Microspectroscopy and Spectromicroscopy

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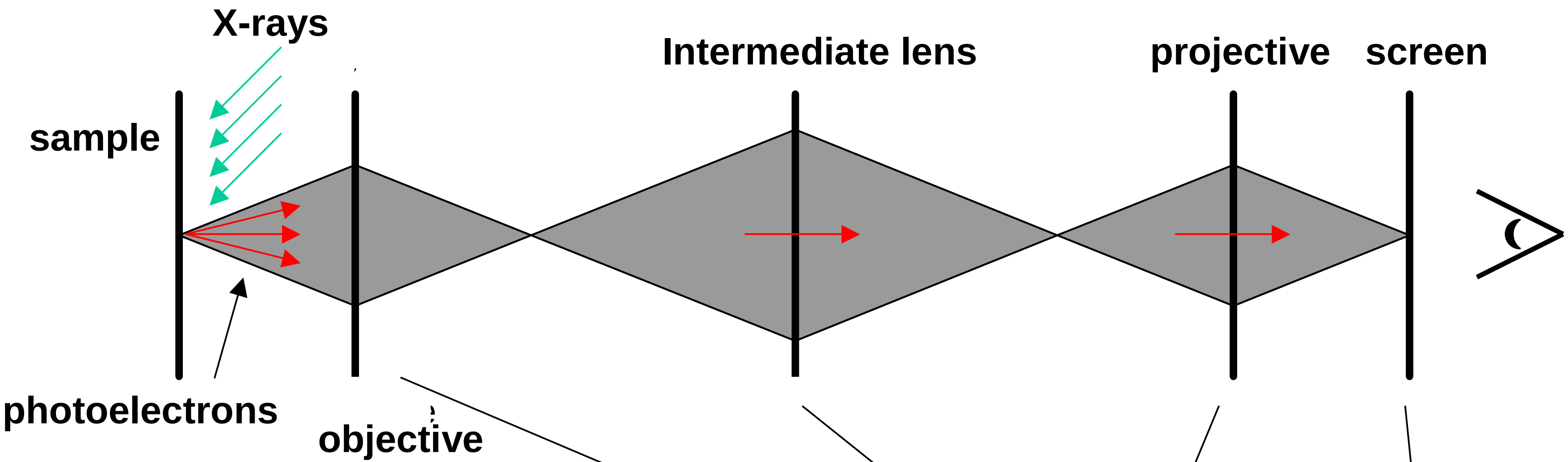
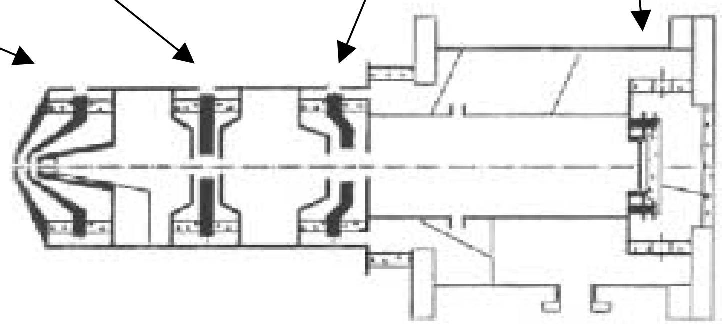
Microspectroscopy and Spectromicroscopy

Part II:

- **basic PEEM principles**
- **imaging modes of a PEEM with imaging analyzer**
- **PEEM with magnetic sector field to couple in an electron beam**
- **comparison SPEM / X-PEEM**
- **Applications**

PEEM PhotoElectron Emission Microscope: principle setup





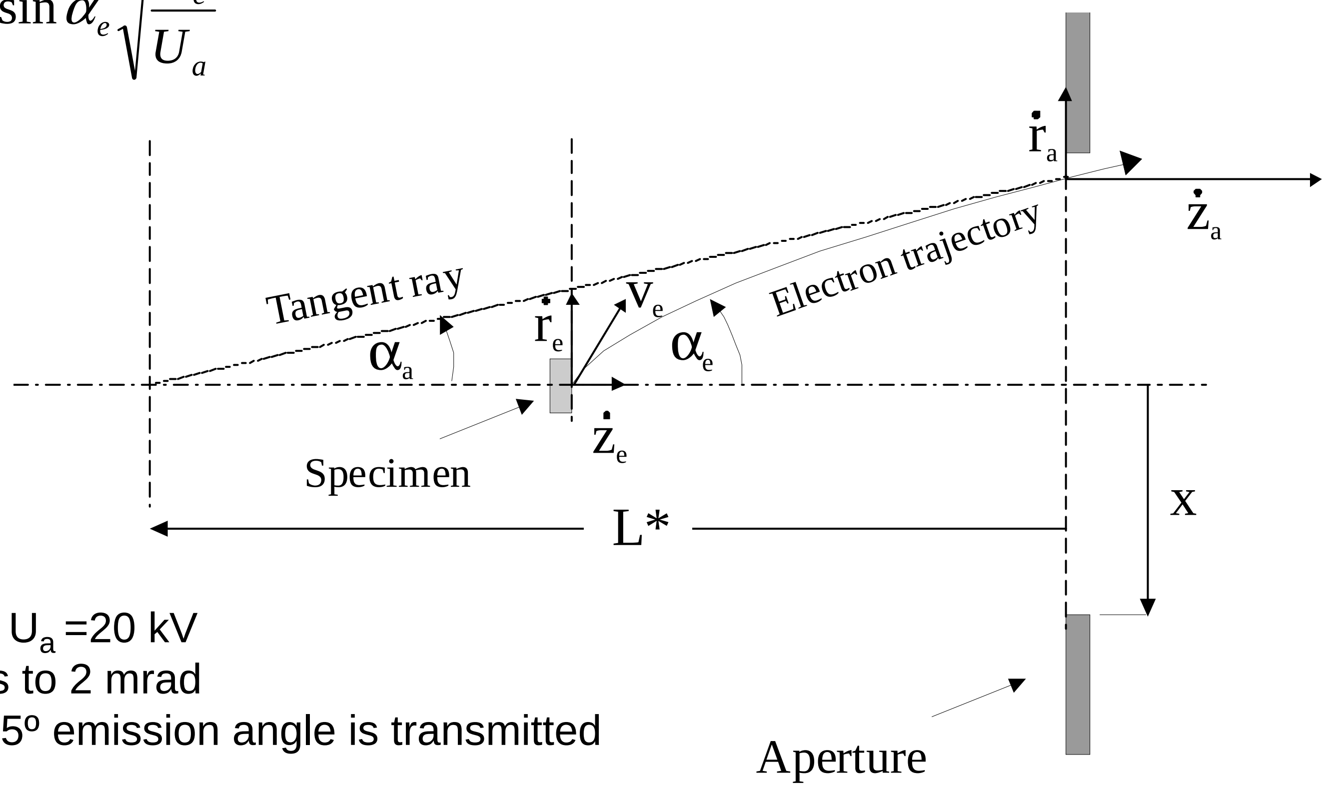
electrons accelerated into lens system

=> small lens aberrations
=> high lateral resolution

Electron imaging systems: basic PEEM principles

Action of aperture and accelerating field:

$$\sin\alpha_a = \sin\alpha_e \sqrt{\frac{U_e}{U_a}}$$



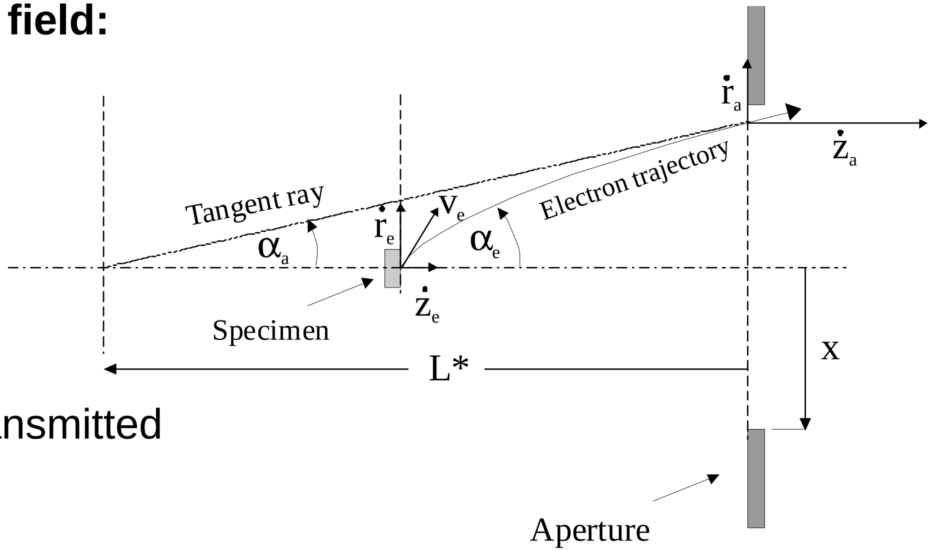
e.g. U_e=10 V, U_a =20 kV
aperture limits to 2 mrad
=> only up to 5º emission angle is transmitted

=> **Aperture cuts most of the signal**

Electron imaging systems: basic PEEM principles

Action of aperture and accelerating field:

$$\sin\alpha_a = \sin\alpha_e \sqrt{\frac{U_e}{U_a}}$$



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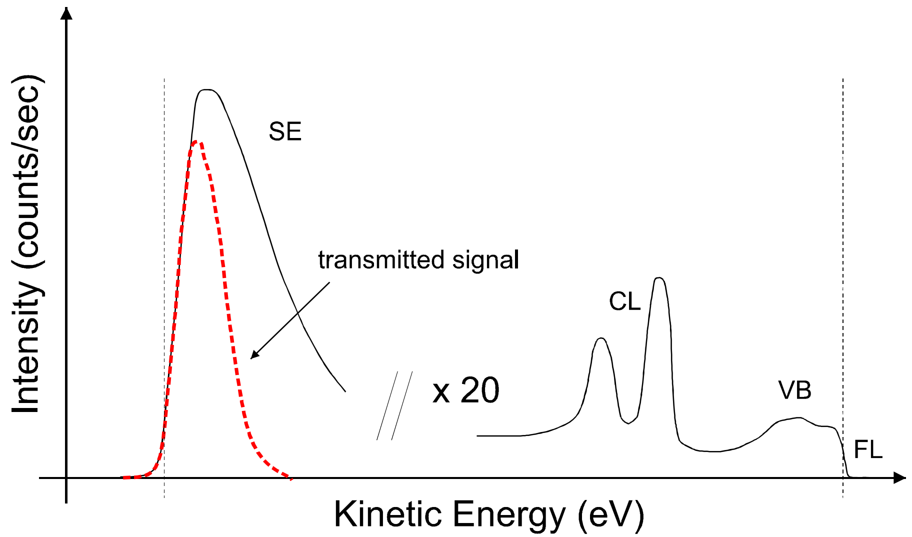


