Probing multilayer nanostructures with hard x-ray standing wave photoemission

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Standing wave formation in reflection from a surface- a unique tool for probing multilayer nanostructures

- Tailoring the photon field as a standing wave to look at different depths

$I_{SW}(|E^2|) \propto |\phi_{inc} + \phi_{refl}|^2 = |\phi_{inc}|^2 + \phi_{inc}\phi_{refl}^* + \phi_{inc}^*\phi_{refl} + |\phi_{refl}|^2$ — SW modulation

ϕ_{refl}, $R \propto I_{refl} \propto |\phi_{refl}|^2$

$\lambda_{SW}(|E^2|) = \lambda_x/2\sin\theta_{inc} \approx d_{ML}$

$\theta_{Bragg} = \theta_{inc}$, $\theta_{refl} = \theta_{inc}$

1st order Bragg: $\lambda_x = 2d_{ML}\sin\theta_{Bragg}$

Periodic atomic planes: $d_{ML} \leq$ ~5 Å—Si(111)—3.74Å, LaB_6(001)—23.52Å→5.88Å, mica—10.0 Å; or Synthetic multilayers: $d_{ML} \approx$ ~20-40 Å

INTRODUCTION AND MOTIVATION

Standing wave formation in reflection from a surface, or single-crystal Bragg planes*, or a multilayer mirror

Incident — Reflected

% modulation ≈ 100 x 4√R: E.g. R = 5% → 90% modulation, R = 1% → 40% modulation

$\lambda_{SW}(|E^2|) = \lambda_x/2\sin\theta_{inc}$

- Rocking curve: $I(\theta_{inc}) \propto 1 + R(\theta_{inc}) + 2\sqrt{R(\theta_{inc})}\, f\cos[\varphi(\theta_{inc}) - 2\pi P]$
- Energy scan: $I(h\nu) \propto 1 + R(h\nu) + 2\sqrt{R(h\nu)}\, f\cos[\varphi(h\nu) - 2\pi P]$

with: f = coherent fraction of atoms, P = phase of coherent-atom position

New → • Phase scan with wedge-shaped sample ("Swedge" method)

XMCD—Kim, Kortright, PRL 86, 1347 (2001)

*Standing waves via Bragg reflection of hard x-rays: Batterman, Phys. Rev A 133, 759 (1964)

X-ray Optical Calculations : Calculating XRO effects on spectroscopy--Yang

- n (hν) = 1 -δ(hν) + iβ(hν)
- -variable polarization
- -multiple reflection/ refraction
- -exact treatment of interlayer intermixing a/o roughness
- -electric field at i-th layer: $|E_{sw,i}(z)|^2 = |E_i^+(z) + E_i^-(z)|^2$

Photoemission:
- -differential cross section
- -inelastic attenuation
- -surface refraction

X-ray emission:
- -fluorescence yield

$h\nu_{incid}$ (s, p, RCP or LCP) → $h\nu_{emission}$ e⁻

Vacuum, V_0 — 1st layer (d_1) — intermixed 1-2 ($2\sigma_1$) — 2nd layer (d_2) — i-th (d_i) — intermixed i-j ($2\sigma_i$) — j-th (d_j) — Substrate $n_s = 1 - \delta_s + i\beta_s$

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

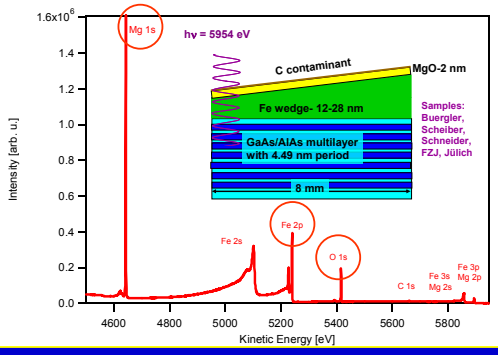
HARD X-RAY PHOTOEMISSION FROM SPring8 – 5.9 keV EXCITATION FROM AN EPITAXIAL MULTILAYER: MgO/Fe

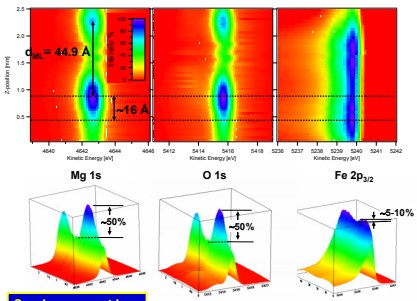
Probing Buried Interfaces: The Standing Wave-Wedge ("Swedge") Method

Photo-Electron, X-ray, ~0.1 mm spot, Buried Interface, MgO, Fe wedge, θ_{Bragg}, Scanned standing wave, Fixed phase, Multilayer Mirror, GaAs, AlAs, d_{ML}, Scanned sample, ~6.9 mm, GaAs substrate

