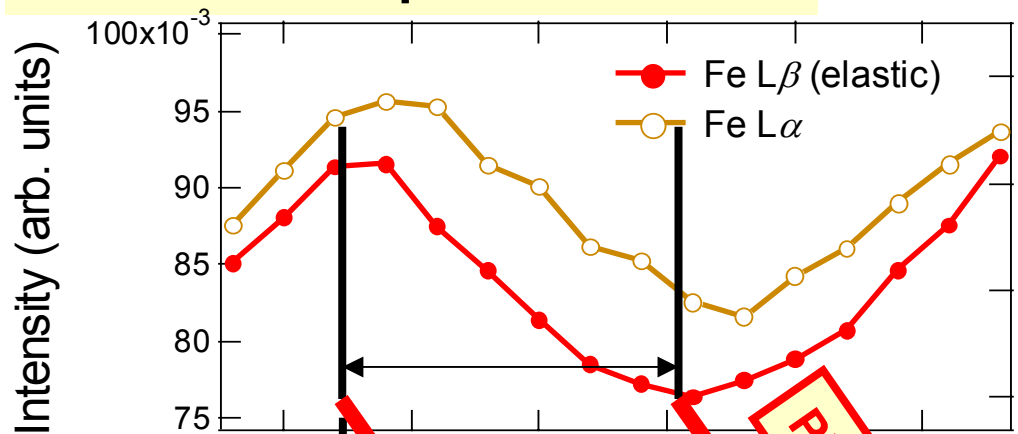


Phase shift→bottom of Fe layer not magnetized, at least along y?

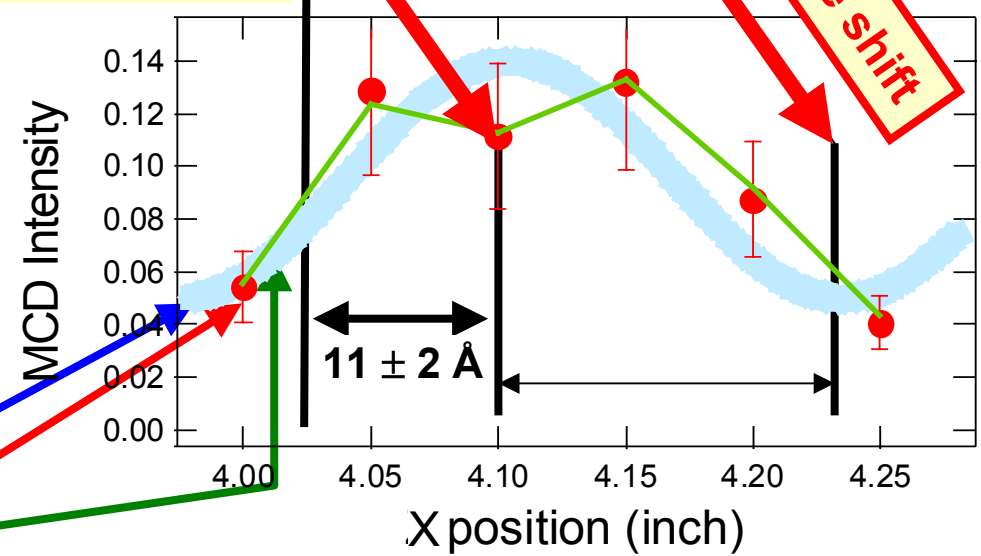


Not magnetized? FeCr intermixing?