PEEM **without energy filtering** and **angle limiting aperture**

=> only very **slow electrons contribute** to the signal

Electron imaging systems: basic PEEM principles

accelerating field itself introduces aberrations:

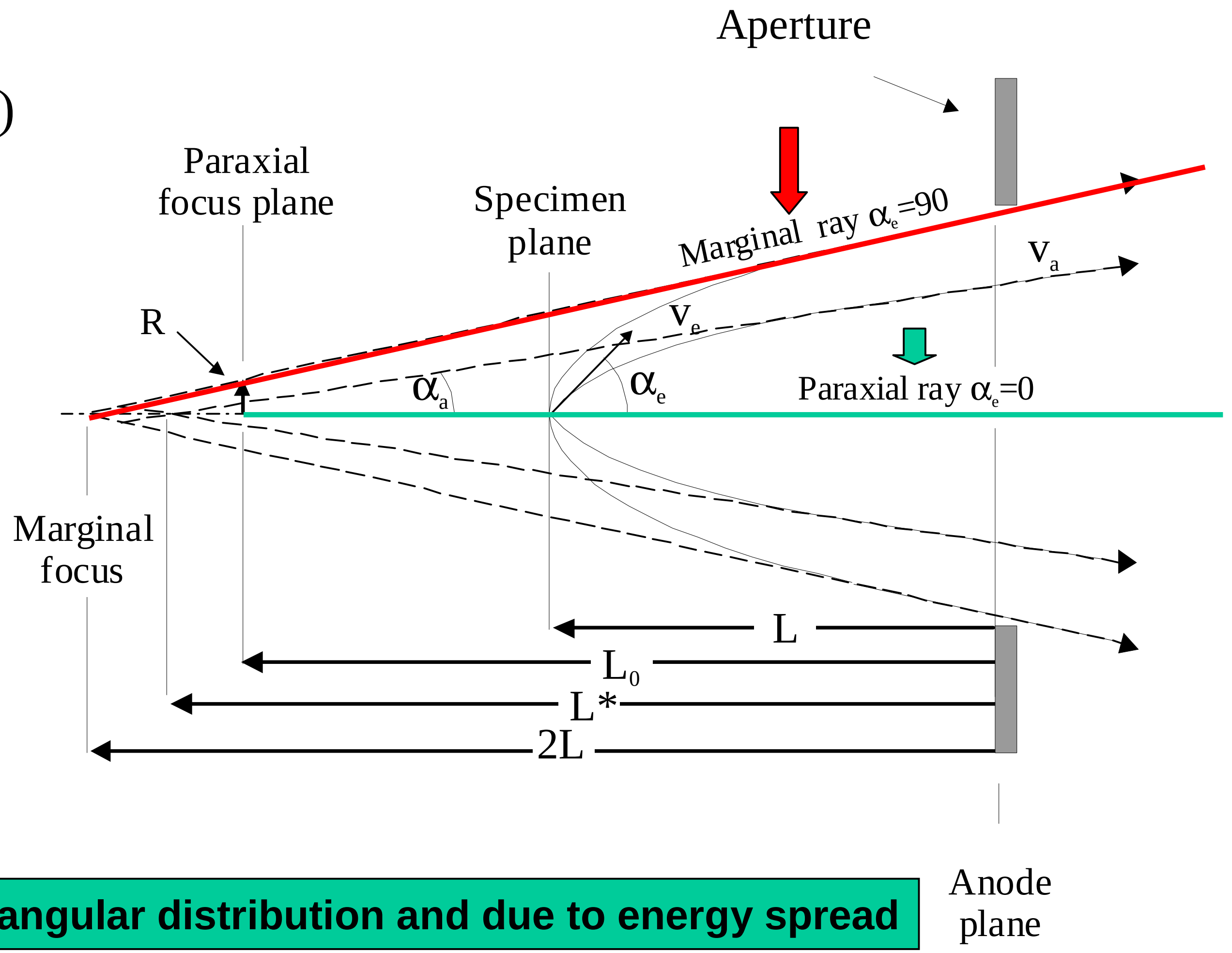
$$L^{*} \approx 2L\left(1-\sqrt{\frac{U_e}{U_a}}\cos\alpha_e\right)$$

α_e = 90°:

$$L^{*} \approx 2L\left(1-\cancel{\sqrt{\frac{U_e}{U_a}}\cos\alpha_e}\right)$$

α_e = 0°:

$$L^{*} \approx 2L\left(1-\sqrt{\frac{U_e}{U_a}}\cancel{\cos\alpha_e}\right)$$

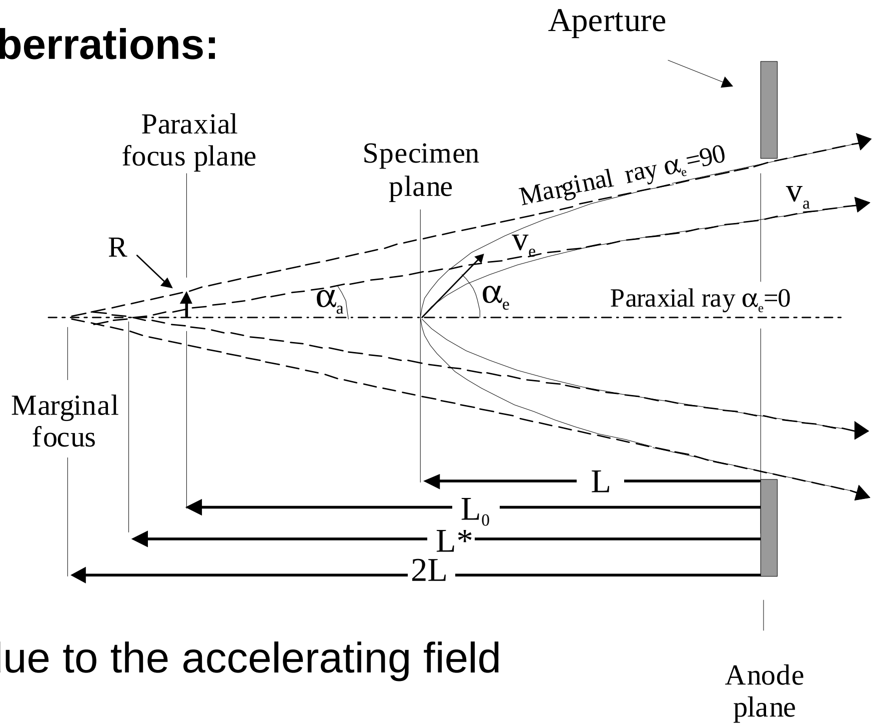


=> image blurred due to angular distribution and due to energy spread

Electron imaging systems: basic PEEM principles

accelerating field itself introduces aberrations:

$$L^* \approx 2L(1 - \sqrt{\frac{U_e}{U_a}} \cos \alpha_e)$$



chromatic and **spherical aberration** due to the accelerating field

angle limiting **aperture reduces** these **aberrations but cuts signal**

furthermore the **aperture introduces diffraction** which limits as well the resolution

=> energy resolution, lateral resolution, transmission all interdependent

Electron imaging systems: PEEM setups

Classification of PEEM systems

A. PEEM **without energy filter**

B. PEEM with **imaging retarding field filter**

C. PEEM with **area selective spectroscopy**

D. PEEM with **full spectromicroscopy capabilities, i.e. imaging analyzer**

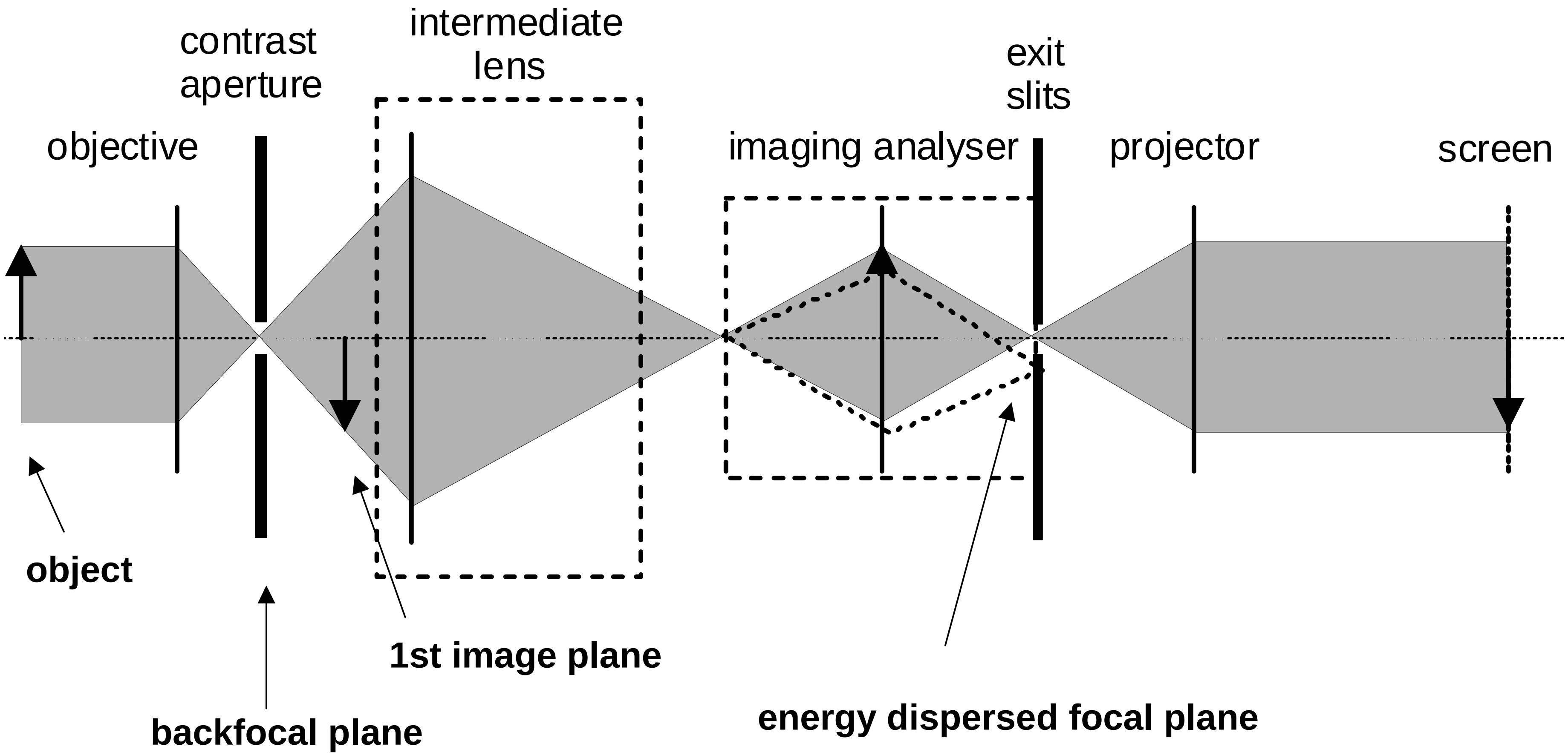
E. PEEM with **magnetic sector field in combination of MEM and LEEM**