$\lambda_{SW}(|E^2|) = \lambda_x/2\sin\theta_{inc} \approx d_{ML}$

1st order Bragg: $\lambda_x = 2d_{ML}\sin\theta_{Bragg}$

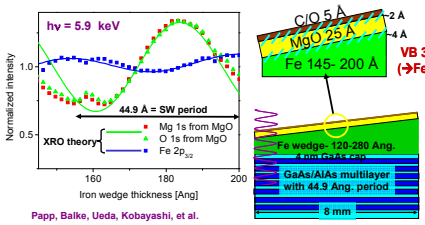




Swedge scans at hν = 5.9 keV

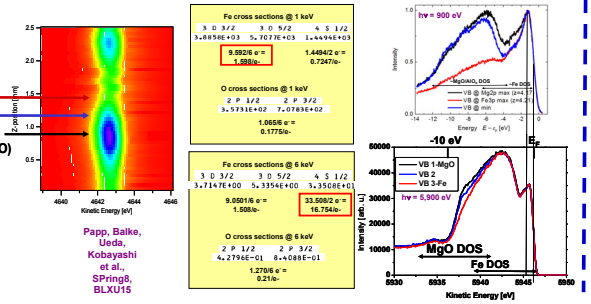
Papp, Balke, Ueda, Yoshikawa, Yamashita, He, Sakai, Kobayashi, Fadley, et al. SPring8, BL15XU

Interface mixing from fits to wedge-scan data



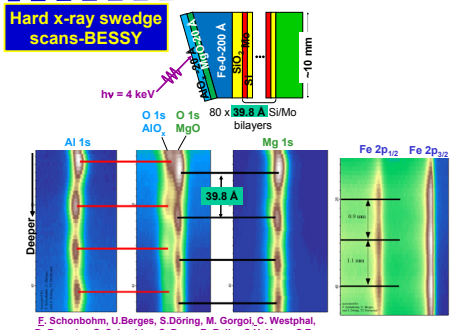
Papp, Balke, Ueda, Kobayashi, et al.

MgO/Fe depth dependent densities of states info. at 0.9 keV and 5.9 keV



Papp, Balke, Ueda, Kobayashi et al., SPring8, BLXU15

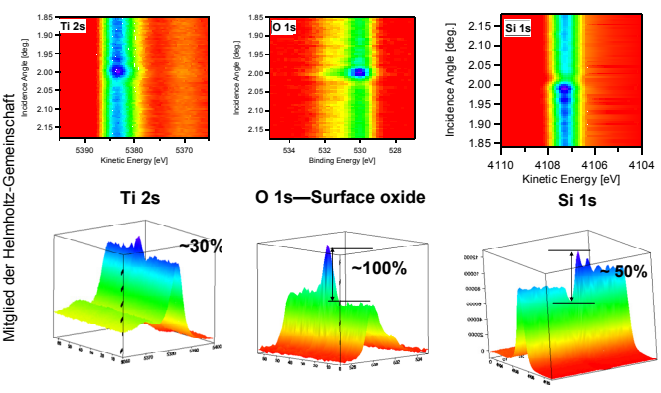
Hard x-ray swedge scans-BESSY



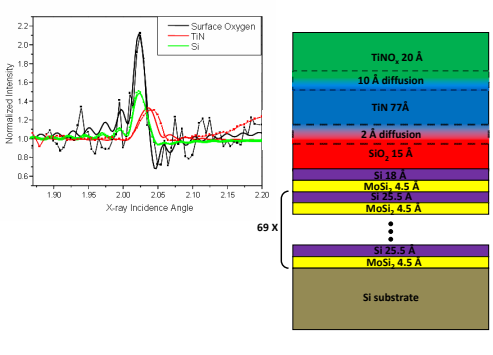
F. Schonbohm, U.Berges, S.Döring, M. Gorgoi, C. Westphal, D. Buergler, C. Schneider, C. Papp, B. Balke, S.H. Yang, C.F...

HARD X-RAY PHOTOEMISSION FROM SPring8 – 5.9 keV EXCITATION FROM A SEMICONDUCTOR-RELATED OVERLAYER: TiN ON SiO_2/Si

Rocking curves for 90 Å TiN/[Si/Mo multilayer-30 Å period]

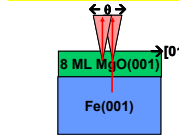


Depth-resolved composition from simulations of the rocking curves



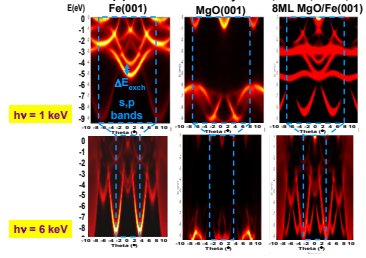
FUTURE PROJECTS IN MULTILAYER SPINTRONIC SYSTEMS

Angle-resolved photoemission through overlayer insulators: A new probe of buried layer/interface electronic structure? Fe/MgO



- Cryocooling to suppress phonon smearing
- Standing-wave excitation to vary depth sensitivity (See talks by Ebert & Papp, Poster by Plucinski)

One-step photoemission theory: Ebert, Braun, Minar, C.F.



Mitglied der Helmholtz-Gemeinschaft