Fe-L emission peak intensities



Fe-Lα MCD

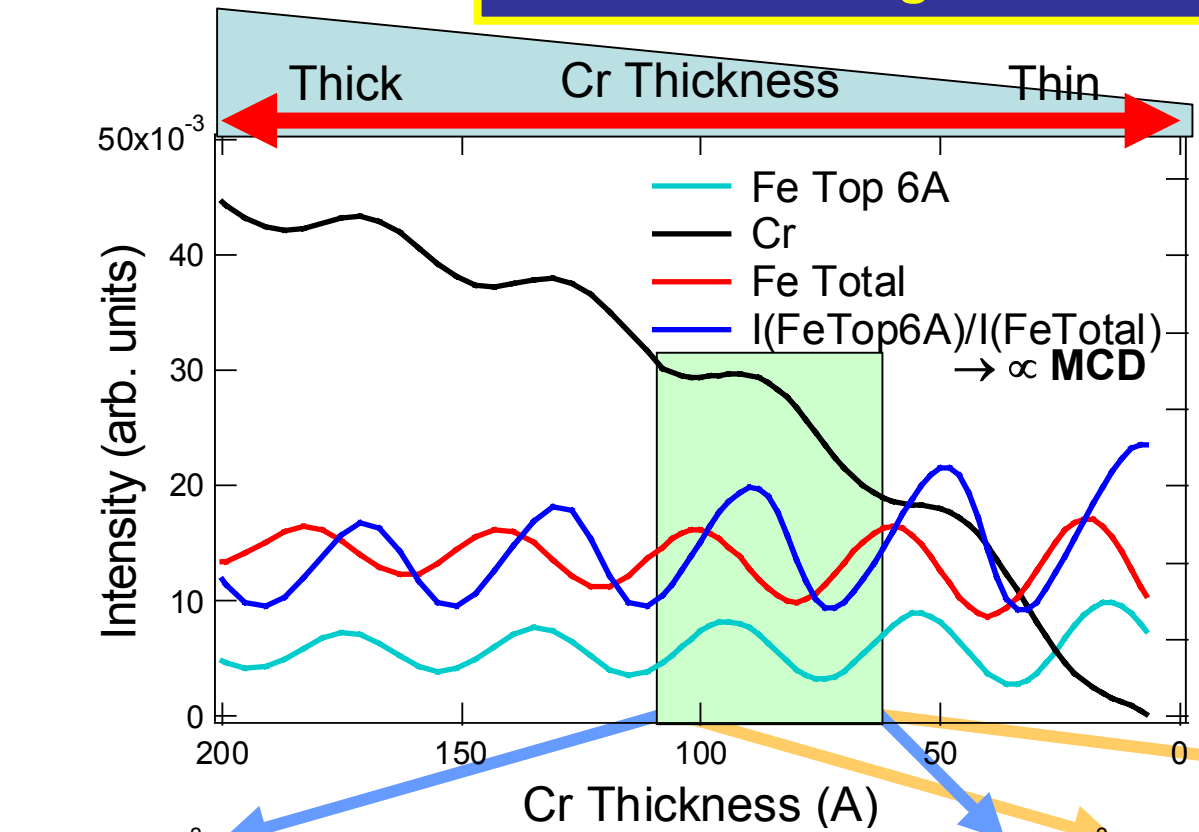


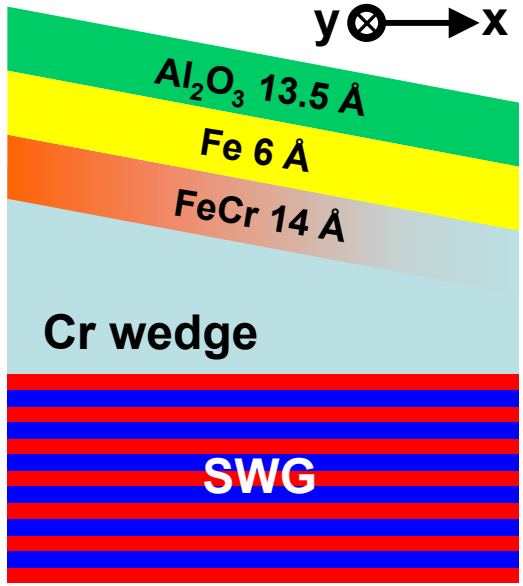