F. PEEM with **aberrations correction** of the accelerating field

G. PEEM with **time of flight detector**

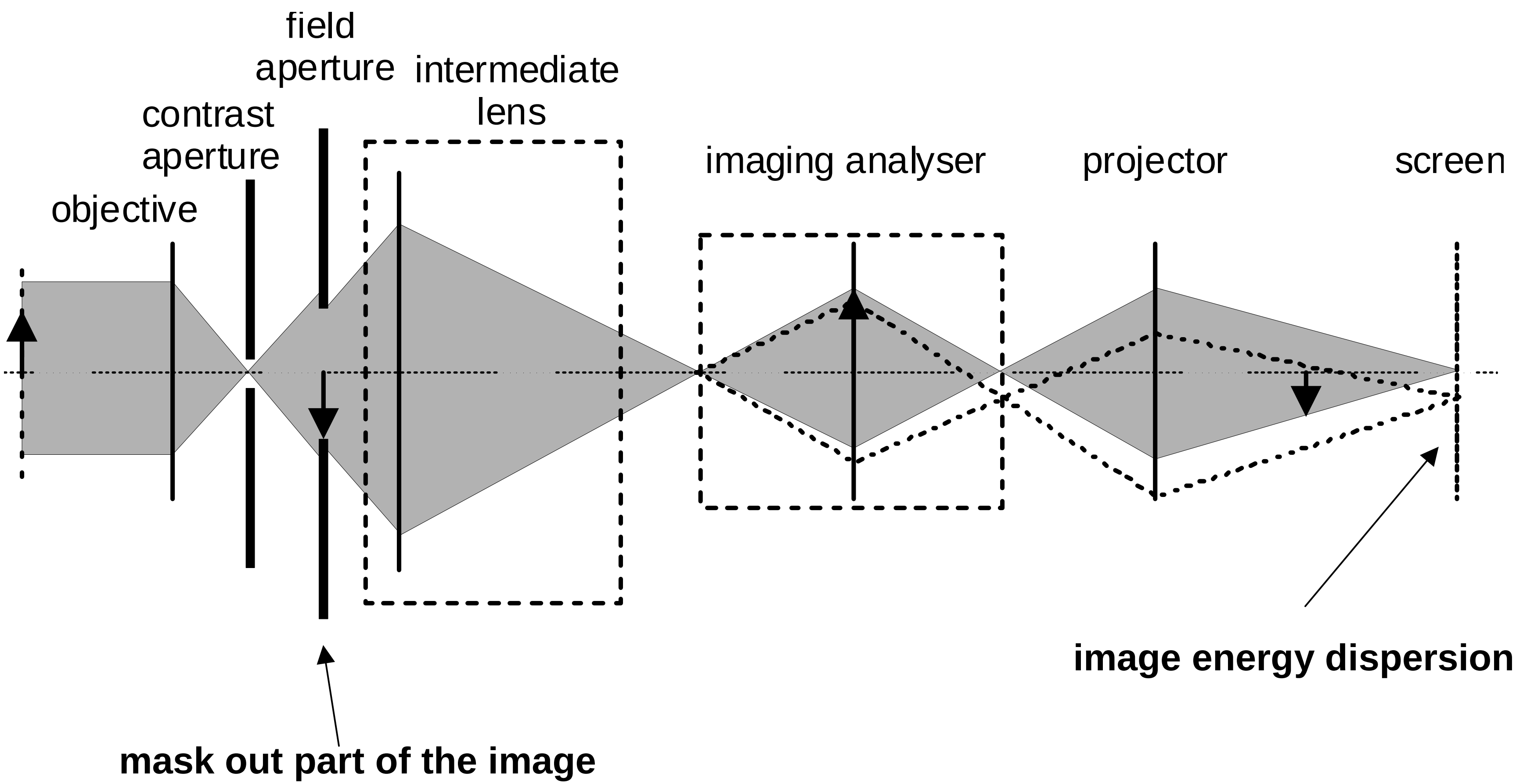
Imaging modes of a PEEM with imaging analyzer

A) energy filtered imaging

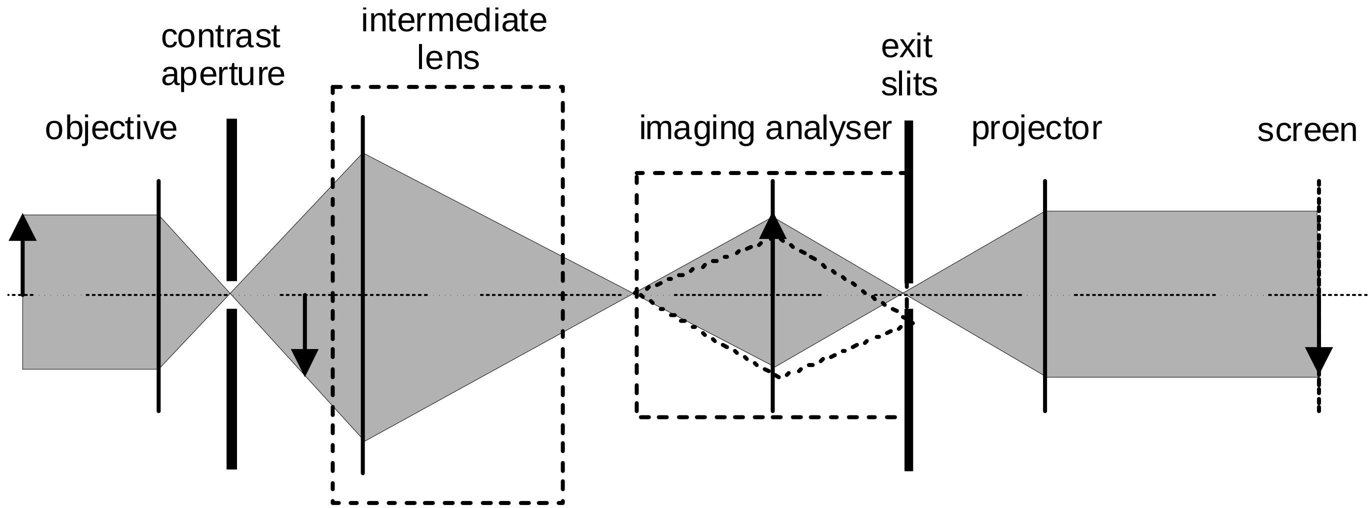


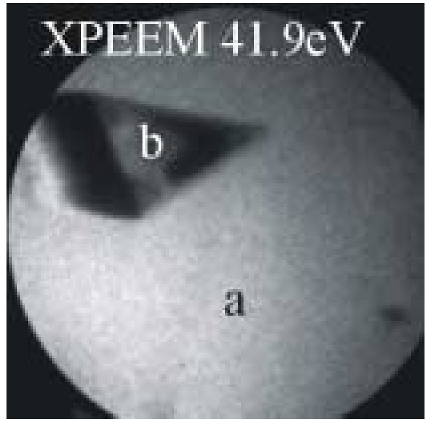
Imaging modes of a PEEM with imaging analyzer

