X-ray and IR spectrometry

Reference-free XRF and GIXRF analysis

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in Nano-science and Environmental Monitoring Trieste, Italy, November 17-28, 2014

Outline

- analytical challenges for nanotechnologies
- reference-free x-ray spectrometry
- surface contamination and nanolayer characterization
- depth profiling at grazing incidence
- chemical speciation at buried interfaces
- towards in-situ speciation of bulk-type films
- high-resolution spectrometry

Analytical challenges for nanotechnologies

- dozens of new nanoscaled materials appear every month
- technology R&D cycles for new materials down to 4 months
- need for correlation of material properties with functionality
- requirements on sensitivity, selectivity and information depth
- most analytical methodologies rely on reference materials or calibration standards but there are only few at the nanoscale
- usage of calibrated instrumentation and knowledge on atomic data enables reference-free techniques such as SR based XRS

Challenges for nanotechnologies – nano-scaled reference materials

X-ray and IR spectrometry

Nanoscaled Reference Materials (in line with ISO/TC 229 Nanotechnologies)

‚Reference materials are the key to guaranteeing realiability and correctness for results of chemical analyses and technical measurements.‘

Categories:

- flatness
- film thickness
- single step , periodic step, step grating
- lateral X-Y-axis, 1-dim
- lateral X-Y-axis, +2-dim,
- critical dimensions
- 3-dimensional
- nanoobjects/nanoparticles/nanomaterial
- nanocrystallite materials
- porosity
- depth profiling resolution

Every month several tens new nanoscaled materials appear.

The number of nanoscaled reference materials is considerably lower.

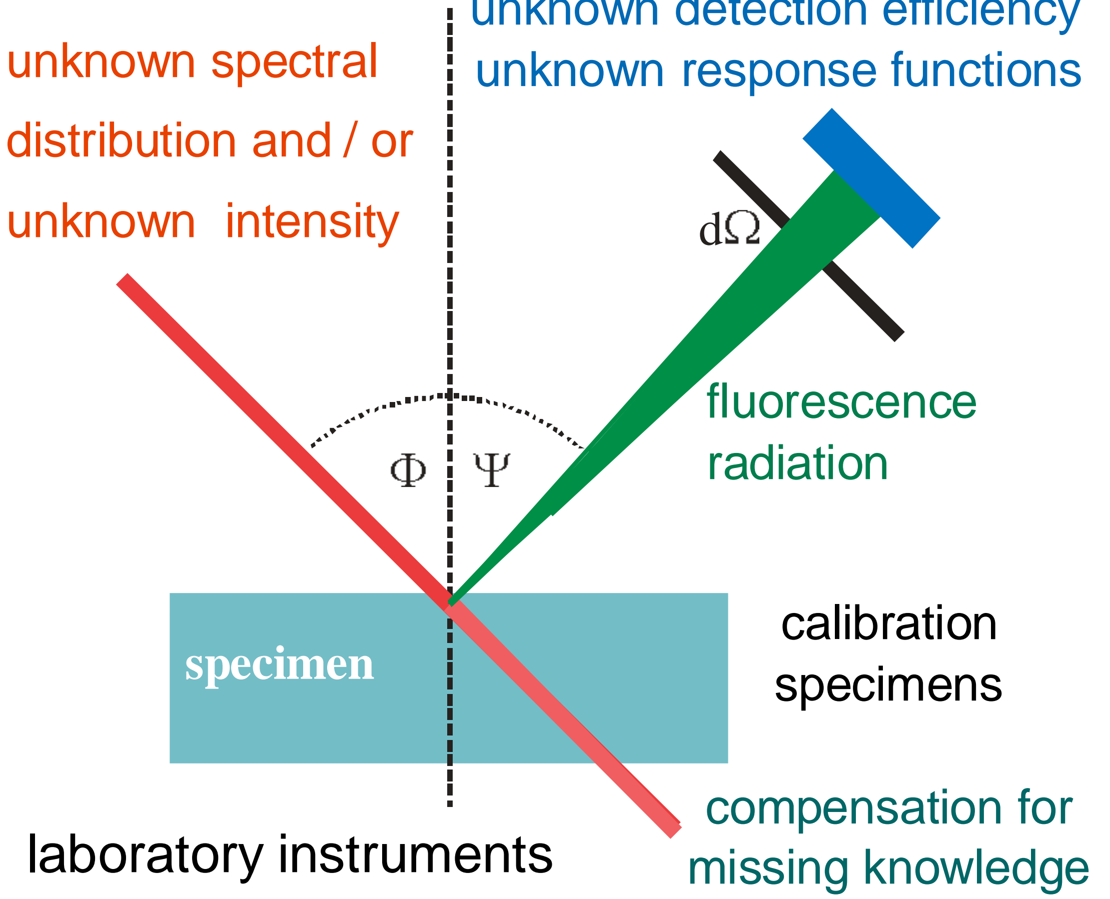
Reference-free / first principles based methodologies can address this increasing gap.

www.nano-refmat.bam.de/en/

X-ray spectrometry methodologies:

reference-based versus reference-free approaches

reference material related technique
based on well known calibration
specimens or reference materials



X-ray spectrometry methodologies:

reference-based versus reference-free approaches

reference material related technique
based on well known calibration specimens or reference materials

reference-free technique
based on calibrated instrumentation and fundamental parameters

Synchrotron radiation based x-ray spectrometry

X-ray and IR spectrometry

XRS excitation channel:

well-known spectral distribution
and a well-known radiant power

XRS detection channel:

absolute detection efficiency
and response functions

derived from
x-ray radiometry

well-known
solid angle dΩ

fluorescence
radiation

Φ Ψ

fundamental parameters

knowledge of atomic parameters
(EMRP IND07, NEW01; EXSA)

transmission measurements

absorption correction factors

PTB capabilities:

→ characterized beamlines

→ calibrated photodiodes

→ calibrated diaphragms

→ calibrated Si(Li) detectors

JAAS **23**, 845 (2008)

Determination of L-shell photoionization cross sections

X-ray and IR spectrometry

PRL 113, 163001 (2014) PHYSICAL REVIEW LETTERS week ending 17 OCTOBER 2014

Experimental Verification of the Individual Energy Dependencies of the Partial *L*-Shell Photoionization Cross Sections of Pd and Mo

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An experimental method for the verification of the individually different energy dependencies of L_1-, L_2-, and L_3- subshell photoionization cross sections is described. The results obtained for Pd and Mo are well in line with theory regarding both energy dependency and absolute values, and confirm the theoretically calculated cross sections by Scofield from the early 1970 s and, partially, more recent data by Trzhaskovskaya, Nefedov, and Yarzhemsky. The data also demonstrate the questionability of quantitative x-ray spectroscopical results based on the widely used fixed jump ratio approximated cross sections with energy independent ratios. The experiments are carried out by employing the radiometrically calibrated instrumentation of the Physikalisch-Technische Bundesanstalt at the electron storage ring BESSY II in Berlin; the obtained fluorescent intensities are thereby calibrated at an absolute level in reference to the International System of Units. Experimentally determined fixed fluorescence line ratios for each subshell are used for a reliable deconvolution of overlapping fluorescence lines. The relevant fundamental parameters of Mo and Pd are also determined experimentally in order to calculate the subshell photoionization cross sections independently of any database.

DOI: 10.1103/PhysRevLett.113.163001 PACS numbers: 32.80.Aa, 32.80.Fb, 78.70.En

Determination of L-shell photoionization cross sections

τ_{L3}
τ_{L2}
τ_{L1}

Jump ratio approx.
Scofield data
Trzhaskovskaya data
fitted Scofield

E_{L1} = 2866 eV
E_{L2} = 2625 eV
E_{L3} = 2520 eV

τ_{Li} / cm^{2}g^{-1}

1000
100
10

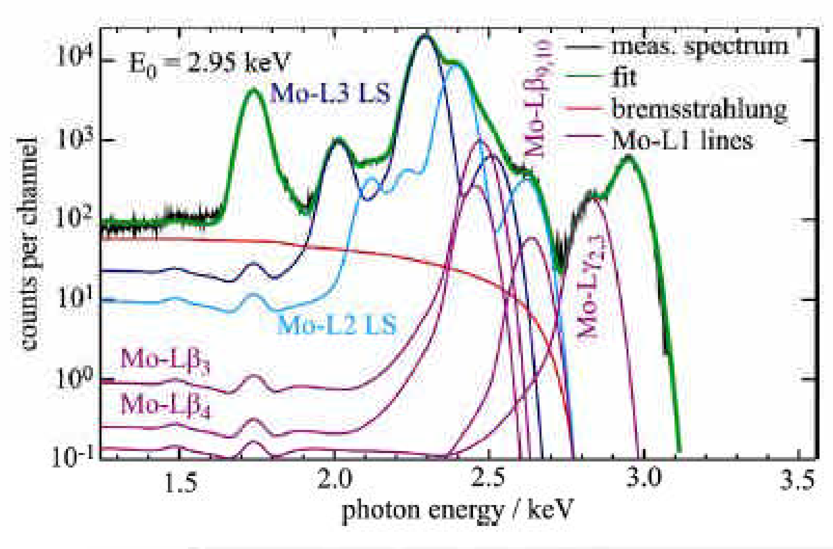
3
10

excitation energy / keV

Phys. Rev. Lett **113**, 163001 (2014)

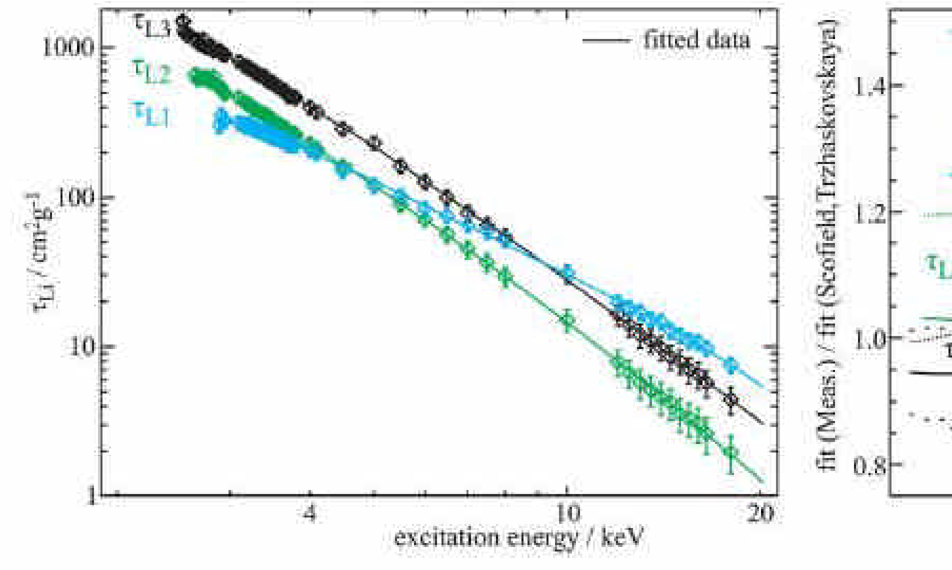
Comparison of different PCS data for Mo

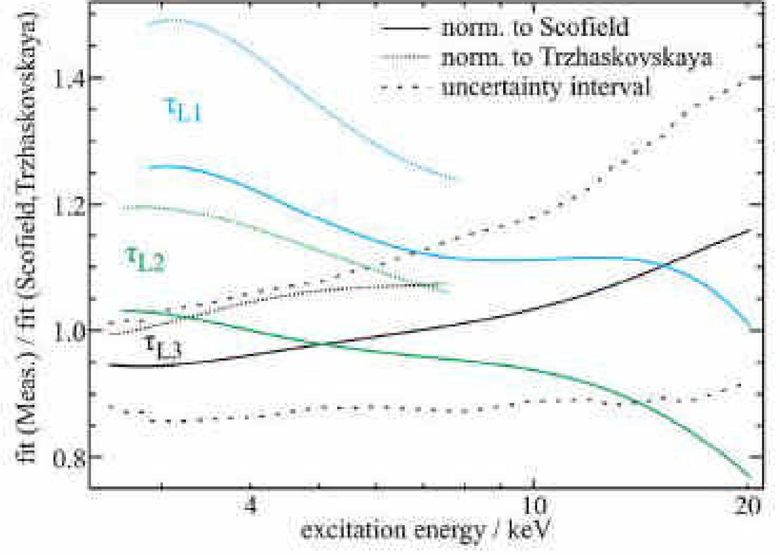
Determination of L-shell photoionization cross sections



Response function based deconvolution of a Mo layer XRF spectrum for each L-shell.

Experimentally determined PCS for the Mo-L subshells and the comparison to calculated data.