Sine curve

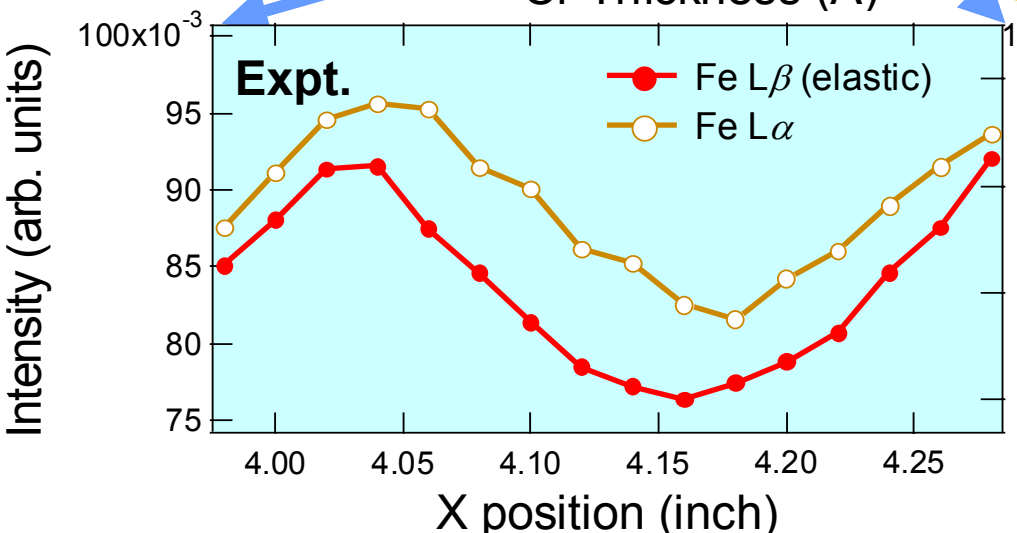
MCD via smoothed data

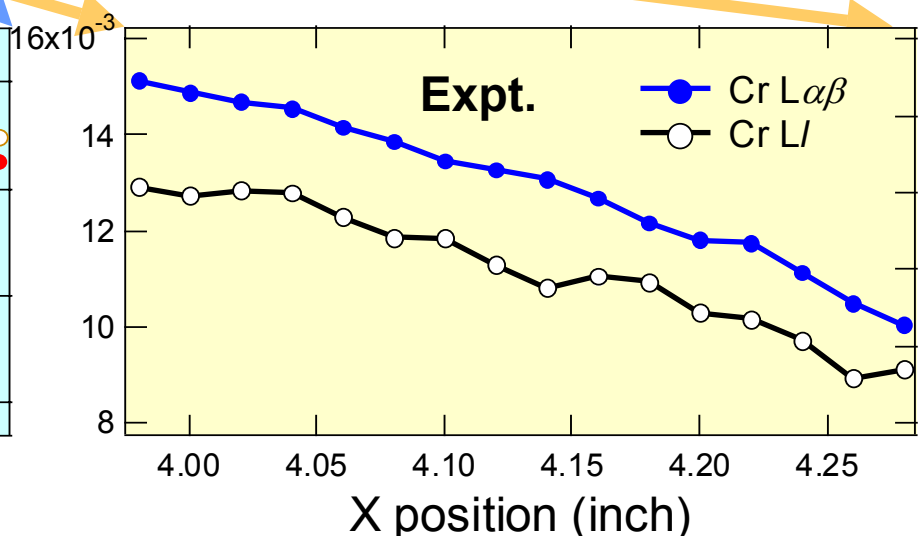