B) area selective spectroscopy

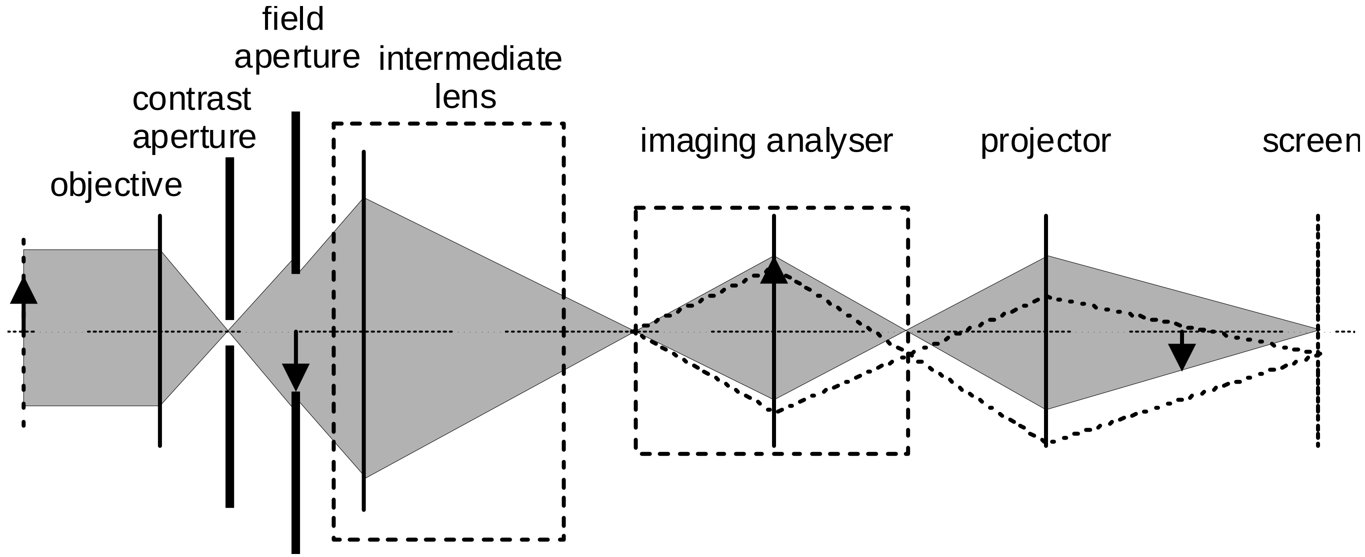


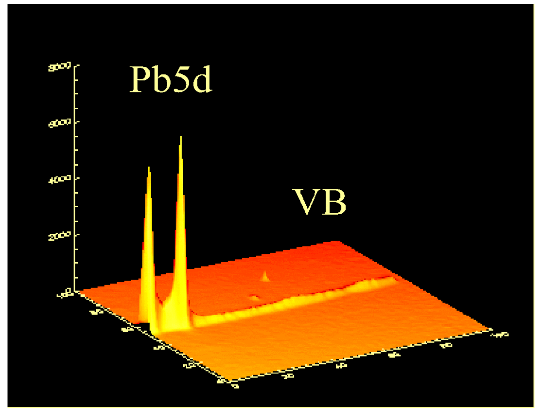
Imaging modes of a PEEM with imaging analyzer





Ag island on Ag / Si(111)

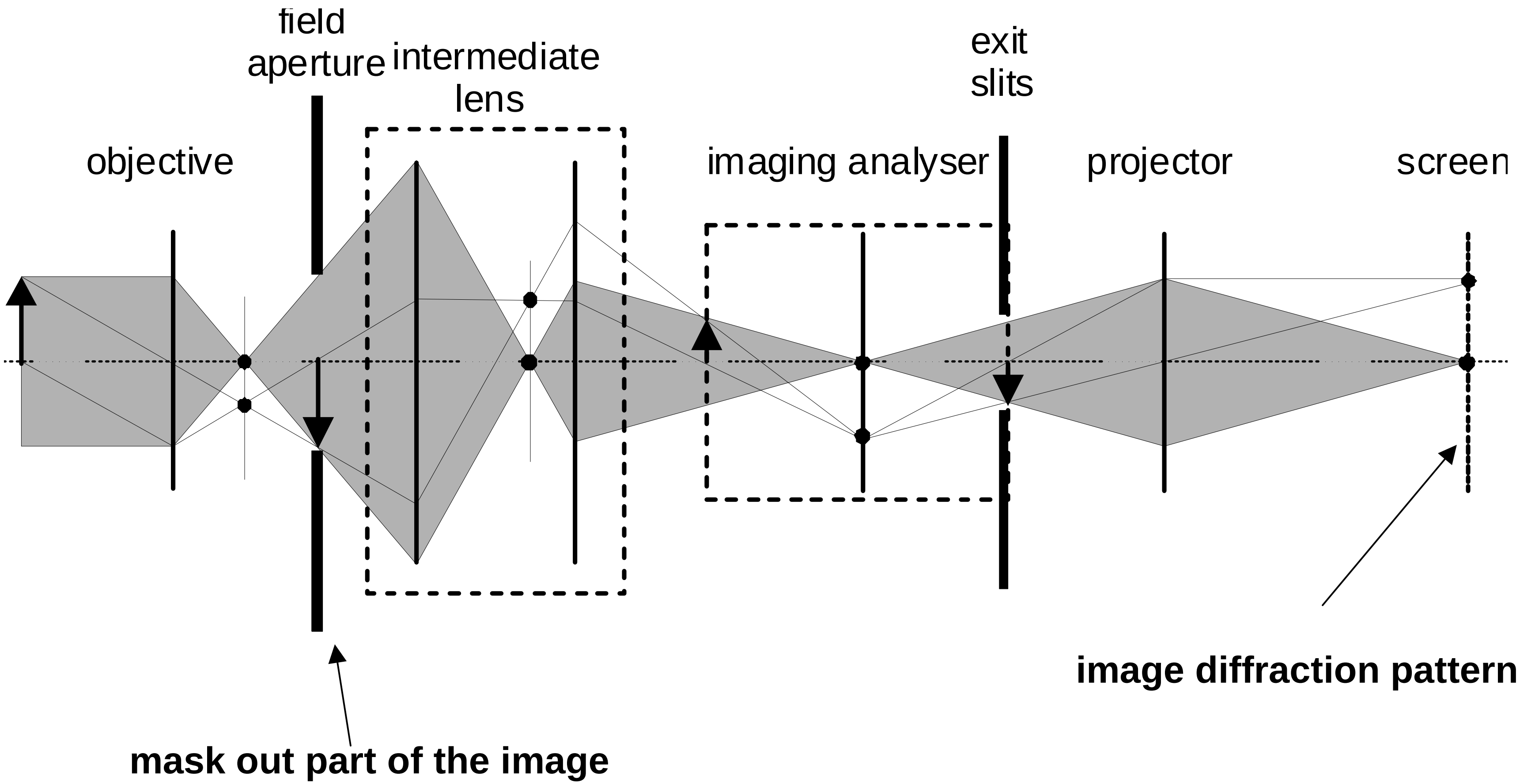




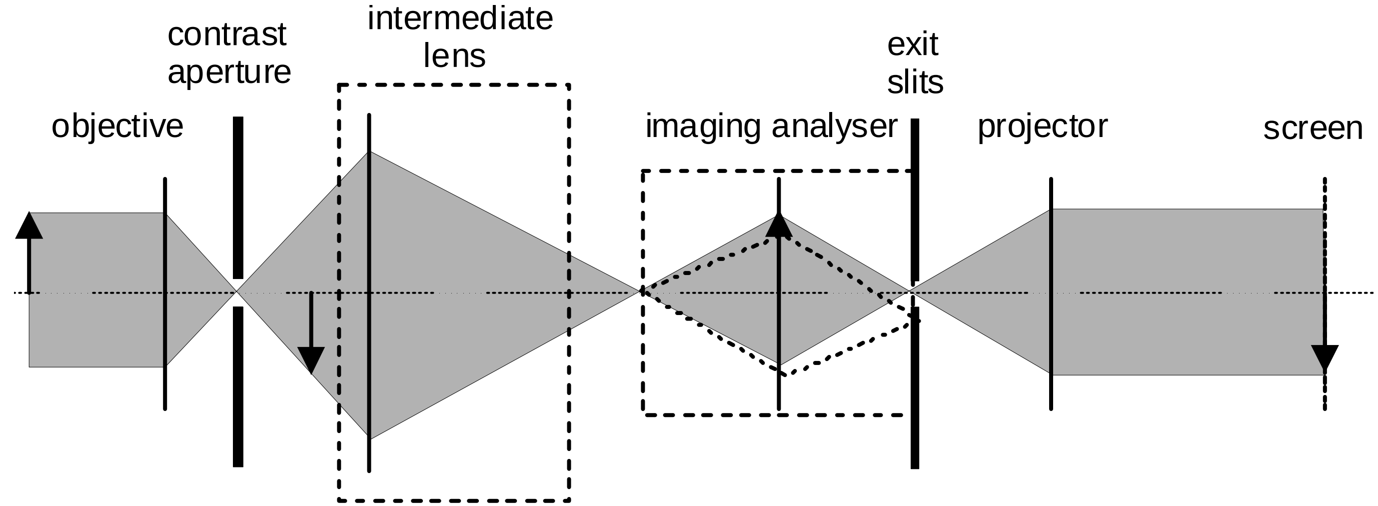
Pb on Ag / Si(111)

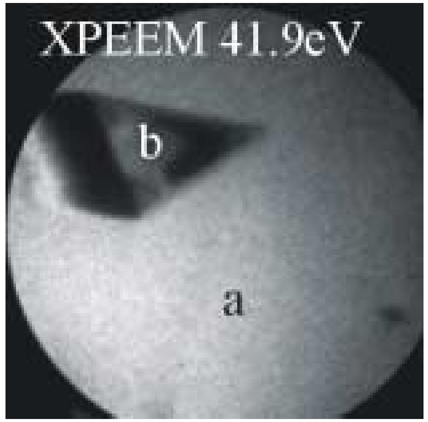
Imaging modes of a PEEM with imaging analyzer