Phys. Rev. Lett **113**, 163001 (2014)

Tuning the analytical sensitivity and information depth by means of appropriate operational parameters

X-ray and IR spectrometry

excitation conditions	total-reflection	tunable incident angle	tunable photon energy
concentration	contamination	nanolayer	nanolayer speciation

tunable incident angle	total-reflection	tunable incident angle	tunable photon energy
depth profile	nanoparticles	interface	interface speciation

E_0 = photon energy of excitation radiation

E_1 = photon energy above absorption edge

E_f = photon energy of fluorescence radiation

XSW = X-ray Standing Wave field

JAAS **23**, 845 (2008)

How can a method (rows) help another method (columns) to improve or complement the results

Methods	TXRF	GIXRF	XRF	XRR	XRD	GISAXS
TXRF		surface contamination	information on surface contamination	information on surface contamination	information on surface contamination	nanoparticle composition
GIXRF	absolute angle calibration		validation measurands	near surface depth profiles	near surface depth profiles	nanoparticle composition
XRF	validation measurands	validation measurands		information on material composition	information on material composition	nanoparticle composition
XRR	layer thickness and roughness for modelling	layer thickness and roughness for modelling	contaminations/ spectral diffrac-tion artefact		layer thickness, roughness, density	substrate surface layer
XRD	information on material morpho-logy, artefacts	information on material morpho-logy, artefacts	information on material morpho-logy, artefacts	information on material morphology		information on material morphology
GISAXS	particle size distribution	particle size distribution	—	particle size distribution	particle size distribution	

J. Anal. At. Spectrom. 28, 549 (2013)

Typical characteristics and properties of x-ray analytical and metrology techniques

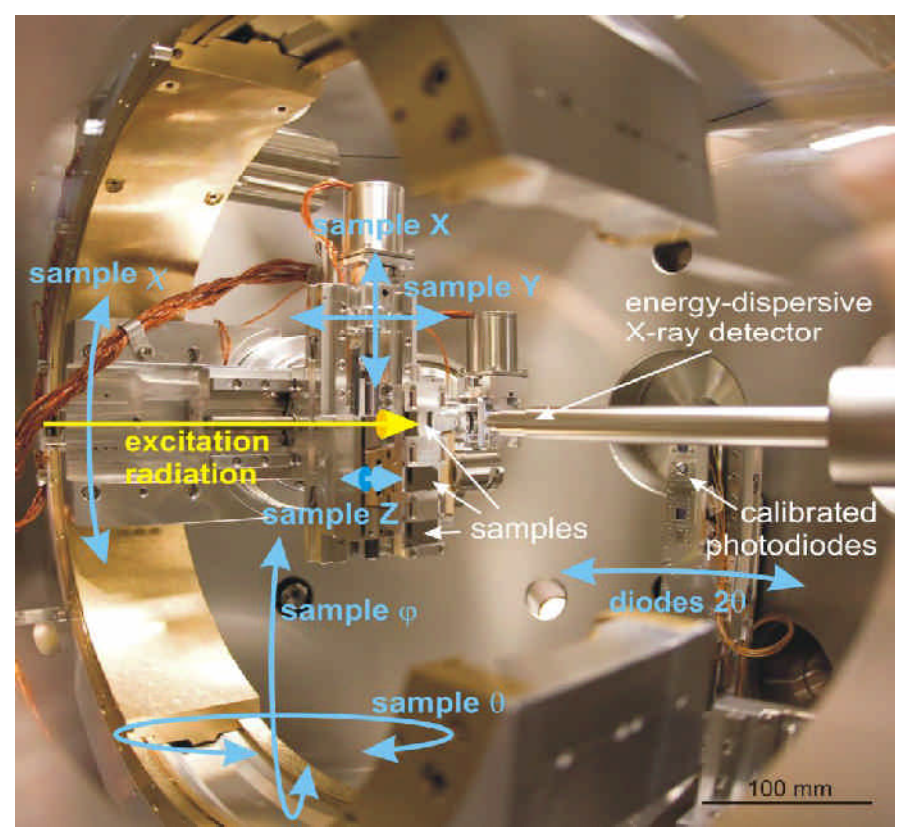
	TXRF	GIXRF	XRF	XRR	XRD	GISAXS
Applications	surfaces	nanolayers, elemental depth profiles, implantation profiles	bulk materials	nano layers	thin layers	nano structured surfaces, thin films
Properties to be measured	mass density in the range of the elements B to U	mass density, concentration, depth profile in the range of the elements B to U	mass density in the range of the elements B to U	layer thickness, roughness, density	layer thickness, orientation	particle size
Detection limit	app. 10^{10} atoms/ cm^2	app. 10^{12} atoms/ cm^2	app. 10^{13} atoms/ cm^2	2 nm – 5 nm	3 wgt.%, 2 nm	2 nm
Range	10^{10} atoms/ cm^2 - 10^{15} atoms/ cm^2	10^{12} atoms/ cm^2 - 10^{17} atoms/ cm2	ppb – %	5- 500 nm	0.1 nm – 10 nm	2 nm – 1µm
Accuracy (and reproducibility) (*reference free)	0.15* / 0,05 (0.02)	0.2*/0.05 (0.03)	0.2*/0.05 (0.03)	0.02 (0.01)	0.05 (0.02)	0,.15 (0.02)
Spatial resolution	1 mm^2-1 cm^2	0.5 mm^2-0.5 cm^2	to 1 mm^2	to 1 mm^2	0.5 mm^2-0.5 cm^2	0.5 mm^2-0.5 cm^2
Measurement speed	50 s – 1000 s/ pt	2000 s – 5 h	100 s – 1000 s	1000 s – 5 h	1000 s – 5 h	10 min/frame

J. Anal. At. Spectrom. 28, 549 (2013)

Novel XRS instrumentation for advanced materials characterizations with synchrotron radiation

X-ray and IR spectrometry

PTB XRS intrumentation at BESSY

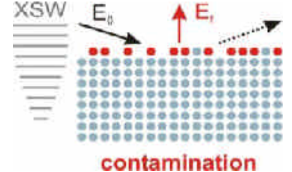


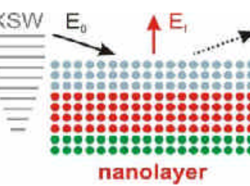
9-axis manipulator and chamber ensuring

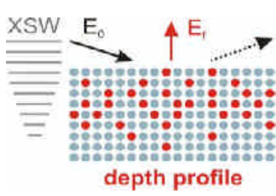
- the entire TXRF, GIXRF and XRF regime
- polarization-dependent speciation by XAFS
- combined GIXRF and XRR investigations
- movable aperture system for reference-free XRF and atomic FP determinations

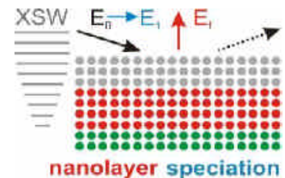
Transfer of modified instrumentation to

- TU Berlin for a **laboratory plasma source**
- LNE/CEA-LNHB for **SOLEIL storage ring**
- IAEA (UN) for **ELETTRA storage ring**









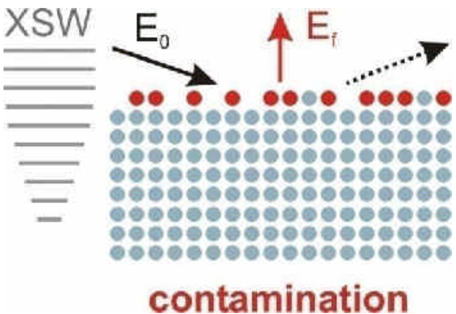
Janin Lubeck et al.,
Rev. Sci. Instrum. **84**, 045106 (2013)

Quantitation in SR-TXRF routine analysis on Si wafers

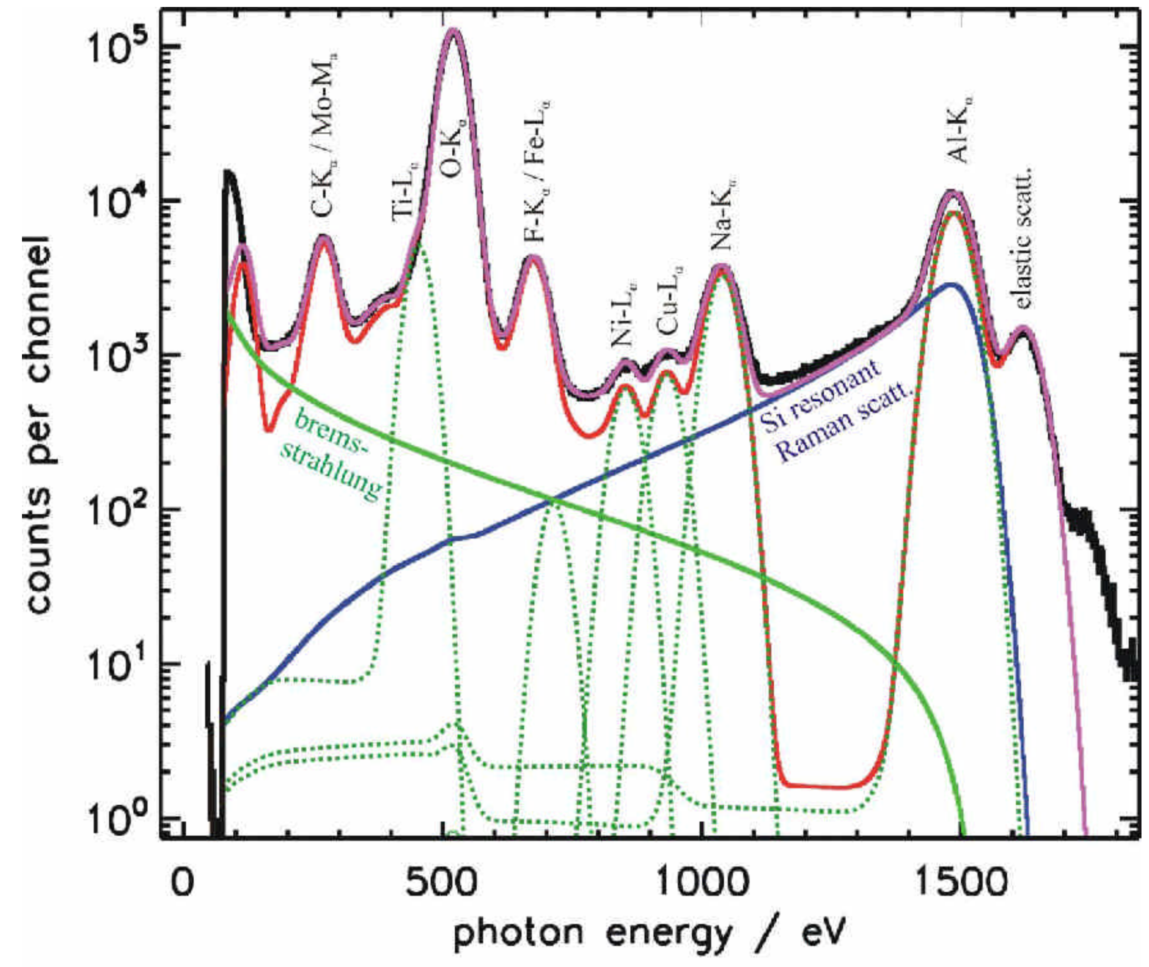
X-ray and IR spectrometry

TXRF **spectra deconvolution** including Si(Li) detector response functions, RRS, and bremsstrahlung contributions.

reference-free TXRF quantitation: known incident flux, detector efficiency and solid angle.



spin-coated wafer with 10^{12} cm^{-2} of various transition metals



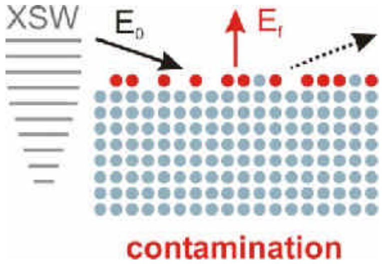
Phys. Stat. Sol. B **246**,1415 (2009)

Reference-free quantitation in SR-TXRF analysis

mass deposition m_i / F_I of the element i with unit area F_I

$$\frac{m_i}{F_I} = \frac{-1}{\mu_{tot,i}} \ln\left\{1 - \frac{P_i}{P_{0,Wsurf}\,\tau_{i,E_0}\,Q\,\frac{\Omega_{det}}{4\pi}\,\frac{1}{\sin\psi_{in}}\,\frac{1}{\mu_{tot,i}}}\right\}$$

E_0	photon energy of the incident (excitation) radiation
$P_0 = S_0 / \sigma_{diode,E_0}$	radiant power of the incident radiation
S_0	signal of the photodiode measuring the incident radiation
σ_{diode,E_0}	spectral responsitivity of the photodiode



Analytical Chemistry **79**, 7873 (2007)

Reference-free quantitation in SR-TXRF analysis

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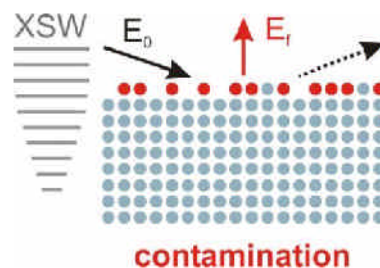
I_{Wsurf} relative intensity of the X-ray standing wave field[1] at the wafer surface

$P_{0,Wsurf} = P_0 I_{Wsurf}$

[1] software package IMD: D. Windt, Computers in Physics **12**, 360-370 (1998)

Ψ_{in} angle of incidence with respect to the wafer surface

E_i photon energy of the fluorescence line l of the element i



Analytical Chemistry **79**, 7873 (2007)

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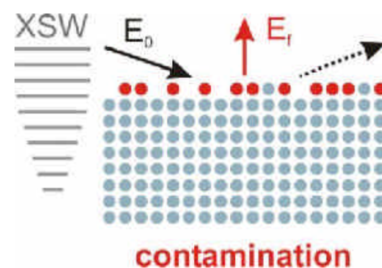
R_i — detected count rate of the fluorescence line l of the element i