MCD via Gaussian fit

XRO modeling of intensities and MCD phase shift

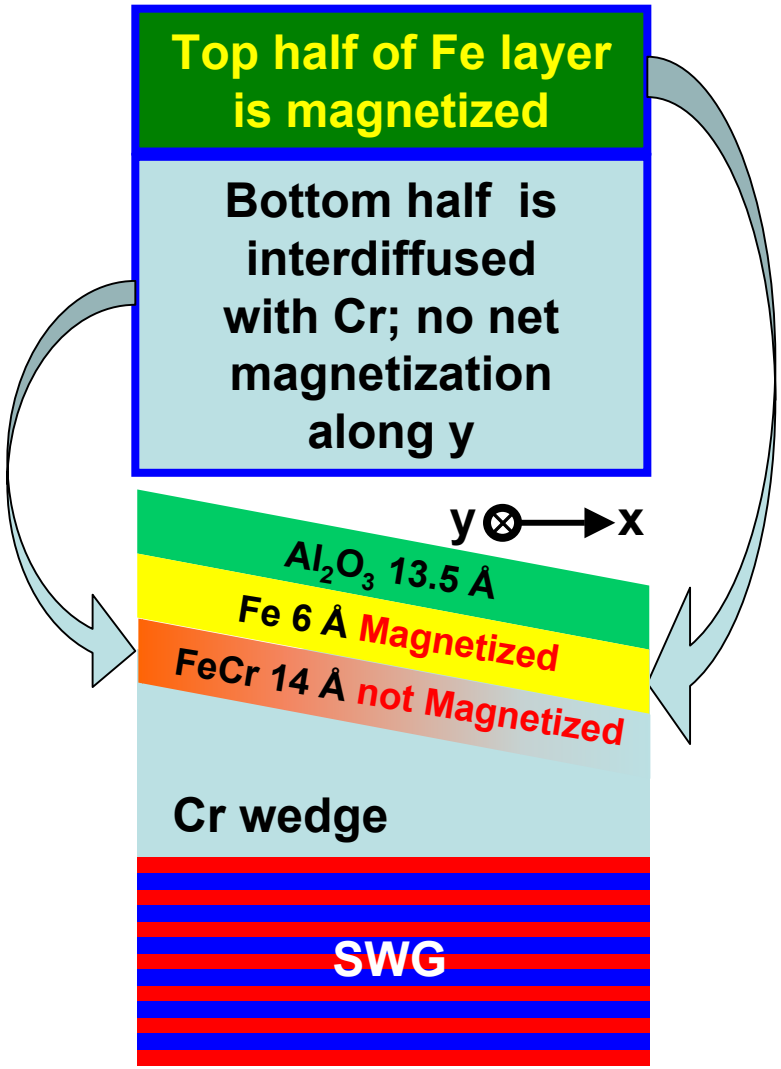


