Coherent X−ray Scattering from Ultrathin Probe Layers

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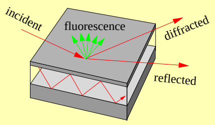
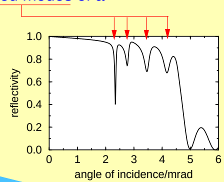
Introduction

Standing waves in thin films are frequently used to enhance x−ray scattering from thin films.
This applies for :

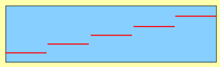
- incoherent scattering
  e.g., fluorescence [1]
- coherent scattering
  e.g. GISAXS, GID [2]



A very strong intensity enhancement is observed, if the x−rays are coupled into guided modes of a waveguide structure



Ultrathin probe layers can be used to study depth−dependent properties with sub−nm spatial resolution.



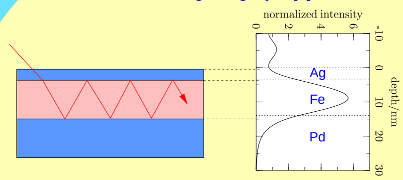
Coherent and incoherent x−ray scattering from such layers exhibits qualitatively different features.

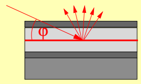
The coherent scattering channels experience a much stronger enhancement than the incoherent channels.

This becomes particularly efffective if combined with standing waves in x−ray waveguide structures.

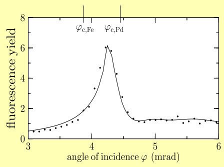
The X−ray Flux in Layered Structures

Coupling the incident radiation into a waveguide mode leads to strong flux enhancement in the guiding layer [3]



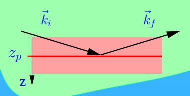


One observes a strong amplification of the fluorescence yield from the guiding layer.



The incoherently scattered intensity scales LINEARLY with the normalized field intensity in the guiding layer.

Coherent scattering from ultrathin layers in the Distorted − Wave Born − Approximation



The Reflected Amplitude

$$R = R_0 + i\,d\,t(\vec{k}_i)\,t(\vec{k}_f)\,f_p$$

R_0 = refl. without probe layer
d = layer thickness
$t(\vec{k})$ = transmission coefficient
f_p = scattering amplitude

$$t = 1 + r$$

= incident + reflected amplitude
= wavefield amplitude at the layer
$= a(z_p)$ Note that $\vec{k}_i \approx \vec{k}_f$

$$R = R_0 + i\,d\,a(z_p)^2\,f_p$$

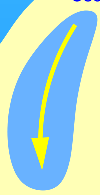
Intensity :

$$I \approx I_0 + d^2\,I(z_p)^2\,|f_p|^2$$

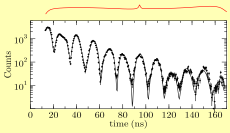
The coherently reflected intensity scales QUADRATICALLY with the normalized field intensity $I(z_p)$ at the layer position.

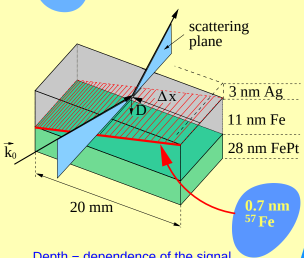
How to verify the coherent enhancement ?

Use nuclear resonant scattering from isotopic probe layers

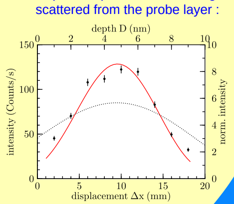


Measured signal:
The time−integrated reflected intensity



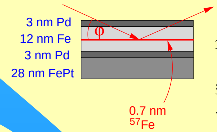


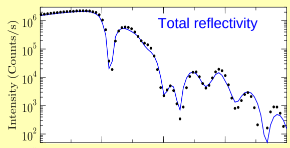
Depth − dependence of the signal scattered from the probe layer :

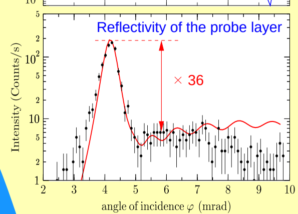


Resonant Reflection from Ultrathin Layers

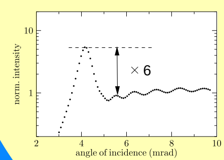
The coherently scattered intensity is proportional to the SQUARE of the x−ray flux at the layer position [4]





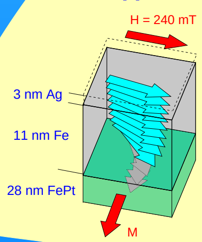


Comparison with the incoherent signal from the probe layer :

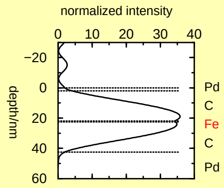


Applications

Imaging the magnetic spin structure of exchange−coupled thin films [5].



Investigation of metallic particles embedded in soft−matter thin films



References

[1] Y. Wang, M. Bedzyk, and M. Caffrey, Science 258, 775 (1992)
[2] F. Pfeiffer, U. Mennicke, and T. Salditt, J. Appl. Cryst. 35, 163 (2002).
[3] Y. P. Feng, S. K. Sinha et al., Phys. Rev. Lett. 71, 537 (1993)
[4] R. Röhlsberger, T. Klein, K. Schlage, O. Leupold, and R. Rüffer, submitted to Phys. Rev. B
[5] R. Röhlsberger, H. Thomas, K. Schlage, E. Burkel, O. Leupold, and R. Rüffer, Phys. Rev. Lett. 89, 237201 (2002)

Acknowledgements

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