ε_{det,E_i} — detection efficiency of the Si(Li) detector at the photon energy E_i

$P_i = R_i / \varepsilon_{det,i}$

Ω_{det} — effective solid angle of detection



Analytical Chemistry **79**, 7873 (2007)

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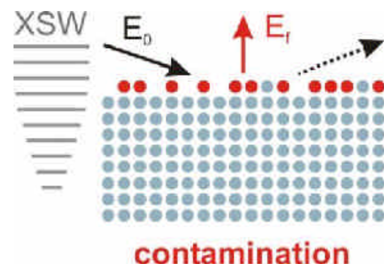
ψ_{out} angle of observation which equals 90 ° in a typical TXRF geometry

τ_{i,E_0} photo electric cross section of the element i at the photon energy

$\mu_{i,E}$ absorption cross section of the element i at the photon energy E

$$\mu_{tot,i} = \mu_{i,E_0} / \sin\psi_{in} + \mu_{i,E_i} / \sin\psi_{out}$$



Analytical Chemistry **79**, 7873 (2007)

Reference-free quantitation in SR-TXRF analysis

X-ray and Ir spectrometry

mass deposition m_i / F_I of the element i with unit area F_I

$$\frac{m_i}{F_I} = \frac{-1}{\mu_{tot,i}} \ln\left\{1 - \frac{P_i}{P_{0,Wsurf}\,\tau_{i,E_0}\,Q\,\frac{\Omega_{det}}{4\pi}\,\frac{1}{\sin\psi_{in}}\,\frac{1}{\mu_{tot,i}}}\right\}$$

ω_{Xi}	fluorescence yield of the absorption edge Xi (of the element i)
$g_{l,Xi}$	transition probability of the fluorescence line l belonging to Xi
j_{Xi}	jump ratio at the absorption edge Xi

$$Q = \omega_{Xi}\, g_{l,Xi}\, (j_{Xi} - 1) / j_{Xi}$$

XSW
E_0
E_f
contamination

Analysis of contamination on novel materials (Ge, SOI, InGaAs, …) or of nanolayered systems (buried interfaces – photovoltaics)

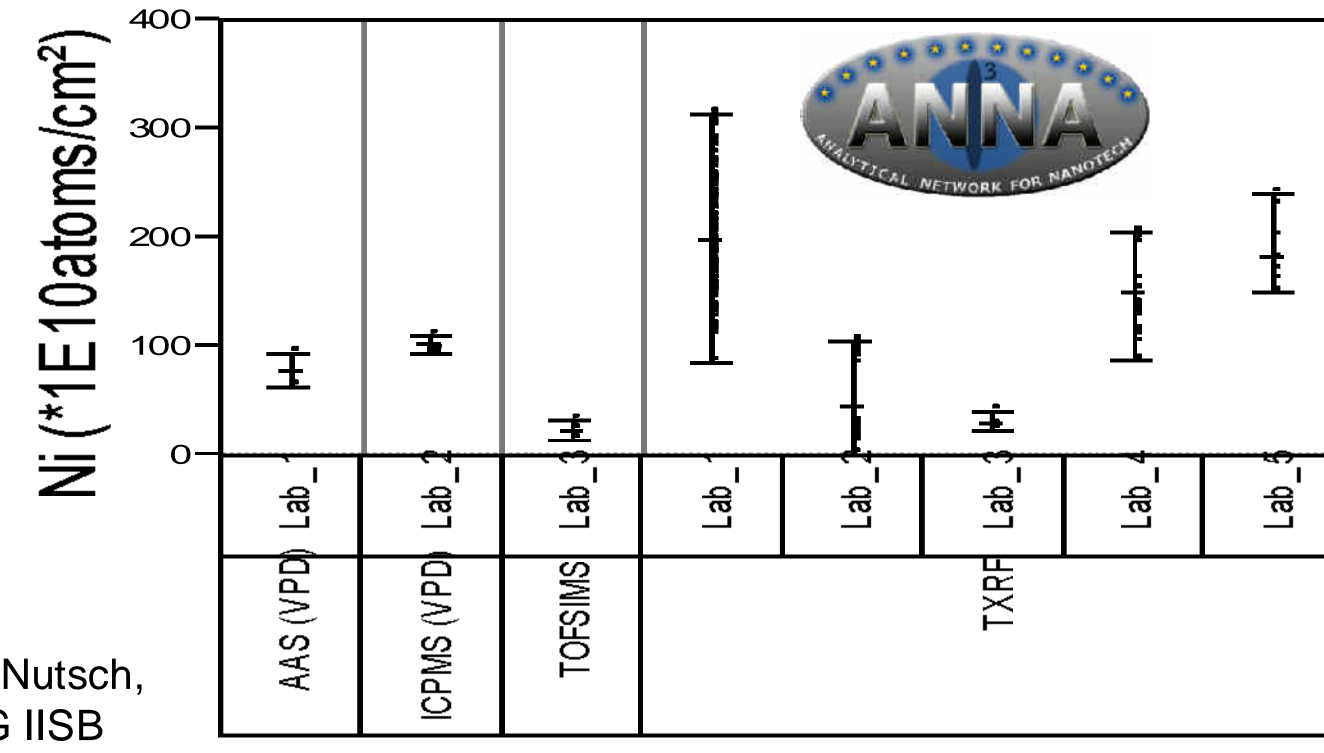
→ calculation of the x-ray standing wave field

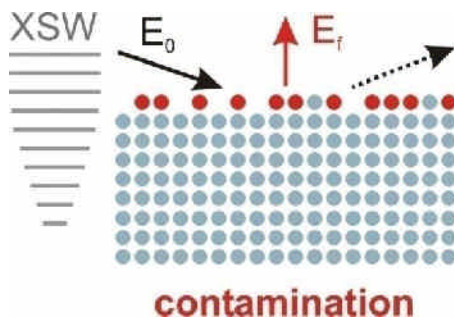
reference based TXRF - Ni surface contamination

Total-reflection X-ray Fluorescence (TXRF) analysis:

- non-consistent results from round robin tests (differences up to a factor of ten)
- reason: problems with employed calibration samples (droplet depositions)

spin coated contamination:
metals 1×10^{12} atoms/cm^2
and light elements (Na, Al)
1×10^{13} atoms/cm^2





A. Nutsch, FhG IISB

Solid State Phenomena **145-146**, 97 and 101 (2009)

Assessment of TXRF calibration samples for Ni surface contamination

X-ray and IR spectrometry

Ni droplets:
100 ng
10 ng
1 ng

mass /ng

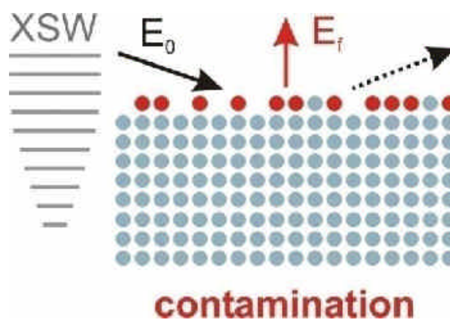
lateral position /mm

Ni droplets:
100 ng
10 ng
1 ng

normalized count rate / Ni-L_α

glancing angle /°

only ‚1 ng‘ thin-layer type



Reason for deviations in contamination results: inhomogeneities and absorption saturation of TXRF calibration droplets

→ “slicing” and “angular scanning” of calibration droplets by reference-free TXRF as validation technique

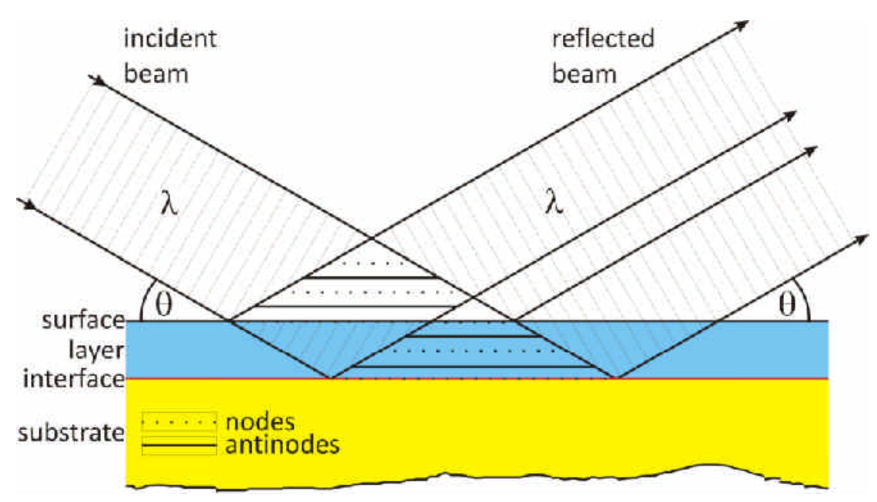
M. Müller

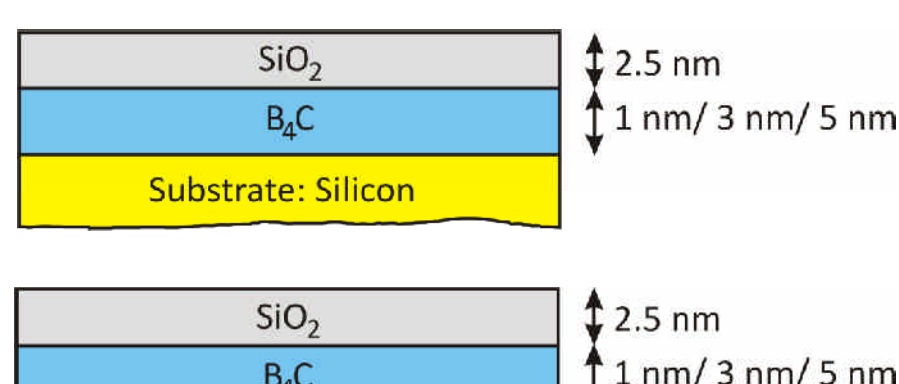
Solid State Phenomena **187**, 291 (2012)

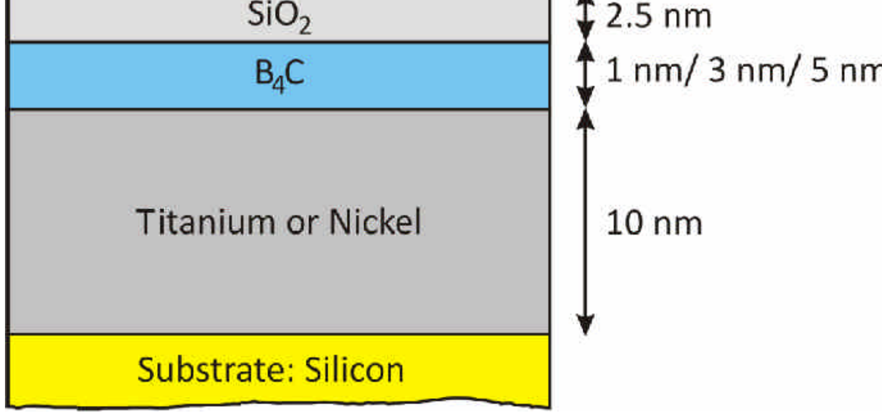
Reference-free XRF and grazing-incidence XRF of buried nanolayers - layer composition and thickness

X-ray and IR spectrometry

X-ray standing wave field (XSW)





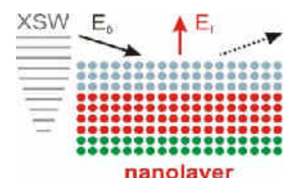


design of samples: total-reflection of the incident beam at silicon or at the metal

→ occurrence of the XSW in boron carbide layer

objective: determination of the boron carbide layer composition and thickness

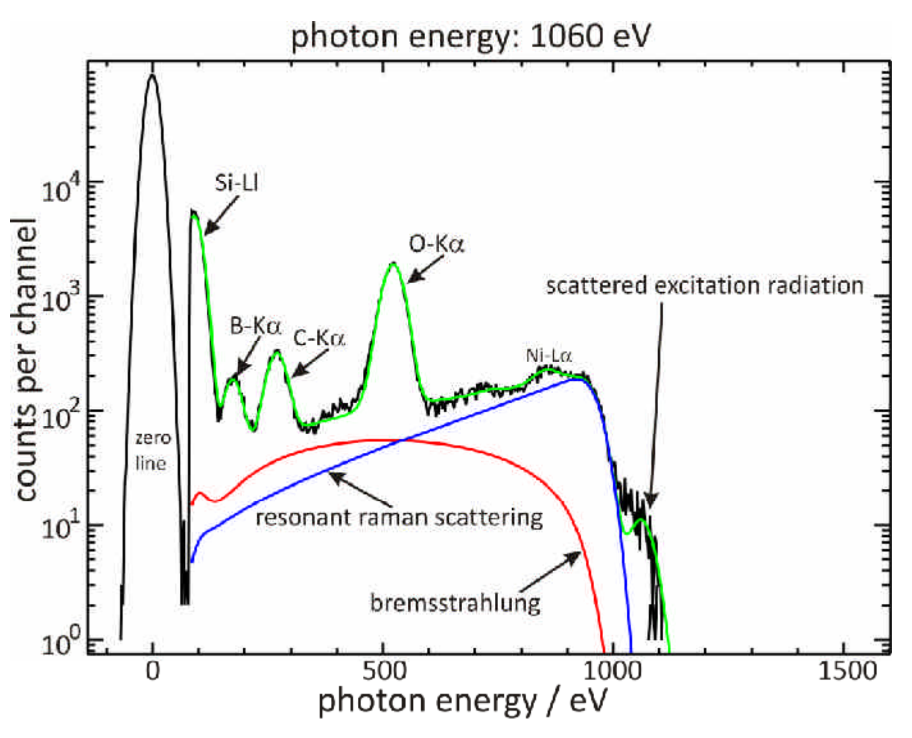
→ comparison of XRF and GIXRF quantification