C) imaging the back focal plane (energy filtered): diffraction pattern



Imaging modes of a PEEM with imaging analyzer





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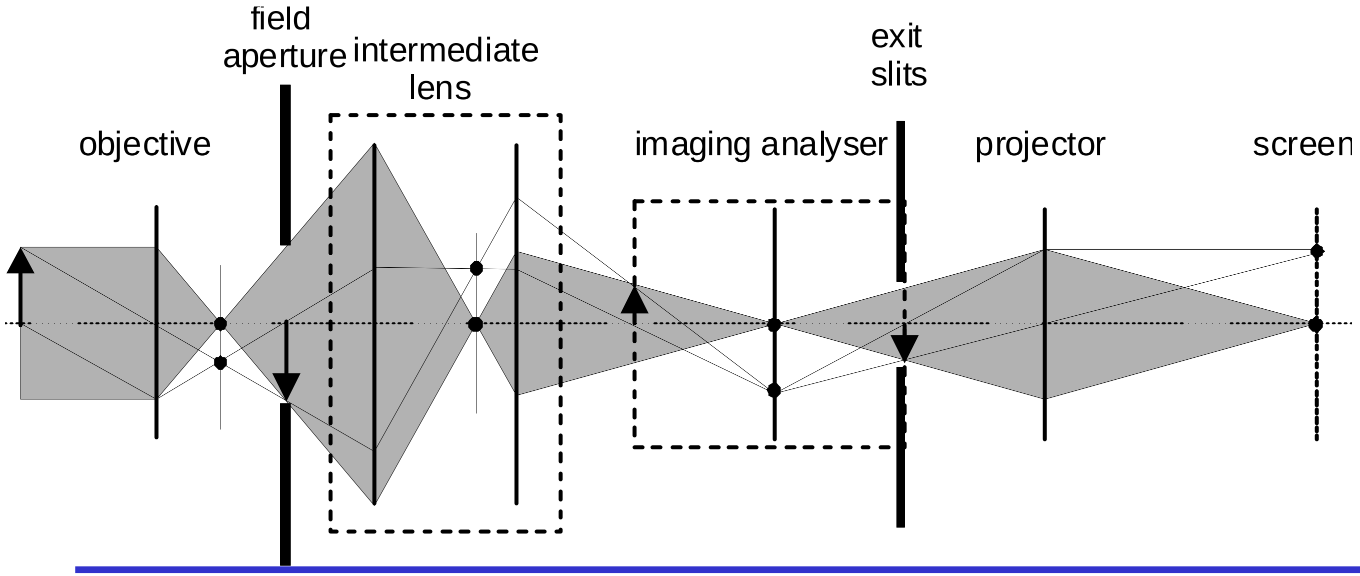
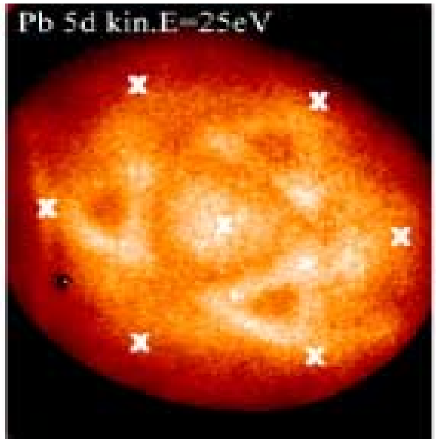
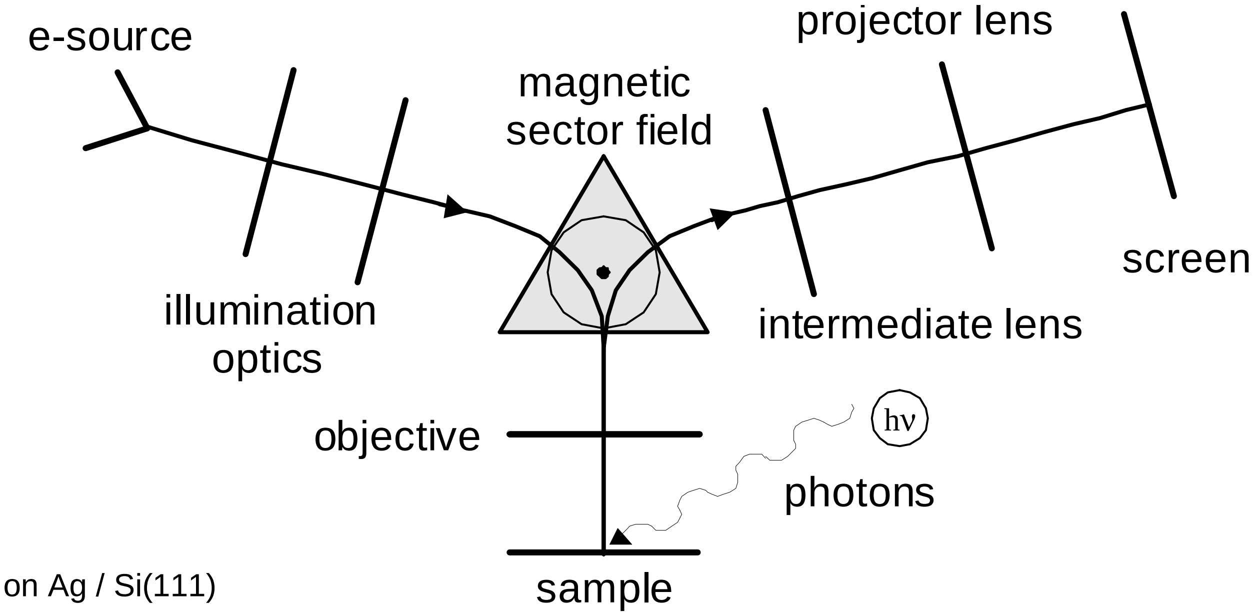




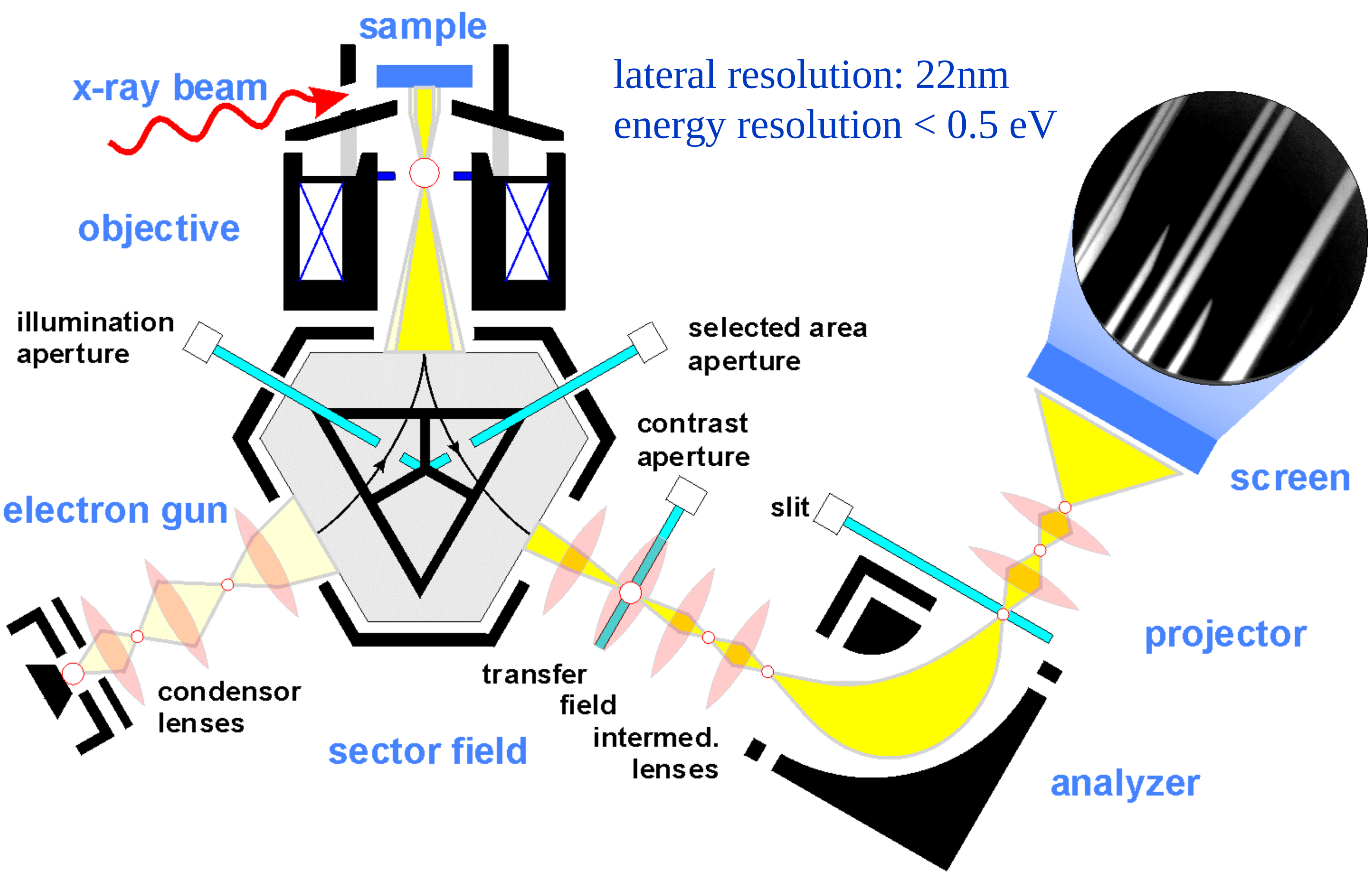
Pb on Ag / Si(111)