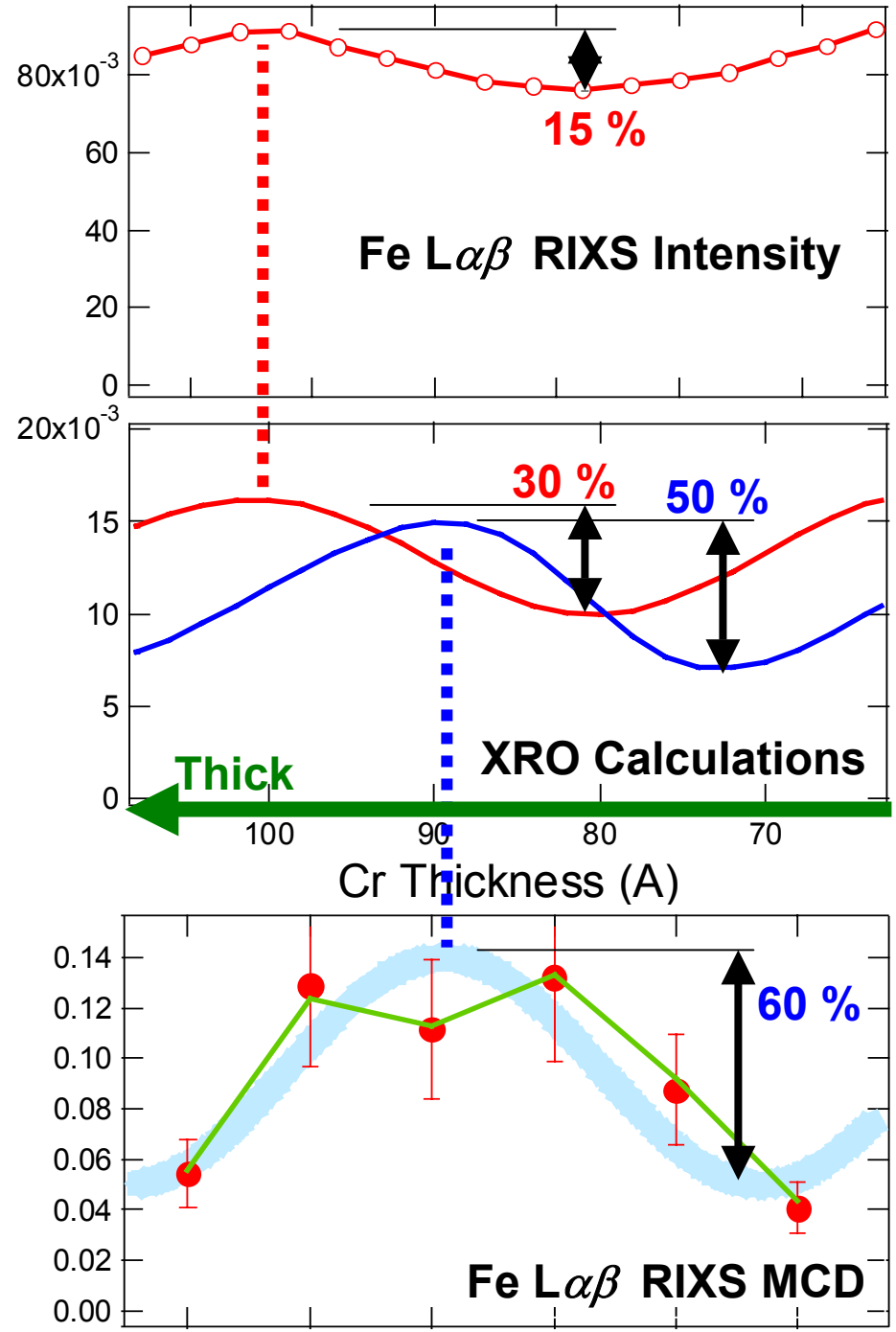






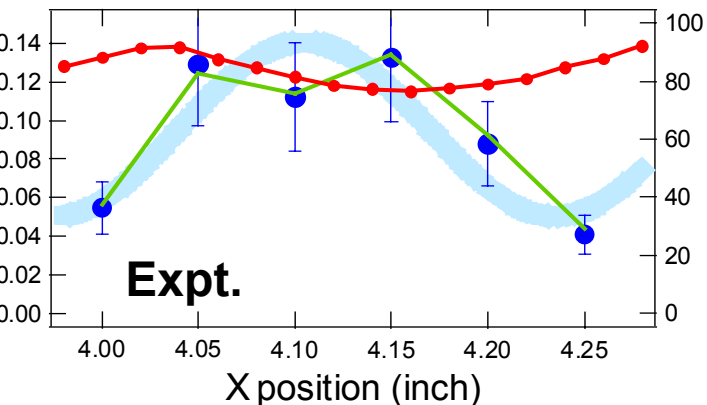
XRO modeling of Intensity / MCD phase shift