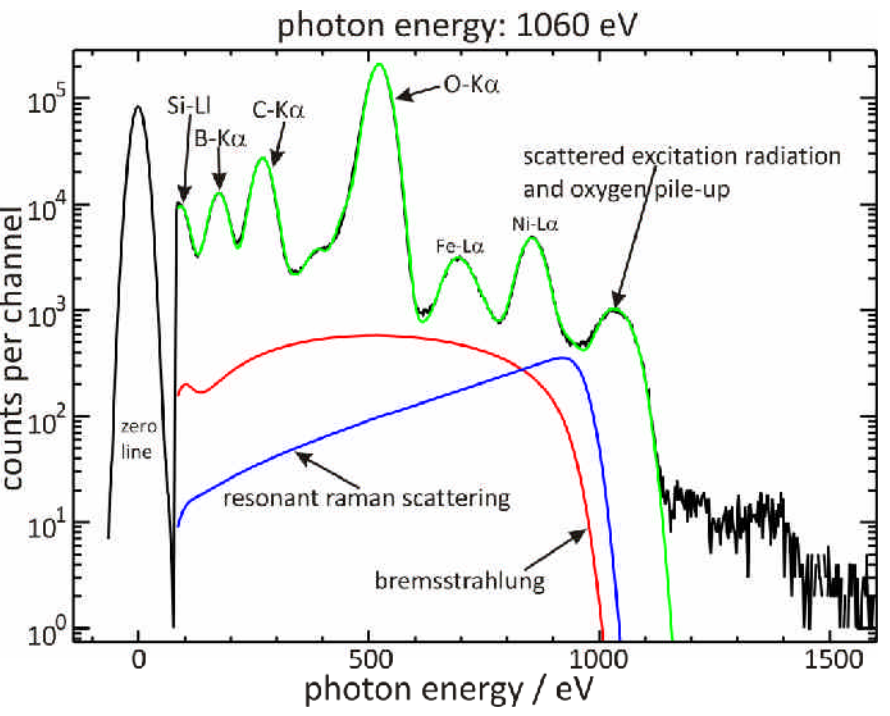


Anal. Chem. **83**, 8623 (2011)

Reference-free XRF and grazing-incidence XRF of buried nanolayers - layer composition and thickness

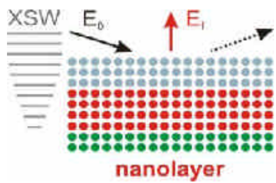
sample: nominal 2.5 nm SiO_2 / 5 nm B-C / Si-substrate





signal to background: XRF 3:1 GIXRF 130:1

quantification reliability better for XRF



Anal. Chem. **83**, 8623 (2011)

Reference-free XRF and grazing-incidence XRF of buried nanolayers - layer composition and thickness

X-ray and IR spectrometry

photon energy: 1060 eV

5nm B_xC

relative count rate /solid angle *sin(inc. angle)

incident angle / °

1.19°
1.28°
1.39°

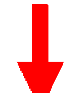
O Kα
C Kα
B Kα
Si Ll

XSW E_0 E_f contamination

XSW E_0 E_f nanolayer

Anal. Chem. **83**, 8623 (2011)

depth-dependent modification of the excitation radiation due to XSW



reveal information about the sequence of the layers

1. oxygen
2. carbon
3. boron
4. silicon (substrate)

carbon contamination at surface recorded

Reference-free XRF and grazing-incidence XRF of buried nanolayers - layer composition and thickness

B-layer thickness	without Ti/Ni-layer /nm	with 10nm Ti-layer /nm	with 10nm Ni-layer /nm	
nominal 0.8 nm B	0.9±0.3 0.9±0.2	0.7±0.2 0.8±0.2	0.6±0.4 1.0±0.3	GIXRF XRF
nominal 2.5 nm B	2.5±0.8 2.6±0.7	2.4±0.7 2.5±0.7	2.0±1.0 2.7±0.7	
nominal 4.2 nm B	4.0±1.2 4.2±1.1	3.9±1.2 4.0±1.0	3.5±1.8 4.3±1.1	

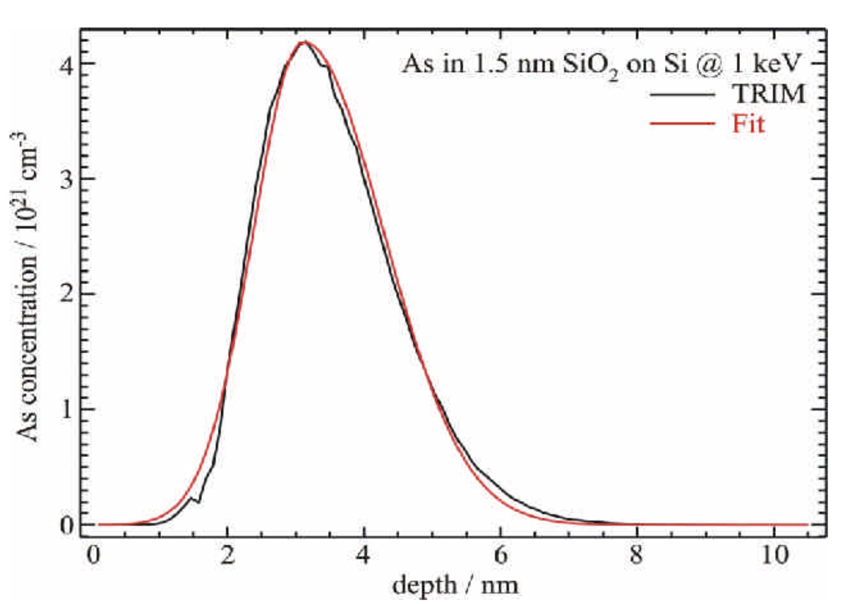
determined thicknesses at 510 eV excitation in line with nominal values deviations

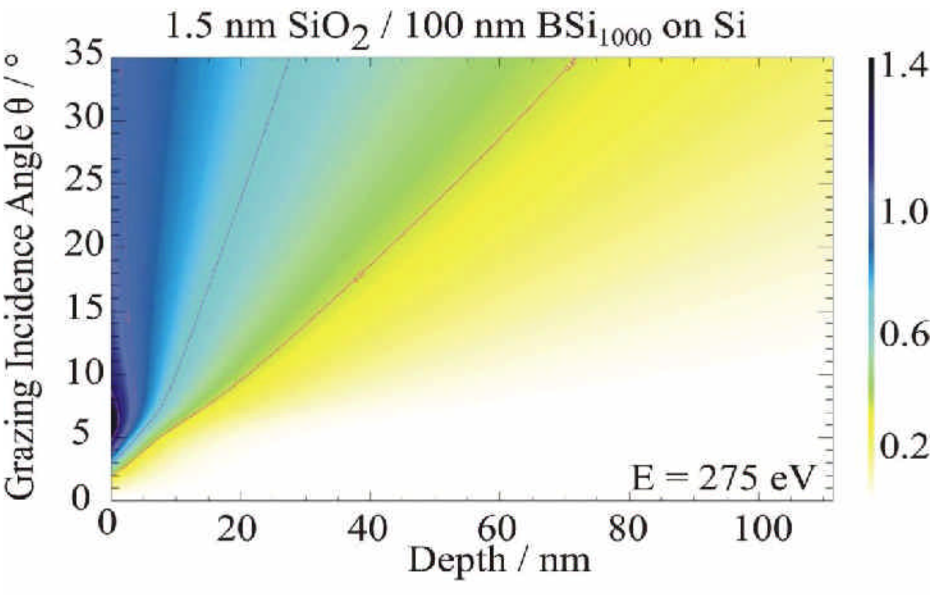
→ relevant influence of XSW and surface carbon contamination

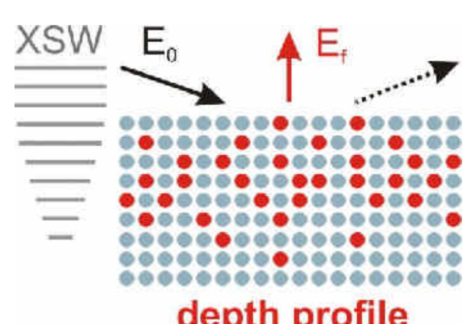
Anal. Chem. **83**, 8623 (2011)

GIXRF analysis of B and As implantation profiles

X-ray and IR spectrometry







fundamental and instrumental parameters — depth distribution of the implant — X-ray Standing Wave field distribution — absorption term

$$F_{Imp}(\theta) = G \int_0^{t_{max}} P_{Imp}(t) \cdot I_{XSW}(t, \theta, E_0) \cdot \left(e^{-\frac{t \rho \mu_{tot}(t)}{\sin \theta_{det}}} \right) dt$$

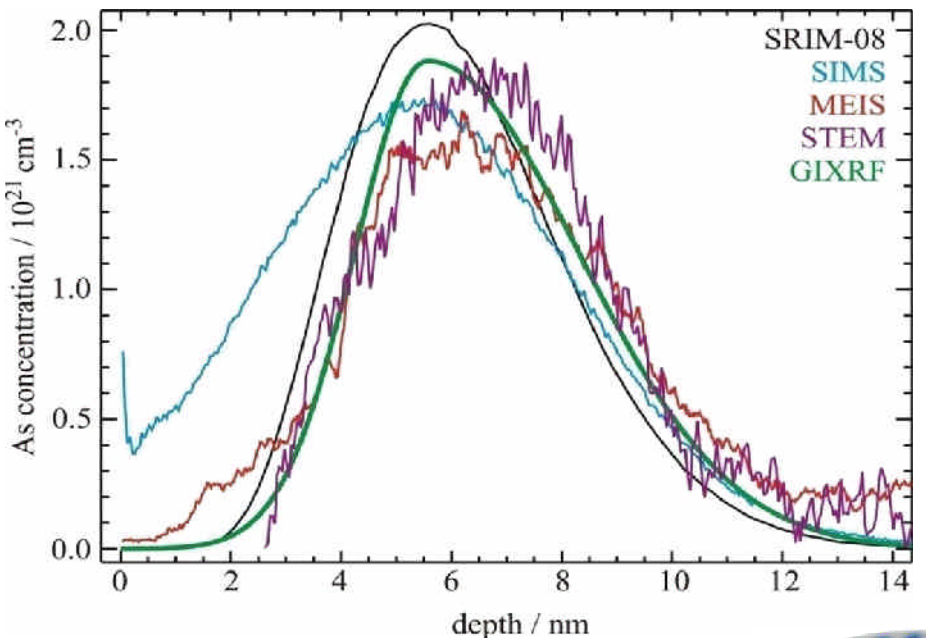
P. Hönicke

Anal. Bioanal. Chem. **396**, 2825 (2010)

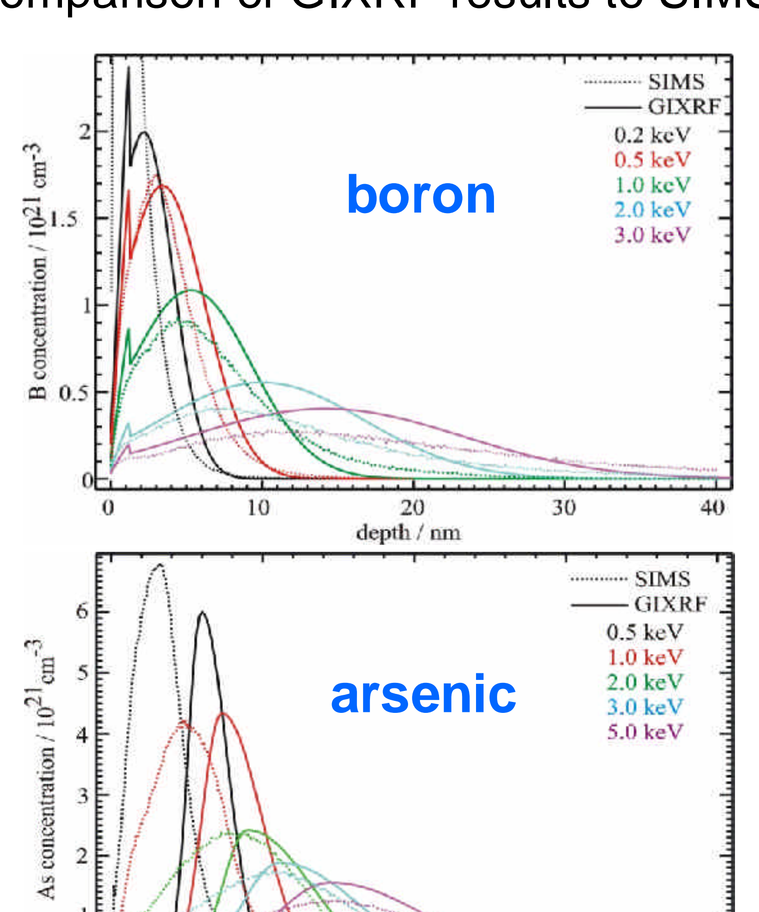
GIXRF analysis of B and As implantation profiles