PEEM with magnetic sector field to couple in an electron beam



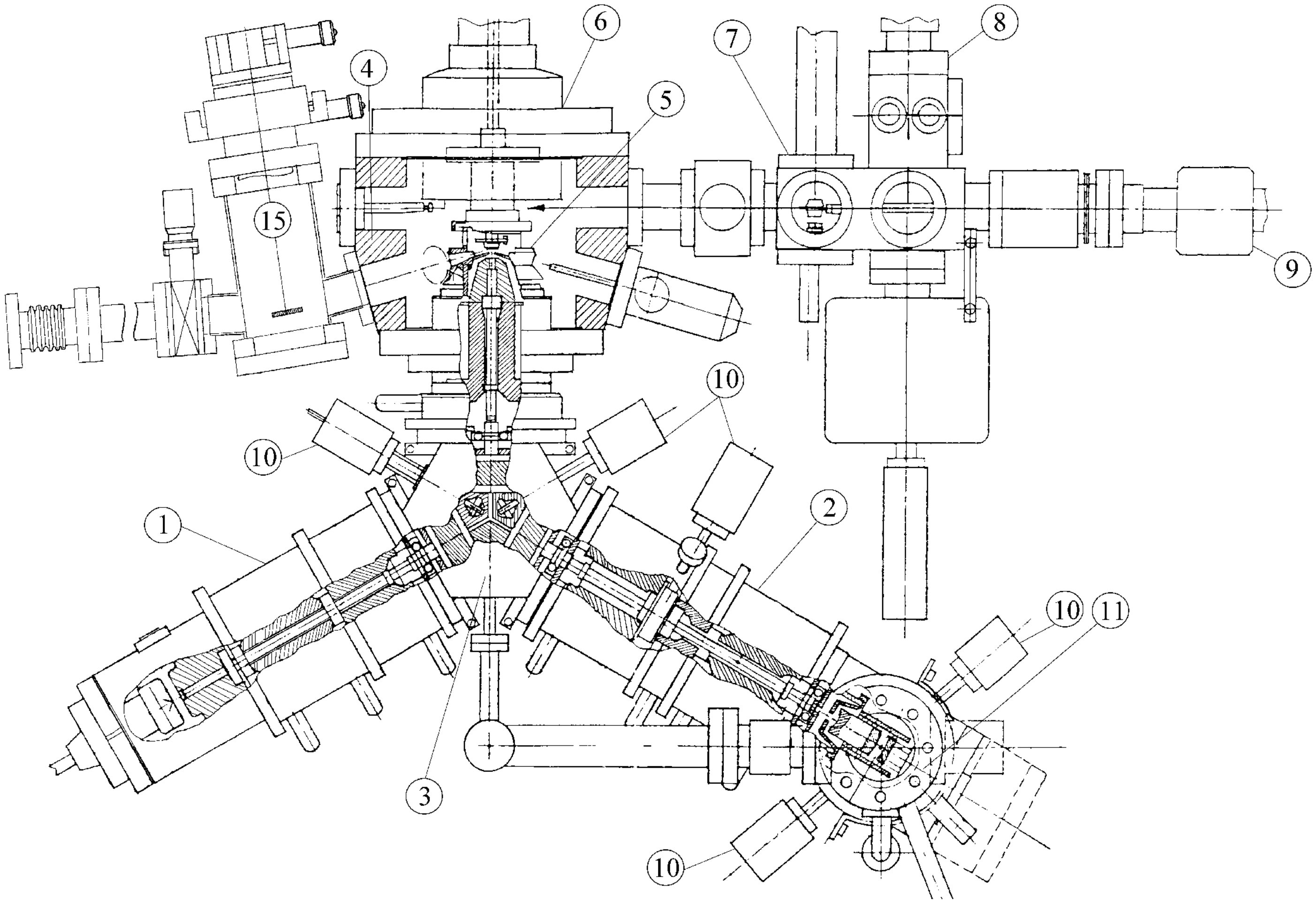
Ag island on Ag / Si(111)

PEEM with magnetic sector field to couple in an electron beam



Th. Schmidt, S. Heun, J. Slezak, J. Díaz, K. C. Prince, G. Lilienkamp, E. Bauer: Surf. Rev. Lett. 5 (1998) 1287.

PEEM with magnetic sector field to couple in an electron beam



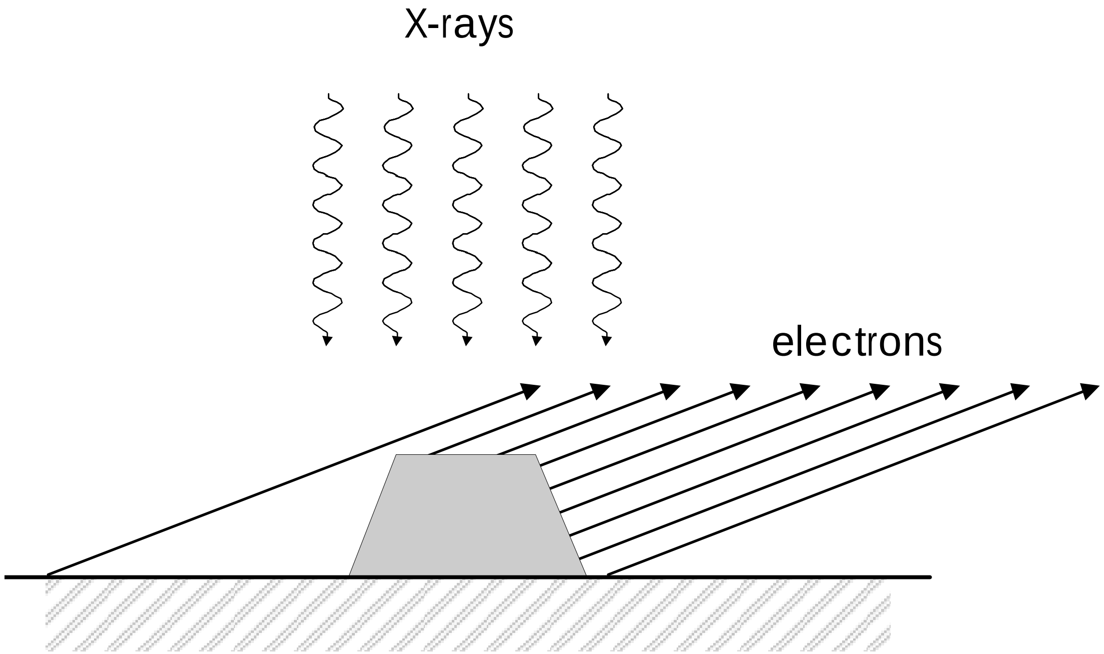
Th. Schmidt, S. Heun, J. Slezak, J. Díaz, K. C. Prince, G. Lilienkamp, E. Bauer: Surf. Rev. Lett. 5 (1998) 1287.

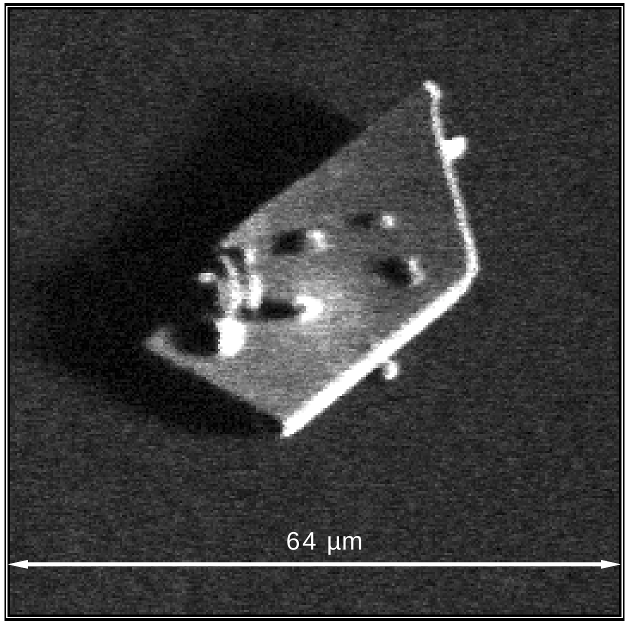
Comparison: SPEM - PEEM

SPEM	PEEM
Lateral resolution (focusing optics) and energy resolution (x-ray monochromaticity and analyzer) **not correlated**	Lateral resolution and energy resolution **correlated** because of instrument transmission.
Lateral resolution: ~ 100 nm at present, 40-50 nm feasible. **Acquisition rate**: ‘slow’ (min) The same in single and multichannel imaging	**Lateral resolution**: 10-20 nm at present, 2 nm feasible **Acquisition rate**: ‘fast’ for one image (s) "slow" for image stack
µ-spectroscopy: fast, with 100 nm resolution energy resolution 10 meV - 500 meV depending on application	**Area selected spectroscopy** fast with ~ 1 µm resolution energy resolution ~ 400 meV reached
other detectors possible	Combination with electron source possible

Applications: handling topographic contrast

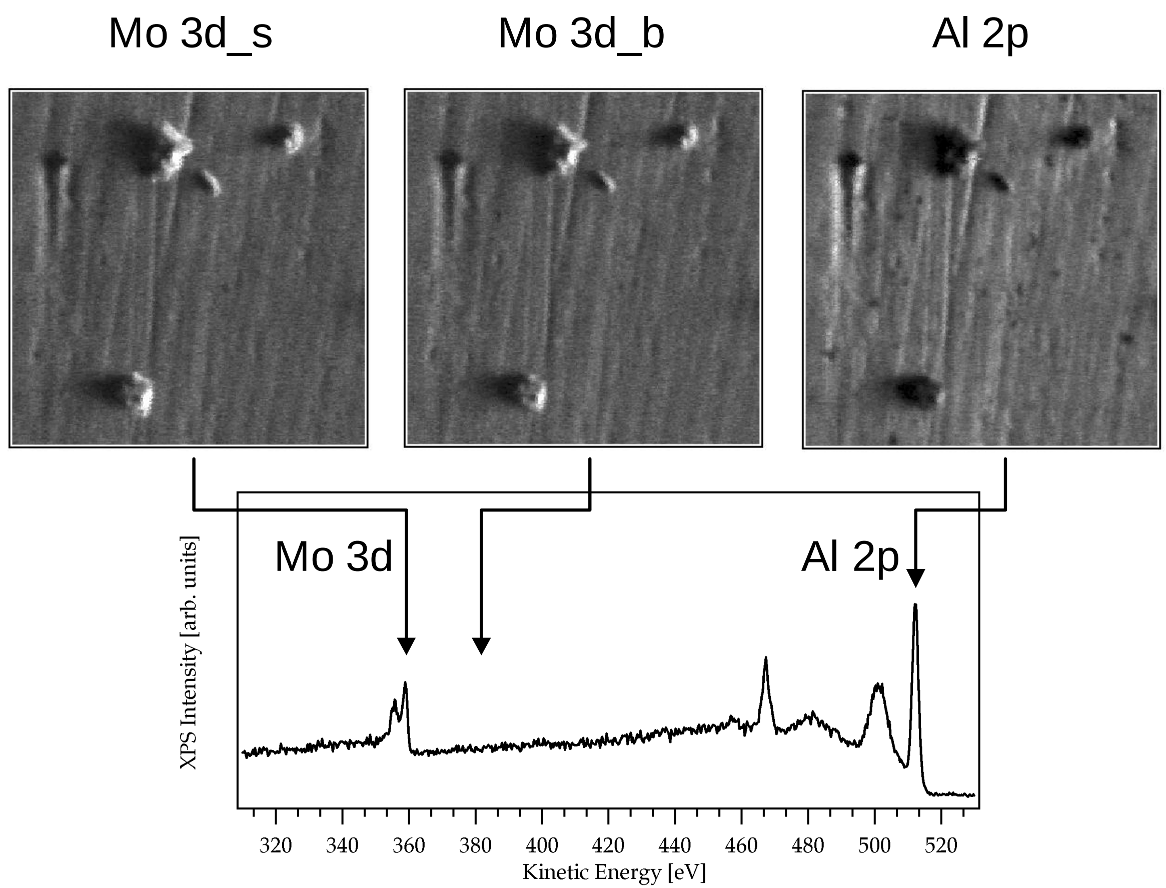
Topographic contrast in the SPEM at ELETTRA