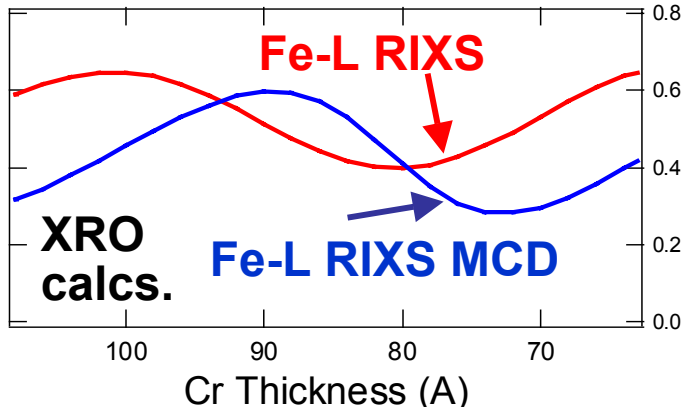


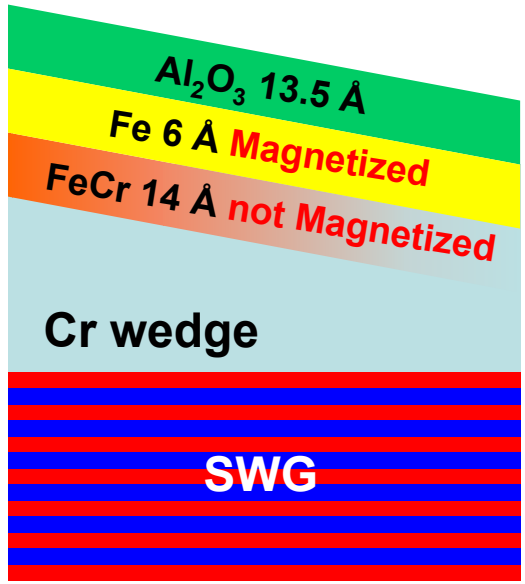


Summary

- First x-ray emission/RIXS results using standing wave-wedge method: Fe/Cr-wedge/multilayer-- Fe-L$\alpha\beta$ emission intensities and MCD
- Fe-L/Cr-L intensity ratios (rocking curves and sample scans) fit well with XRO calculations
- Strong modulation of Fe-L RIXS and Fe-L RIXS MCD with sample scans→phase shift of 11 ± 2 Å
- Phase shift is reproduced by XRO calculations with Fe-Cr interdiffusion and reduced magnetization in interface
- Suggests many interesting future applications of standing wave-wedge approach with XES/RIXS detection