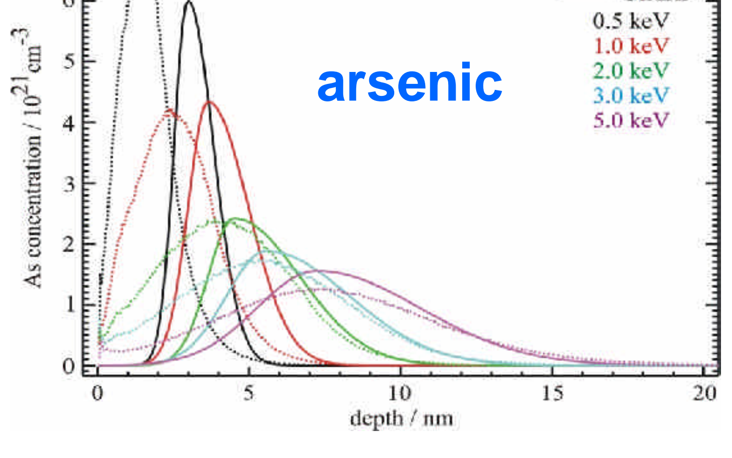
X-ray and IR spectrometry

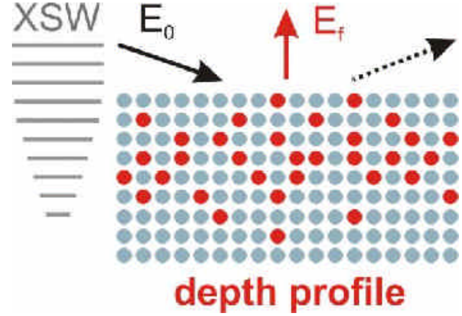
Comparison of GIXRF results on arsenic samples to SIMS, MEIS and STEM



Comparison of GIXRF results to SIMS







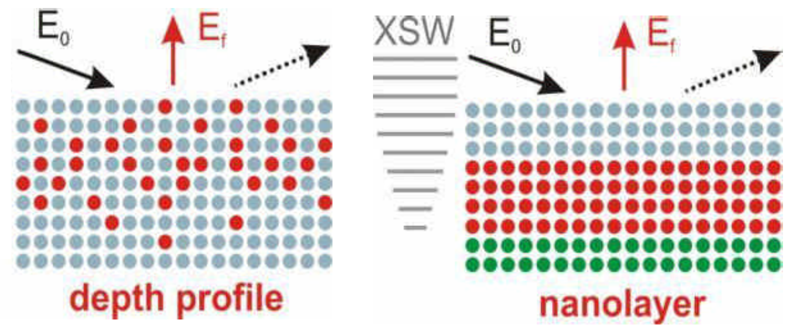
D. Giubertoni (FBK)
J. van den Berg (Univ. Salford)
P. Hönicke

Anal. Bioanal. Chem. **396**, 2825 (2010)

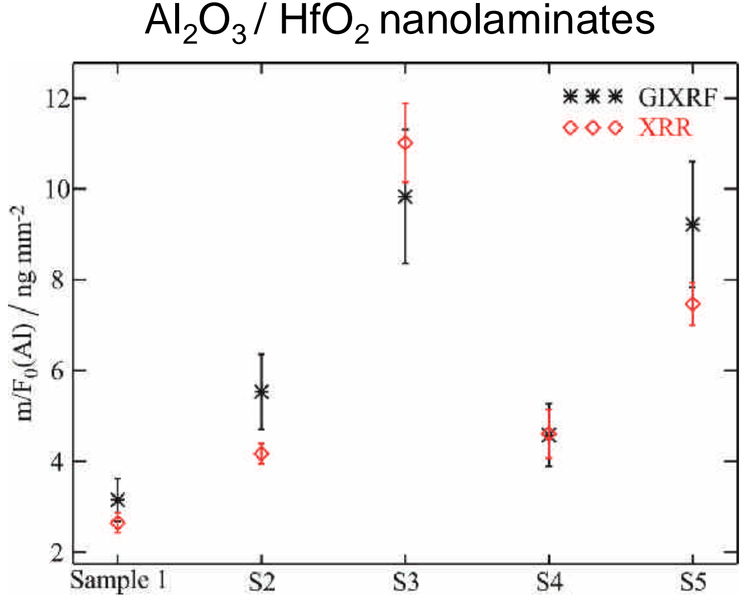
XRR enhanced GIXRF depth profiling

X-ray and IR spectrometry

- GIXRF can be used to depth profile gradient (e.g. ion implants) or nanolayered samples
- iterative calculation of the XSW using X-ray reflectivity data for reliable modeling

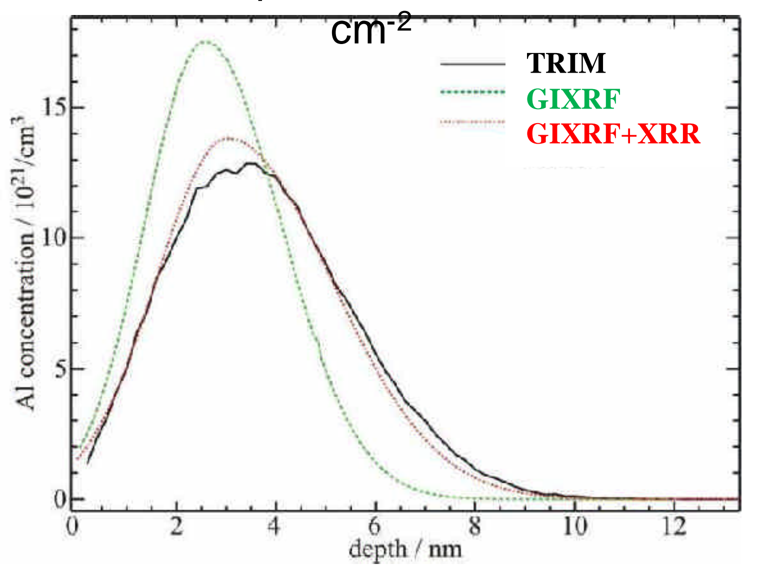


Al_2O_3 / HfO_2 nanolaminates



XRR not matching reference-free GIXRF

1 keV Al implant into Si, dose: 10^{16} cm^{-2}

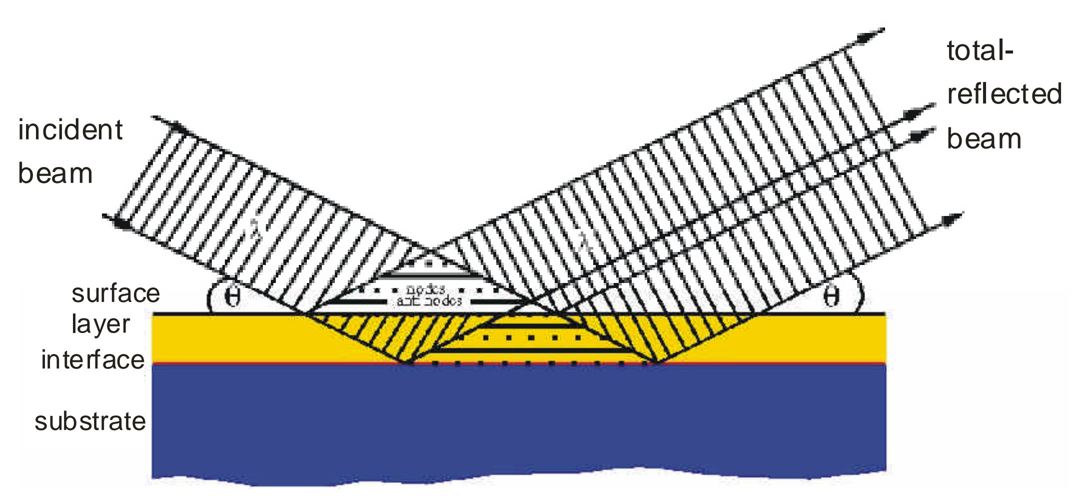


Combining XRR and GIXRF improves result

P. Hönicke

J. Anal. At. Spectrom. **27**, 1432 (2012)

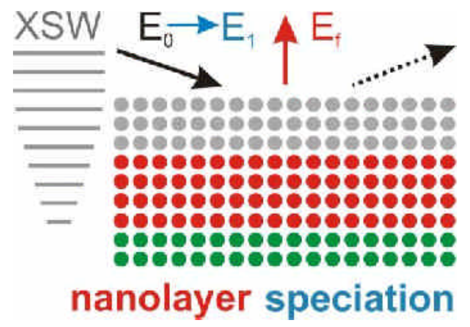
Speciation of buried nanolayers by GIXRF-NEXAFS



→ **composition and speciation of buried nanolayers**

→ **higher information depth (>> 5nm) than XPS**

→ **parallel variation of incident angle and photon energy**

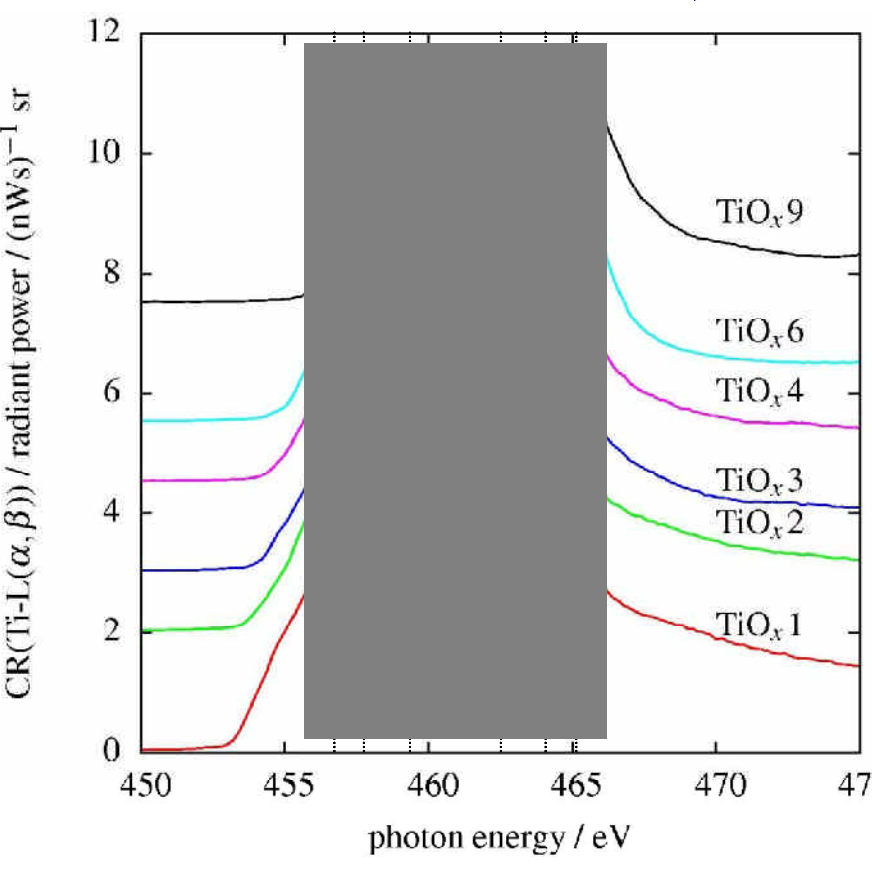


B. Pollakowski

Phys. Rev. B **77**, 235408 (2008)

Anal. Chem. **85,** 193 (2013)

GIXRF-NEXAFS at the Ti-$L_{iii,ii}$ edges



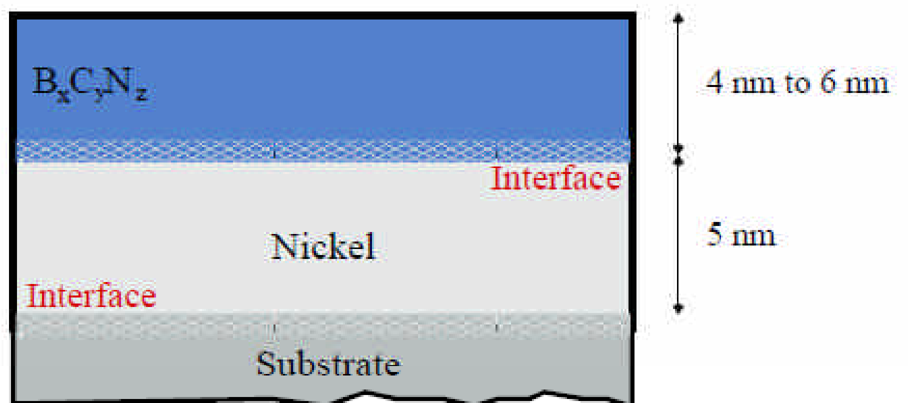
speciation of buried Ti oxide nanolayers