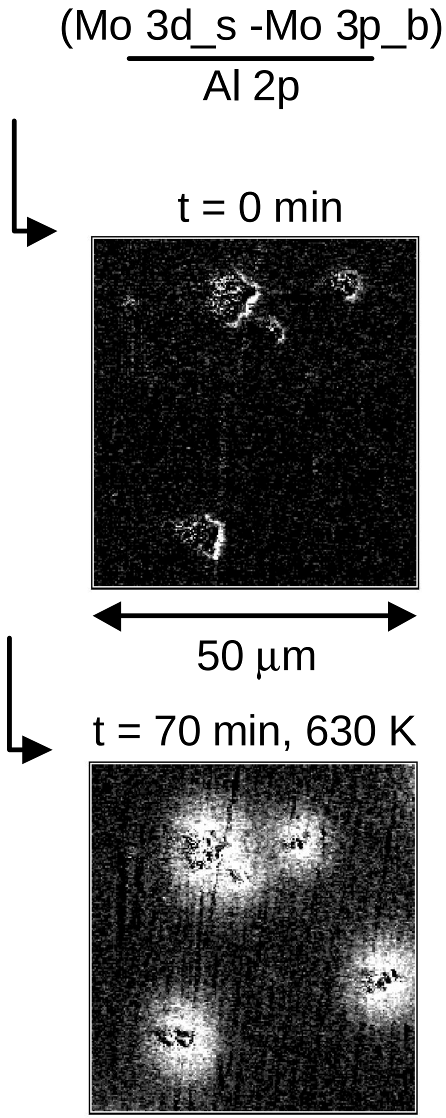




MoO_3 crystal on Al_2O_3 support

Applications XPS: removing topography- chemical map

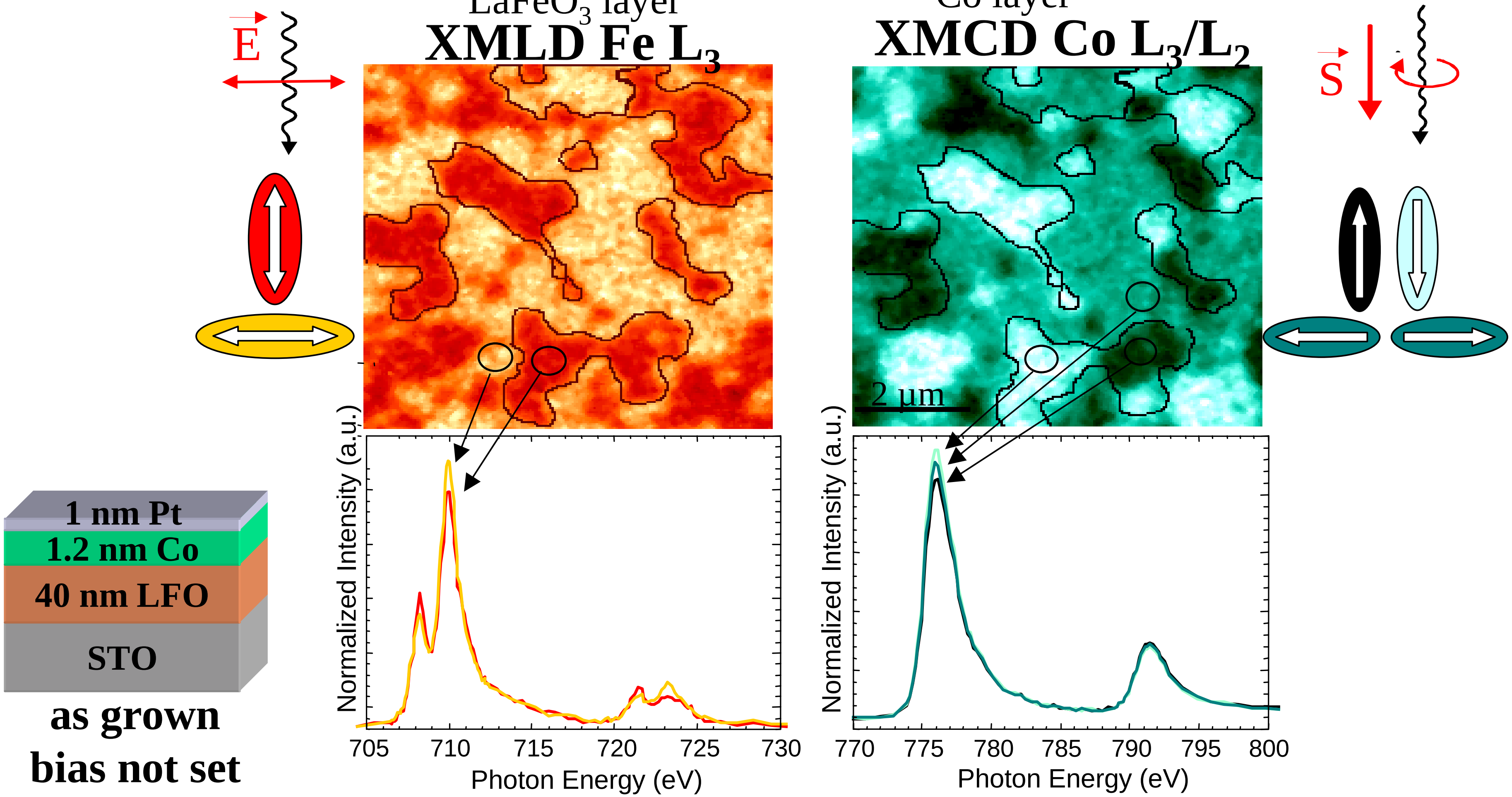




release of material from MoO_3 crystals and wetting of Al_2O_3 support imaged on Mo 3d

S. Günther et al., J. Chem. Phys. 112(12) 2000, 5440.

Applications XAS- XPEEM: imaging ferromagnet - antiferromagnet interface



1:1 correlation of domain structure

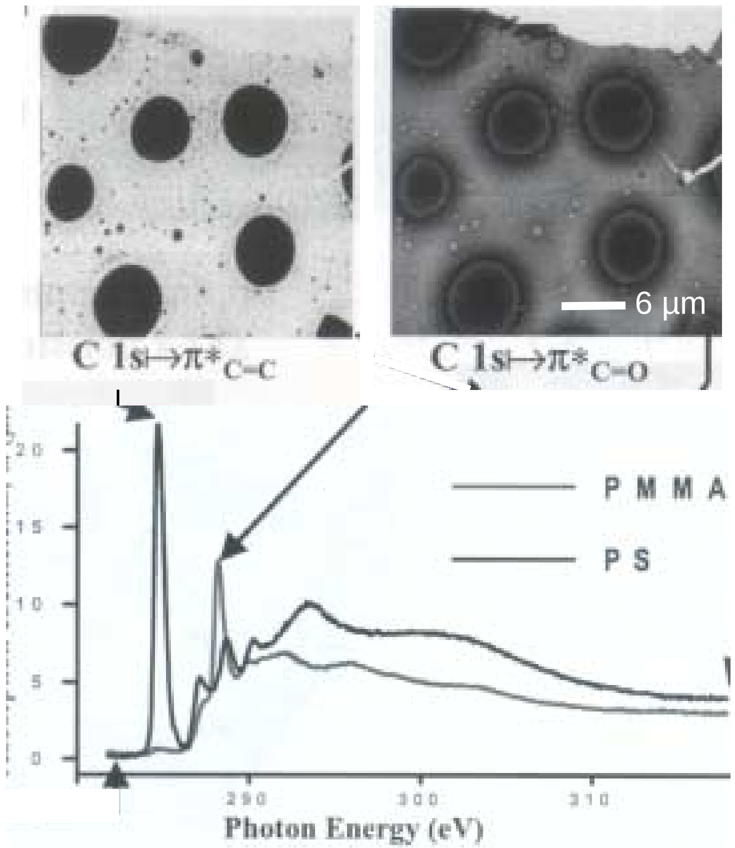
F. Nolting et al, Nature, **405**, 767 (2000)

Applications XAS- STXM: imaging polymer blends

XAS-XANES

Contrast due to:

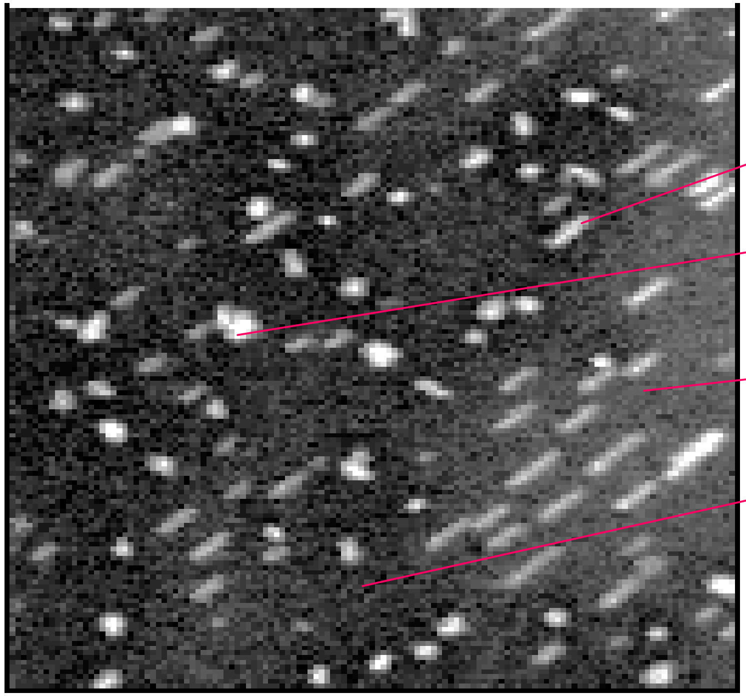
C1s transitions into the C=C and C=O π* orbital