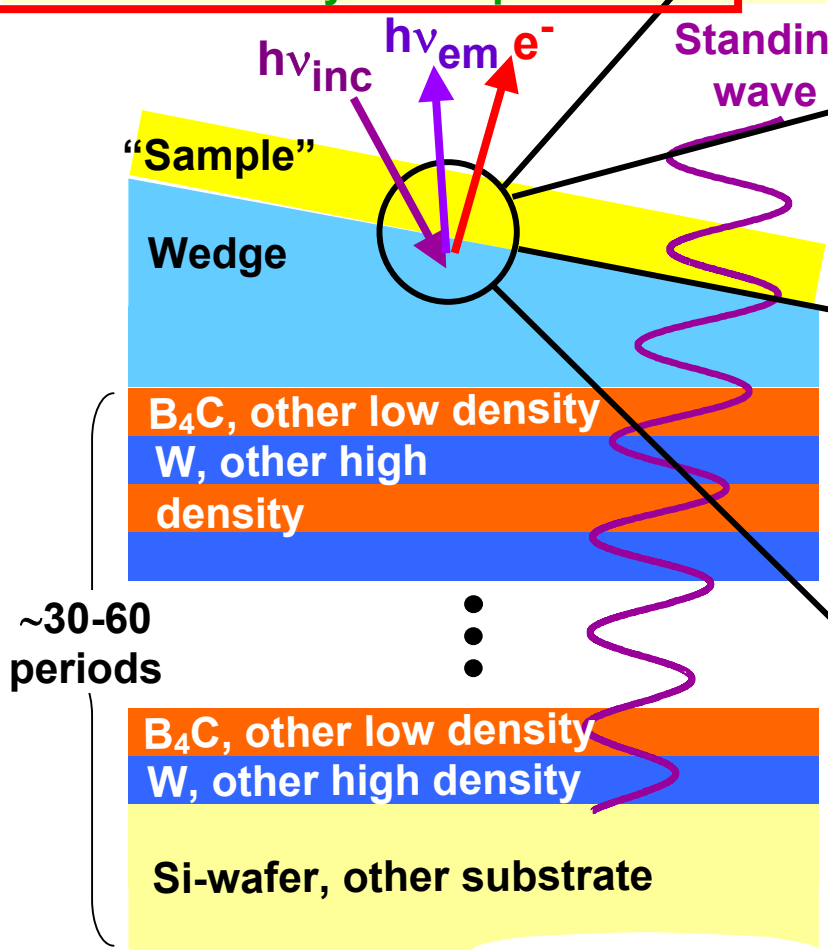


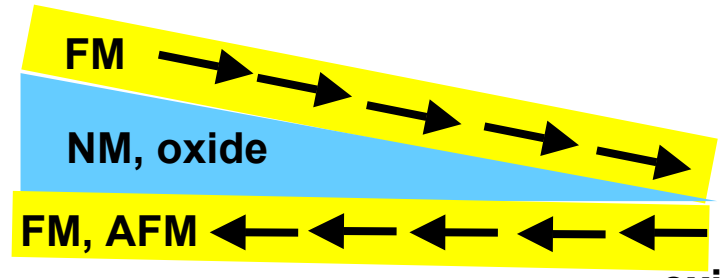




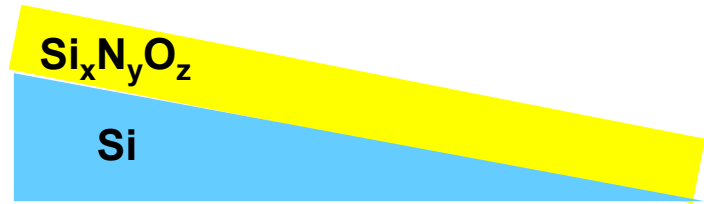
STANDING-WAVE EXCITED SPECTROSCOPY--FUTURE POSSIBILITIES

- Other material pairs in multilayer (B_4C/W, Al_2O_3/Pt,…) + epitaxial multilayers → epitaxial samples
- Smaller periods (to ~25-30 Å) → smaller SW period, better resolution
- Lower $h\nu_{inc}$ →higher Bragg angles→perpend. component of M
- X-ray emission→ deeper layers, more sensitivity to SW position

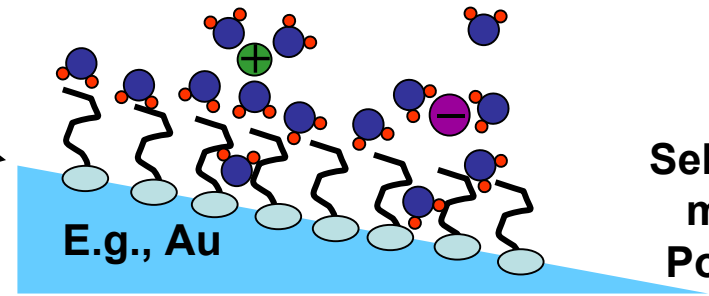




GMR, exchange biassing, tunnel junction, oxide multilayers

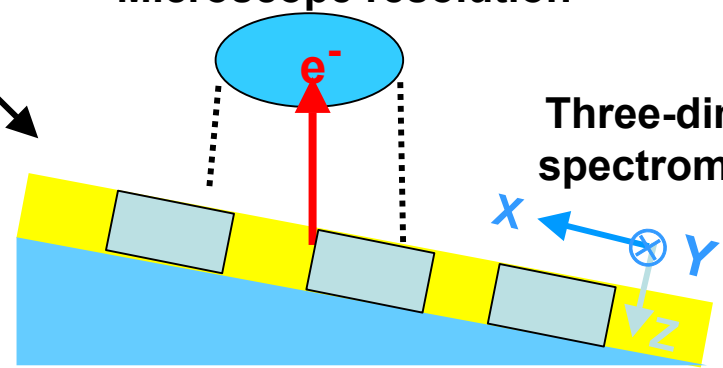


Ultrathin gate oxide, oxynitride films



Clusters, Self-assembled monolayers, Polymer films, Liquid layers, Conc. distributions

Microscope resolution



Three-dimensional spectromicroscopy

P. Fischer
G. Denbeaux
ALS XM-1