(the degree of oxidation scales with indices)

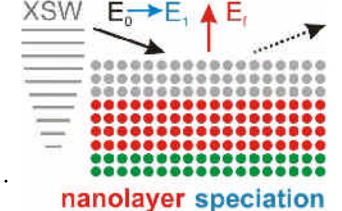
Speciation of buried interfaces by GIXRF-NEXAFS

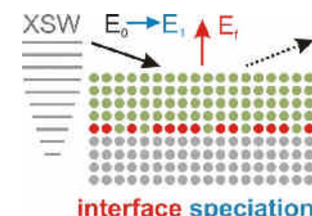
Further developing GIXRF-NEXAFS for interfacial speciation

- Nickel layer deposited with PVD technique, $B_xC_yN_z$ with CVD technique
- Variation of the temperature in the CVD process



No.	Temperature $B_xC_yN_z$ T / °C
1	200
2	300
3	500





B. Pollakowski

Anal. Chem. **85,** 193 (2013)

Speciation of buried interfaces by GIXRF-NEXAFS

photon energy: 510 eV

200°C
400°C
500°C

deriving shallow and steep angles

2.0°
12.0°

CR(C-Kα) / radiant power / nW^{-1}s^{-1}

Grazing Incidence Angle θ / °

photon energy: 1060 eV

200°C
400°C
500°C

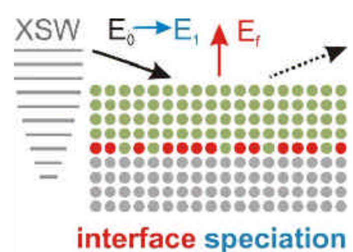
deriving shallow and steep angles

0.5°
1.0°
1.5°
15°

CR(Ni-L(α,β)) / radiant power / μW^{-1}s^{-1}

Grazing Incidence Angle θ / °

- Criterion: percentage of the maximum intensity
- Variation of the angle of incidence depending on the temperature for the interface analysis

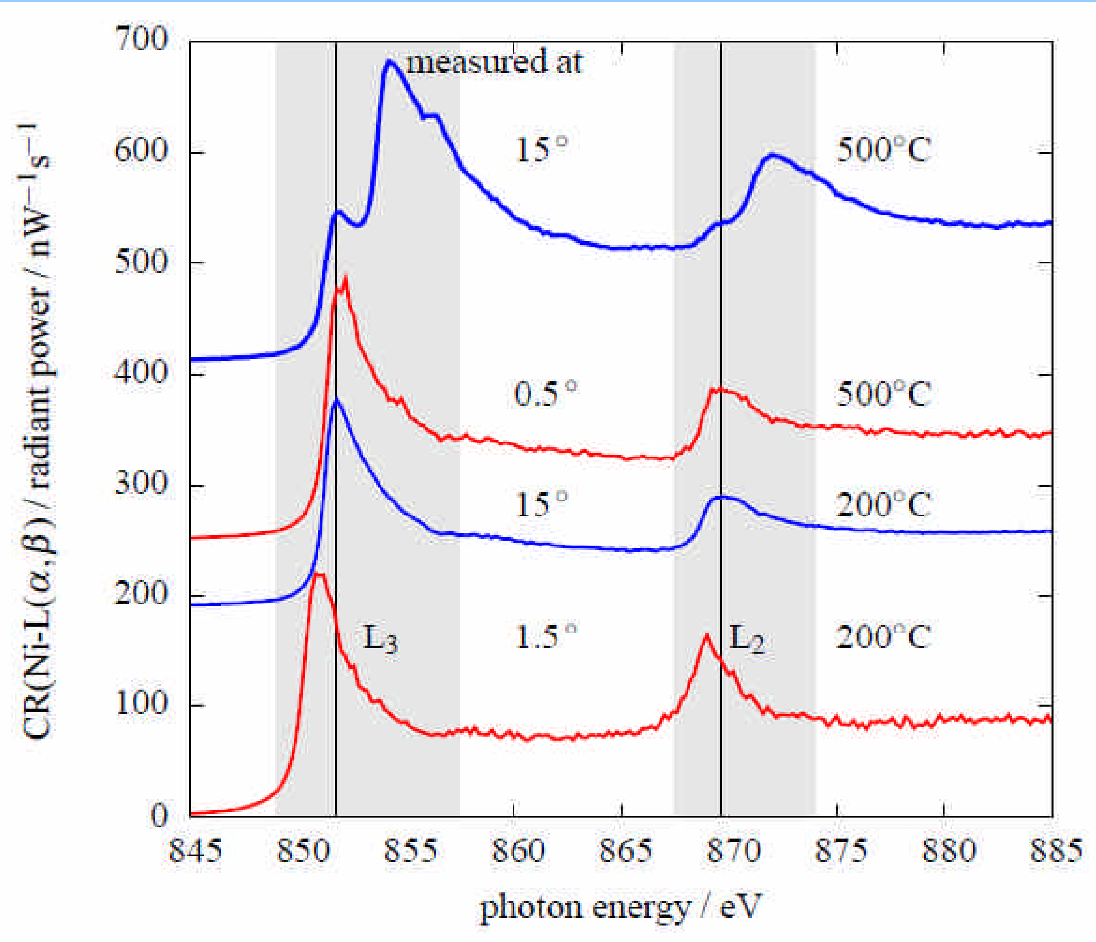


B. Pollakowski

Anal. Chem. **85,** 193 (2013)

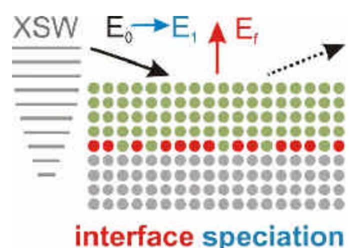
Speciation of buried interfaces by GIXRF-NEXAFS

X-ray and IR spectrometry



- **Comparison** between a **shallow** and a **steep** angle
- Interface observable: Ni-C, Ni-N or Ni-Si bonds possible

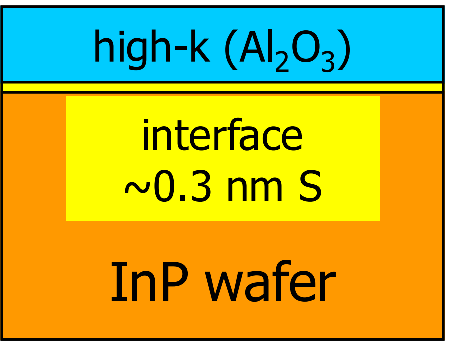
B. Pollakowski Anal. Chem. **85,** 193 (2013)



X-ray and IR spectrometry

Quantitative characterization of nanoelectronics

Optimization of high-k nanolayer fabrication



3 nm Al_2O_3 on S passivated INP substrate

norm. count rate

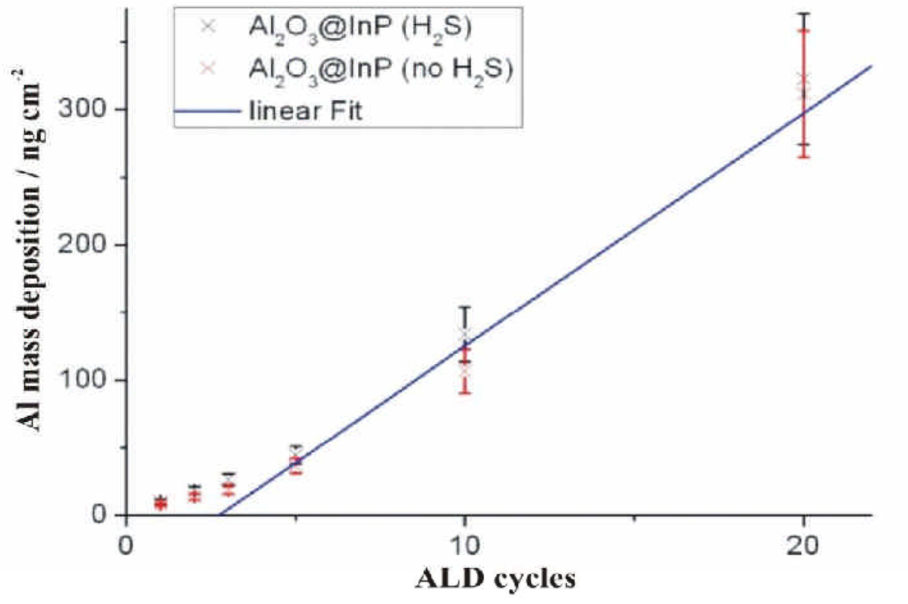
Al

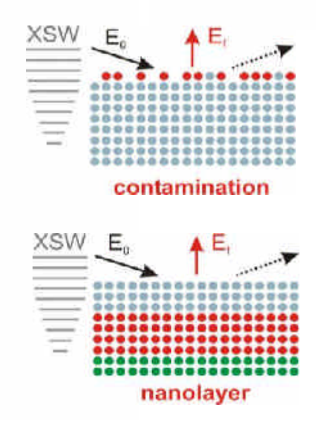
S

P (Substrat)

gracing angle /°

Quantification of the ALD growth rate





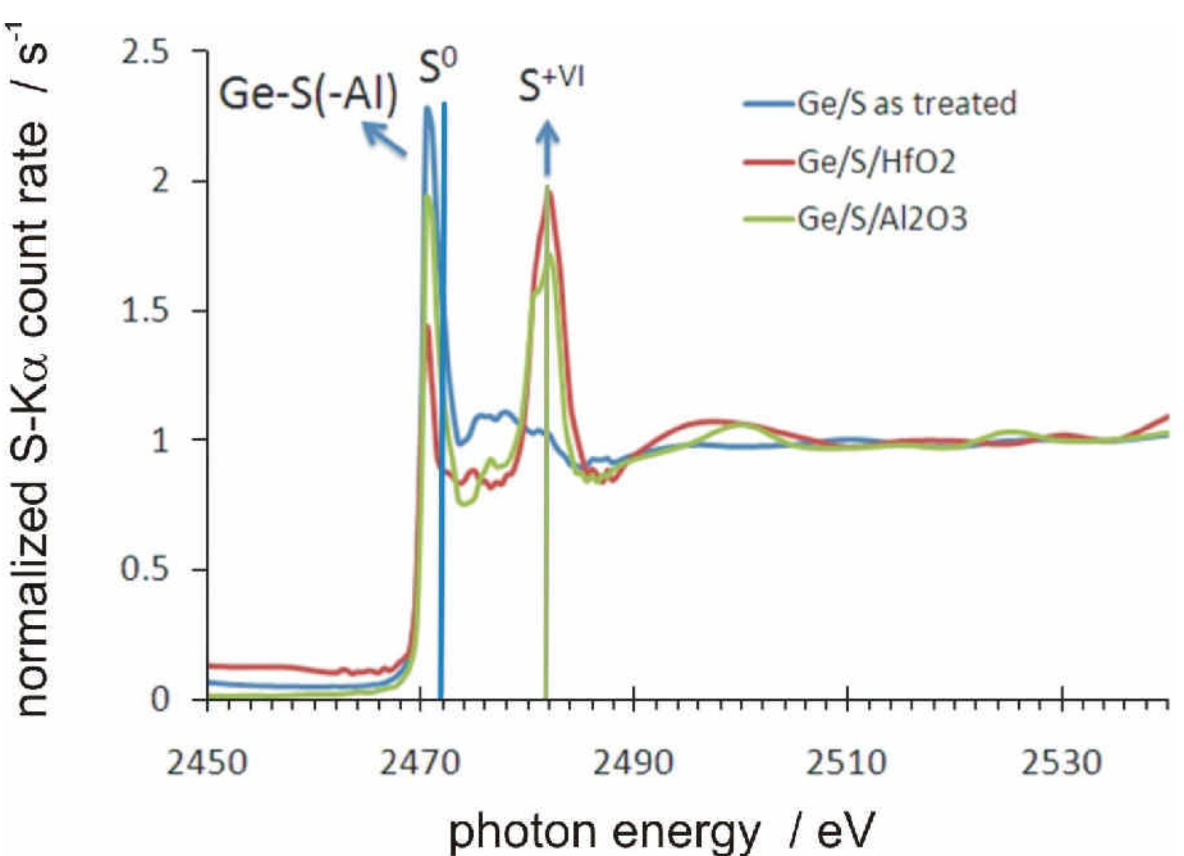
M. Müller

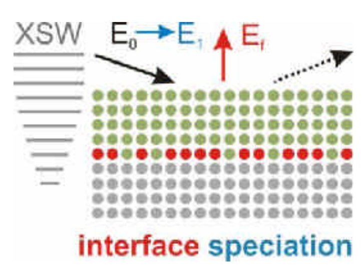
linear growth on S passivated InP substrate after the 3rd ALD cycle

J. Vac. Sci. Technol. A **30**, 01A127 (2012)

Quantitative interface characterization and speciation

XAFS speciation of the S passivated interface as treated and for two high k cap layer





high-k (e.g. 5 nm HfO_2)

Ge wafer

passivated interface (S monolayer ~0.3 nm)

M.Müller

J. Electrochem. Soc. **158**, H1090 (2011)

GIXRF-NEXAFS at thin-film Si photovoltaics: probing the chemical state of buried interfaces

X-ray and IR spectrometry

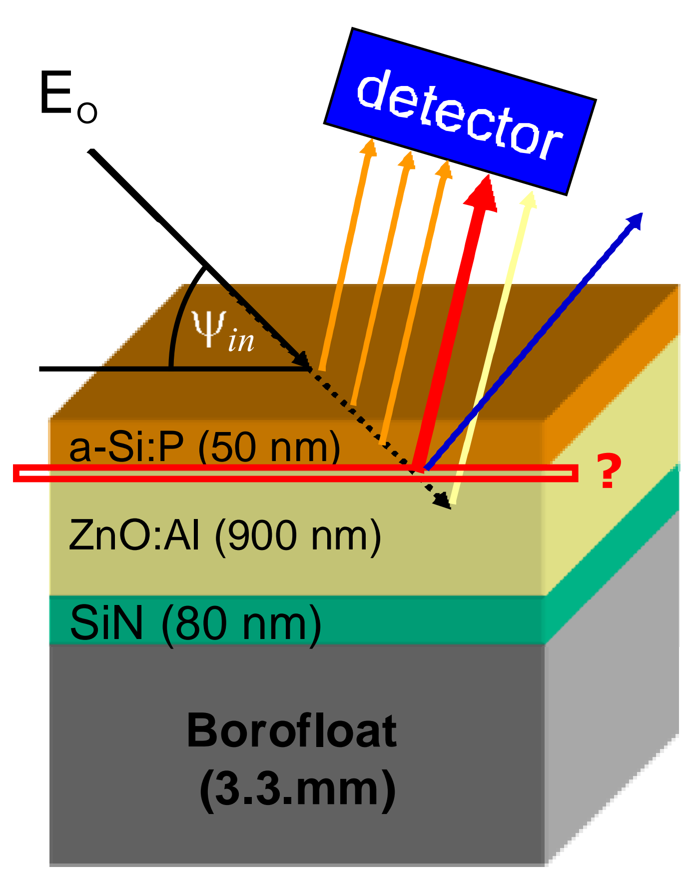
GIXRF-NEXAFS requirements:

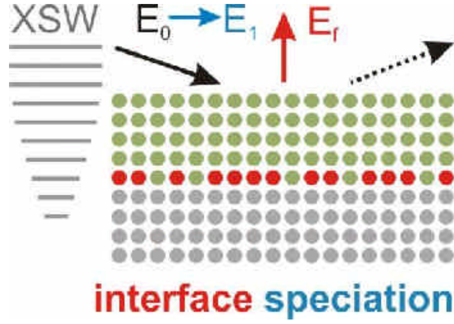
- transmission through a-Si layer
- total reflection at interface

Si:P - Si doped with 0,2 at% P

ZnO:Al - ca. 2 at.% Al

SiN - Si:N = 3:4





M. Pagels,
TUB / HZB

B. Pollakowski

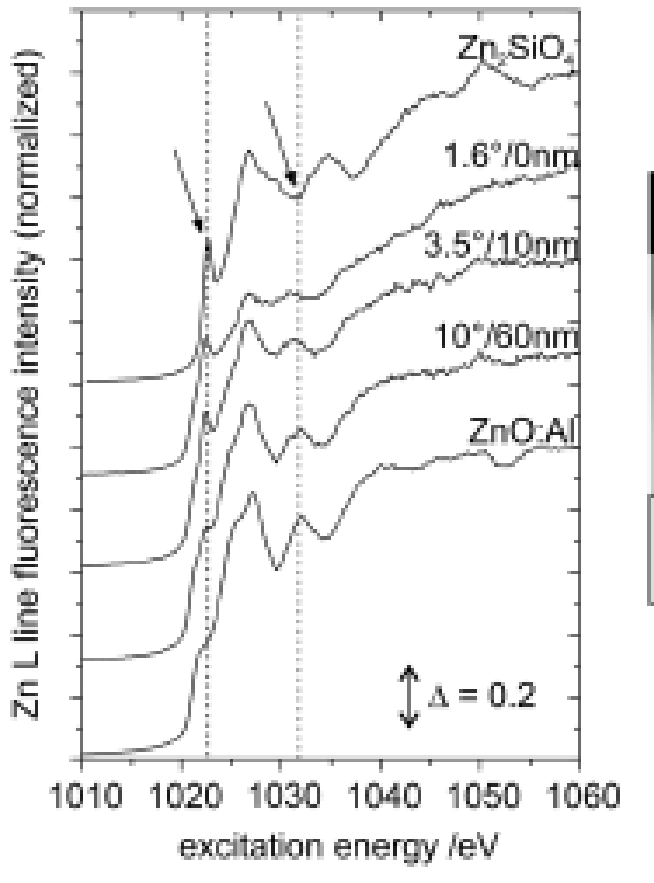
NIMB **268**, 370 (2010)

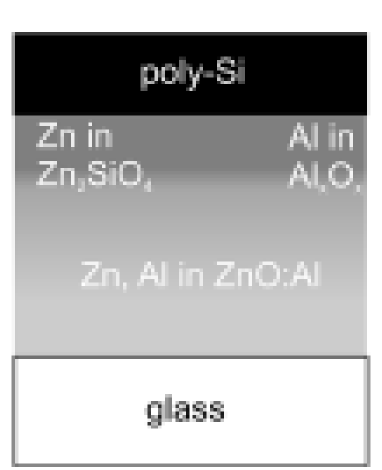
GIXRF-NEXAFS at thin-film Si photovoltaics: probing the chemical state of buried interfaces

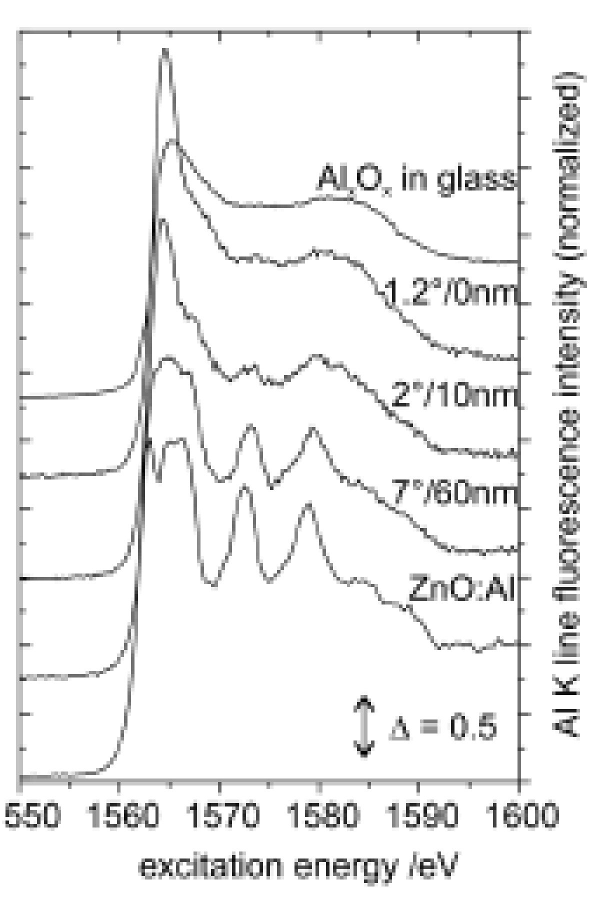
HELMHOLTZ ZENTRUM BERLIN für Materialien und Energie

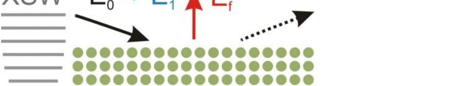
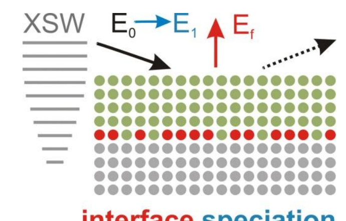
TU berlin

NEXAFS investigations at the Zn-$L_{iii,ii}$ and Al-K edges







M. Pagels, TUB / HZB

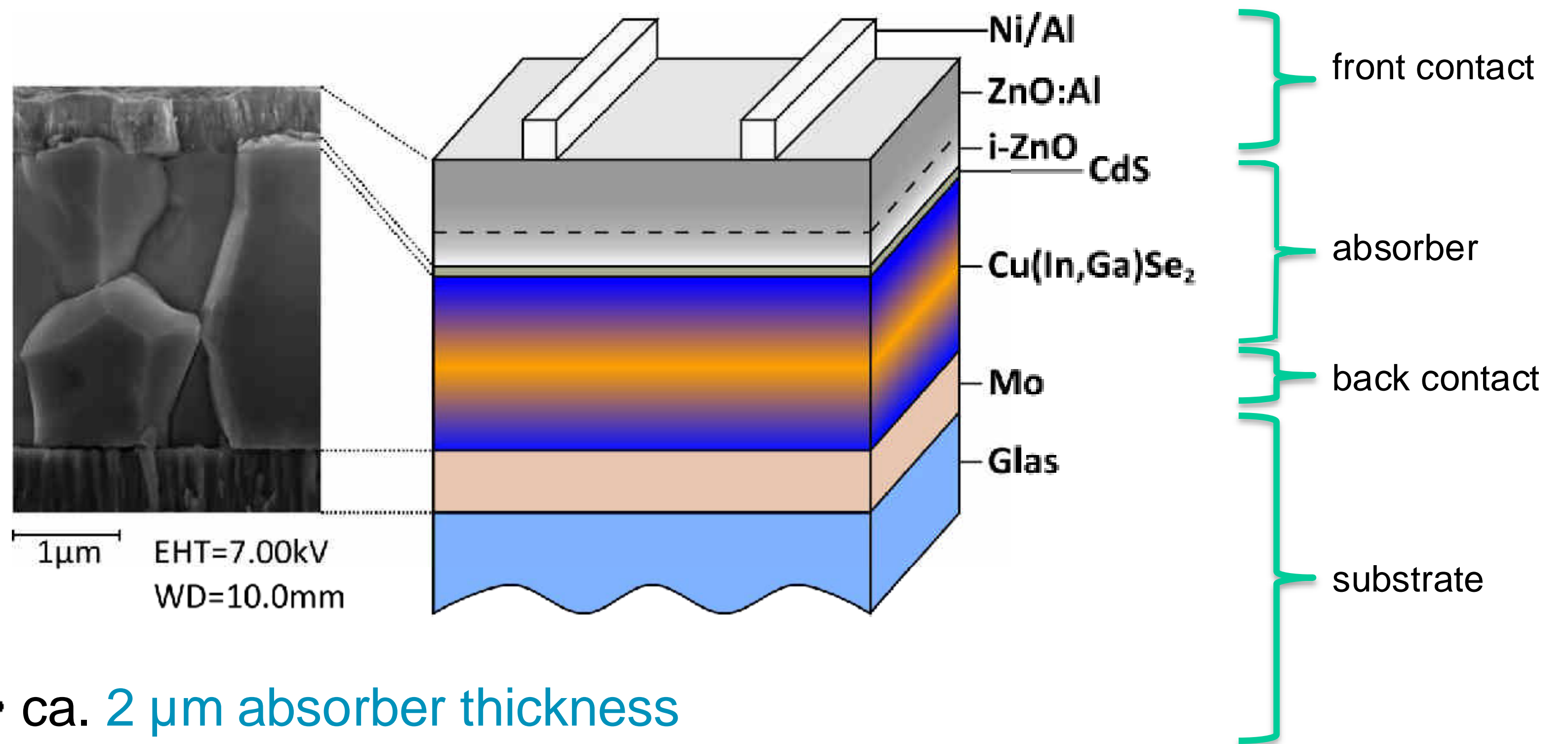
C. Becker, HZB

B. Pollakowski

J. Appl. Phys. **113**, 044519 (2013)

Elemental depth profiling of CIGS photovoltaics by GIXRF using calibrated instrumentation

Cu(In,Ga)Se2 absorber for thin film solar cells



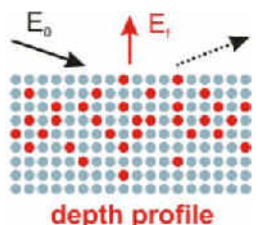
front contact

absorber

back contact

substrate

- ca. 2 µm absorber thickness
- inhomogeneous element depth distribution of In and Ga influences the efficiency



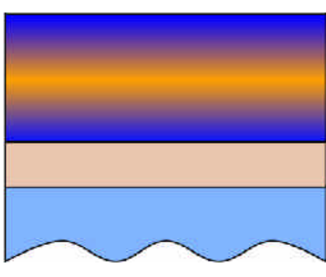
C. Streeck

Appl. Phys. Lett. **103**, 113904 (2013)

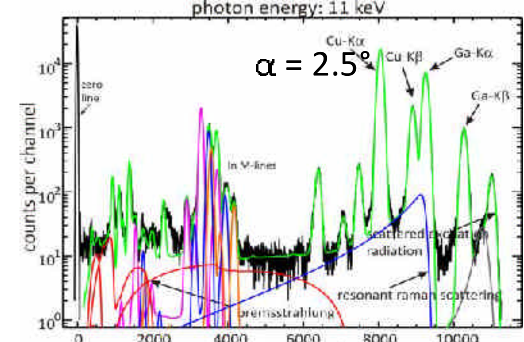
Elemental depth profiling of CIGS photovoltaics by GIXRF using calibrated instrumentation

X-ray and IR spectrometry

Increasing information depth with increasing incidence angle

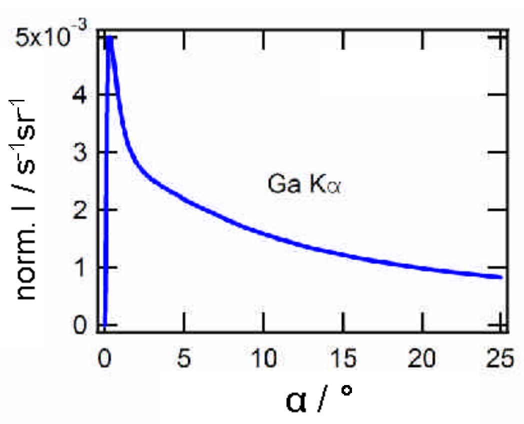


XRF-spectrum



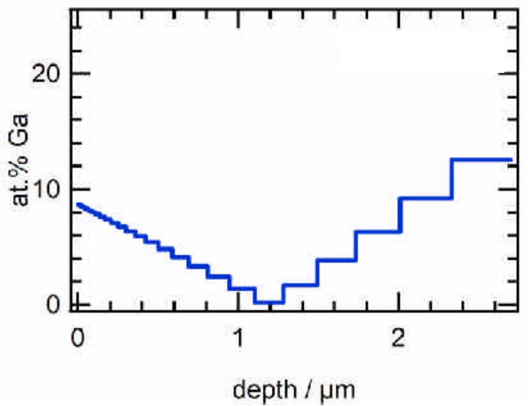
Fluorescence intensity in dependence of the angle of incidence

GIXRF



Non-destructive access to the elemental depth profile

Fundamental parameter-based quantification



C. Streeck

Appl. Phys. Lett. **103**, 113904 (2013)

Comparison of in-depth resolving techniques

Microsc. Microanal. 17, 728–751, 2011
doi:10.1017/S1431927611000523

Microscopy AND Microanalysis
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Comprehensive Comparison of Various Techniques for the Analysis of Elemental Distributions in Thin Films

D. Abou-Ras,[1,*] R. Caballero,[1] C.-H. Fischer,[1] C.A. Kaufmann,[1] I. Lauermann,[1] R. Mainz,[1] H. Mönig,[1] A. Schöpke,[1] C. Stephan,[1] C. Streeck,[1] S. Schorr,[2] A. Eicke,[3] M. Döbeli,[4] B. Gade,[5] ...,[8] V. Hoffmann,[9] D. Klemm,[9] V. Efimova,[9] A. Bergmaier,[10] ...[11] A.A. Rockett,[12] A. Perez-Rodriguez,[13,14] J. Alvarez-Garcia,[15] ...P. Choi,[17] M. Müller,[18] F. Bertram,[18] J. Christen,[18] ...llac,[19] and I. Kötschau[20]

Ga concentration (at. %)

surface, Mo, XPS, AES, SIMS, Raman depth profiling, Raman mapping, RBS, ERDA

Non-destructive traceable analytical technique: reference-free X-ray fluorescence analysis

- more then 20 analytical techniques
- On sections of a laterally homogeneous sample
- Quantitative differences larger than uncertainties of single techniques
- Most methods require a calibration sample

D. Abou-Ras (HZB) et al. Microscopy & Microanalysis **17**,728-751, (2011)

Elemental depth profiling of CIGS photovoltaics by GIXRF using calibrated instrumentation

X-ray and IR spectrometry

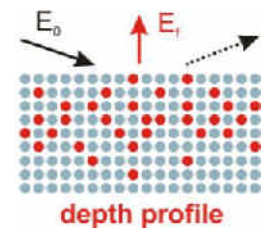
Pilot-study CCQM-P140

CCQM-P140

SURFACE ANALYSIS

Measurement of atomic fractions in Cu(In,Ga)Se_2 Films

Composition / at.%	Certified values KRISS	Reference-free GIXRF PTB
Cu	**23.8** ± 0.6	**24.0** ± 1.3
In	**19.1** ± 0.6	**19.3** ± 1.1
Ga	**6.6** ± 0.3	**6.3** ± 0.4
Se	**50.6** ± 1.5	**50.4** ± 2.8
d / µm	ca. **2**	**2.06** ± 0.09



C. Streeck

Metrologia, in print (2014)

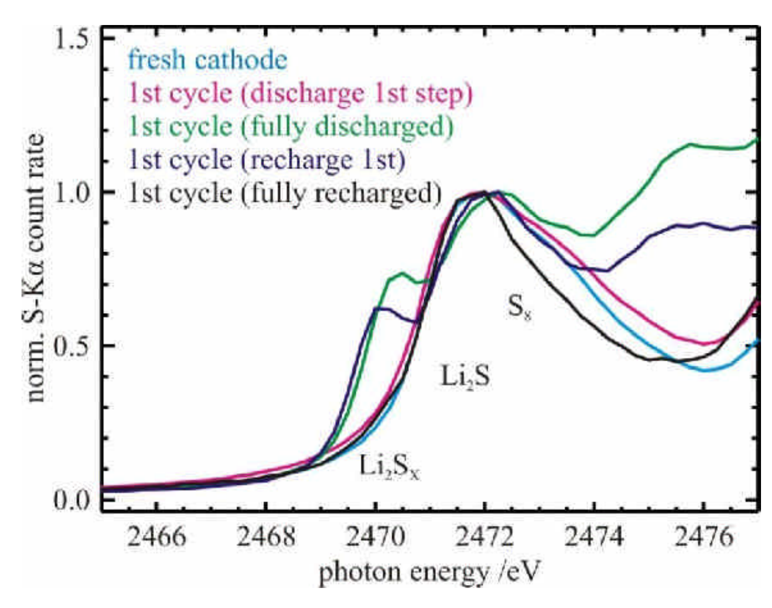
Directed development of new energy storage materials: towards in-operando XAFS speciation of cathode films

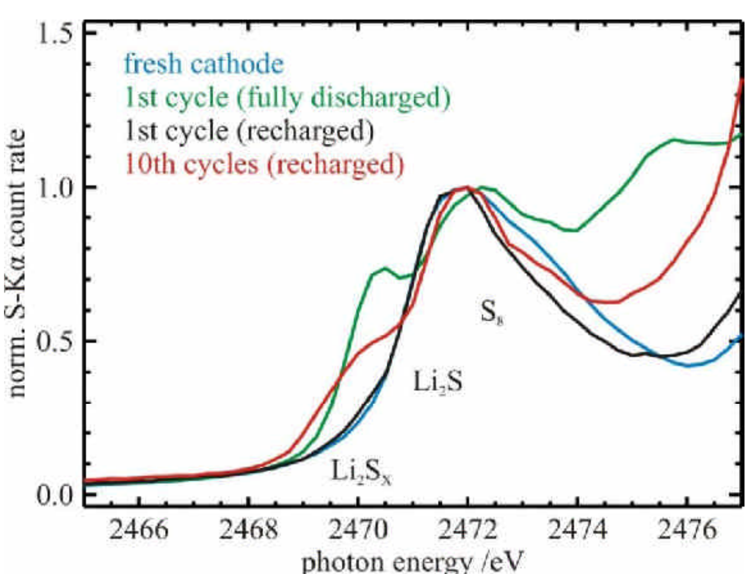
X-ray and IR spectrometry

First step: No ambient air exposure

Employing a thin window argon cell for transport and x-ray spectrometric measurements.

- NEXAFS measurements at different states of charge (not in-operando so far)
- Formation of lithium polysulfides during discharge observed
- Polysulfides disappear during recharge
- After several recharge cycles some of the polysulfides remain



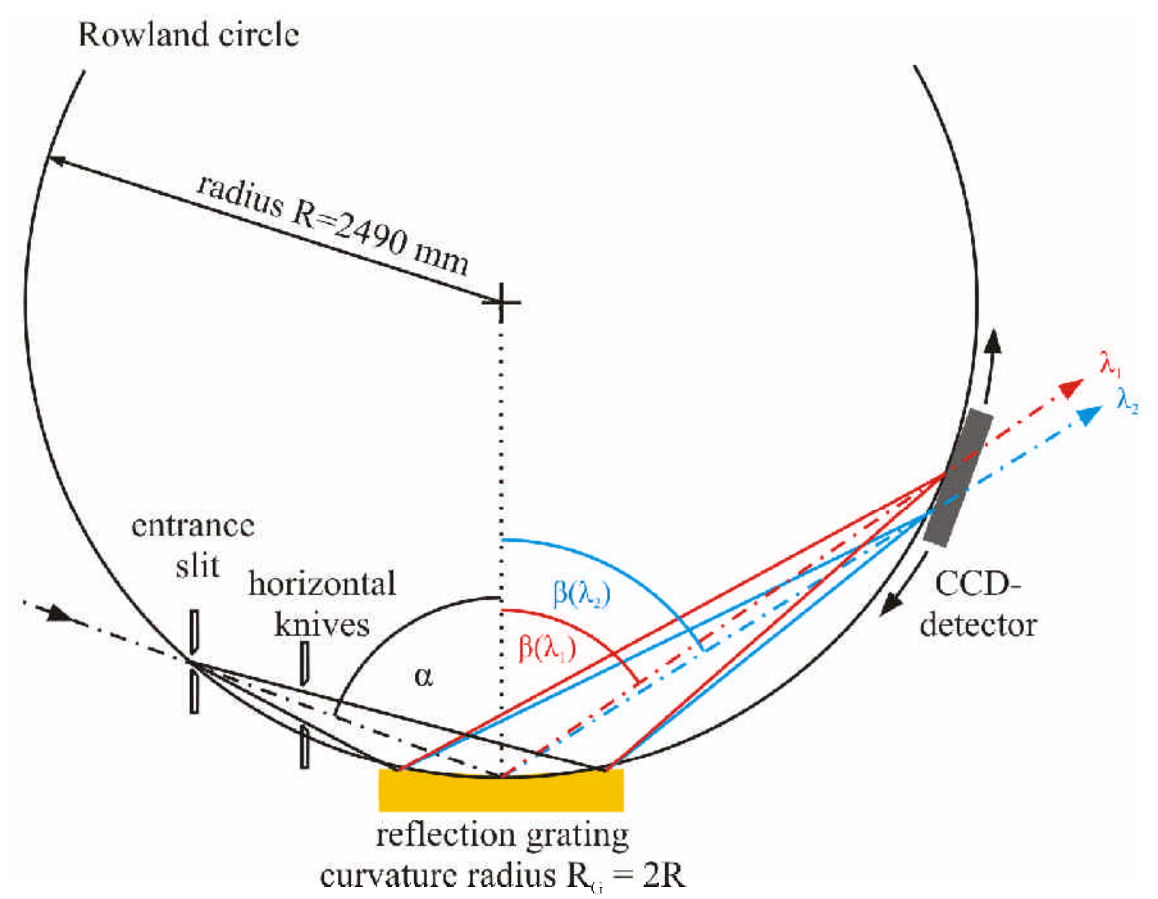


Spectrochimica Acta Part B **94–95**, 22 (2014)

M. Müller

Calibrated Wavelength-Dispersive Spectrometer (WDS)

X-ray and IR spectrometry



energy range:

75 eV to 1760 eV

energy resolution E/ΔE:

150 to 400

calibration → allows for the determination of fundamental parameters

disadvantage: → low efficiency, moderate detection limit, long integration time

M. Müller

Phys. Rev . A **79**, 032503 (2009)

Calibrated Wavelength-Dispersive Spectrometer (WDS)

X-ray and IR spectrometry

5 nm boron carbide (red)
50 nm boron carbide (black)
Kα
- - width (3σ)
— background
······ 3*standard deviation of the background
events per channel
photon energy / eV

10 nm titanium
Ll
Lα
- - width (3σ)
— background
······ 3*standard deviation of the background
events per channel
Photonenenergie / eV

- titanium (buried) measurable
- boron Kα (180 eV) detectable, despite a minimal sensitivity of the CCD
- lower limit of detection is in both cases (B and Ti) about 0.4 nm
- **access to thin films and buried nanolayers**

SiO_2
50 nm B_4C 5 nm
titanium 10 nm
substrate: silicon

R. Unterumsberger, M. Müller

Spectrochim. Acta B **78**, 37 (2012)

Summary

X-ray and IR spectrometry

- Reference-free analysis of contamination on Si and on novel materials
- Quantitative characterization of nanostructured and gradient systems (~2 µm)
- Depth profiling (~500 nm) and interfacial speciation of advanced materials
- Novel XRS instrumentation available at PTB, TUB, LNE-LNHB, IAEA/ELETTRA
- Calibrated high-resolution soft (and hard) x-ray emission spectrometer

Further information on reported activities and instrumentation

at **EMRP IND07** and **NEW01** at **www.EURAMET.org**

Acknowledgements: IMEC, KU Leuven, FhG IISB, LETI, LNHB, MEMC, Numonyx, Siltronic, Univ. Salford, HZB, IWS, AXO, FBK, KFKI AEKI, Technical Universities Berlin and Darmstadt, IPF

ALTECH 2014 - ‘Analytical techniques for precise characterization of nanomaterials’ symposium at the E-MRS spring meeting 2014 (www.european-mrs.com), France