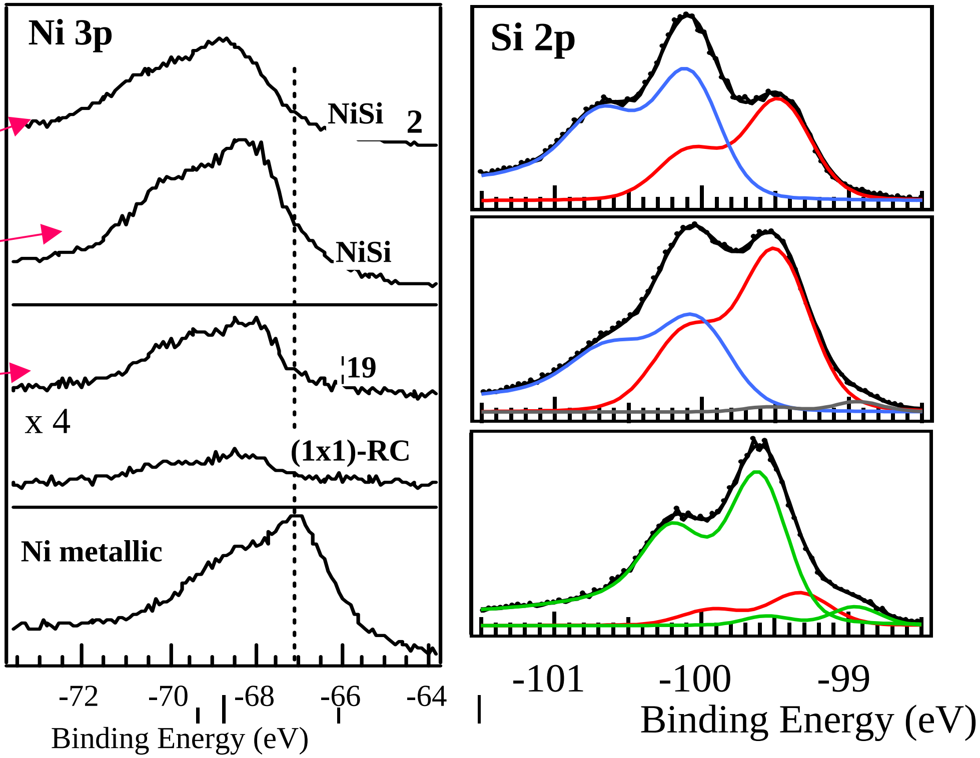


e.g. H. Ade, X-ray microscopy 99, AIP507, p197

Applications XPS-SPEM: Ni-Si(111) interface

imaging coexisting phases: NiSi, $NiSi_2$ islands and 2 dim √19x√19 and 1x1 ring-cluster phase



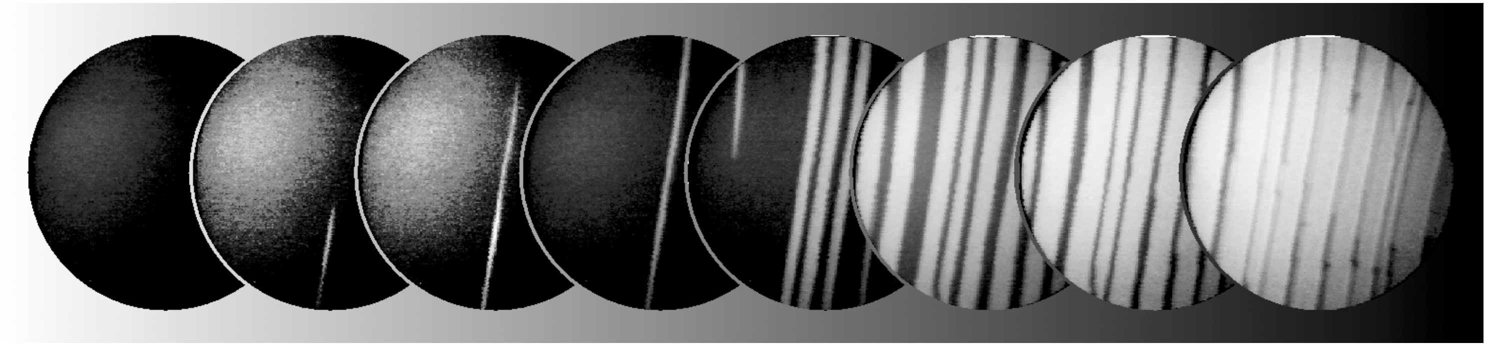


L. Gregoratti, et al, PRB 57 (98) L2134; PRB 59 (99) 2018.

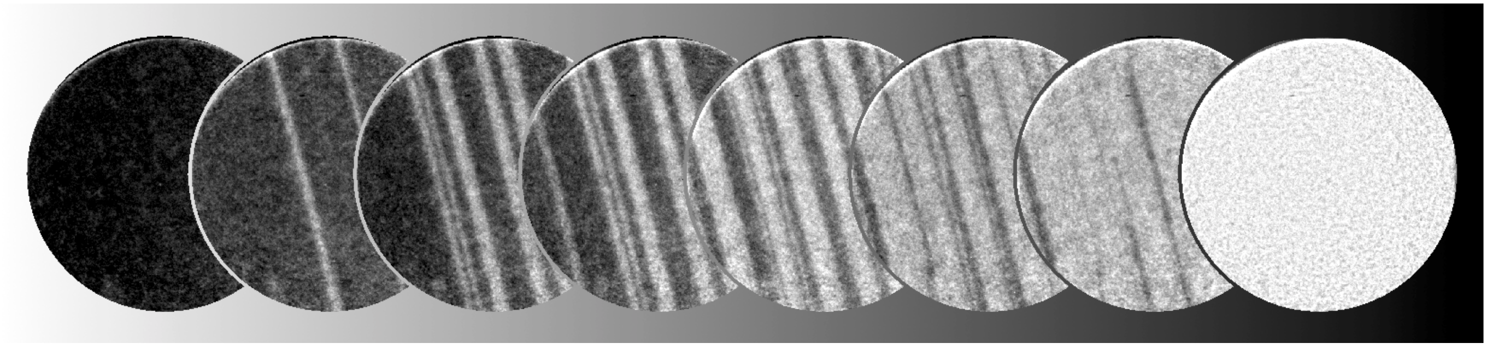
Applications XPEEM-LEEM: imaging giant vicinal facetting

facetting of a miscut SI(100) surface upon Au evaporation

LEEM



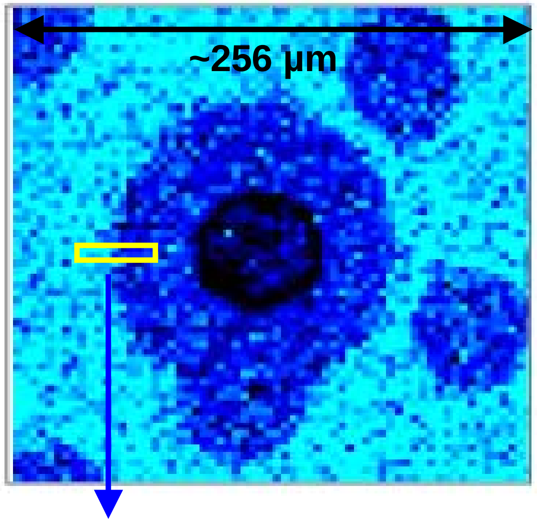
XPEEM Au 4f

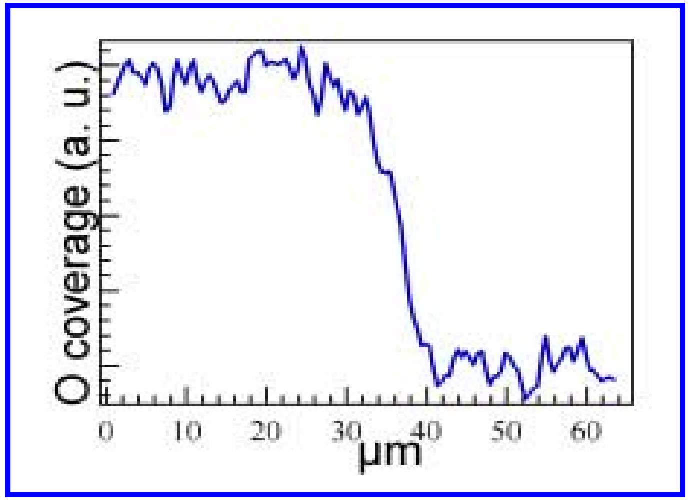


e.g. F.-J. Meyer zu Heringsdorf et al., PRL 86(22) 2001, 5088.

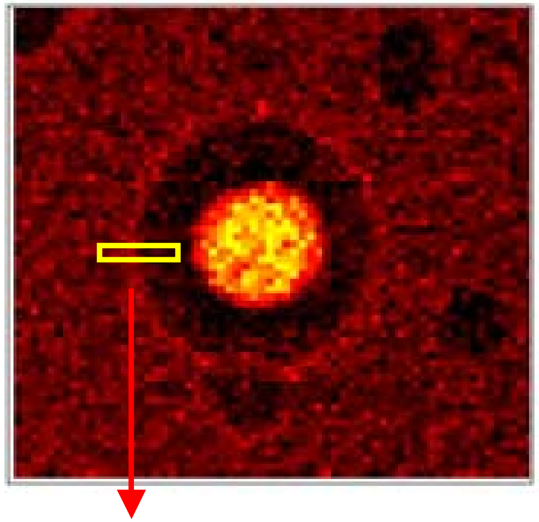
Applications XPS-SPEM: imaging chemical reactions

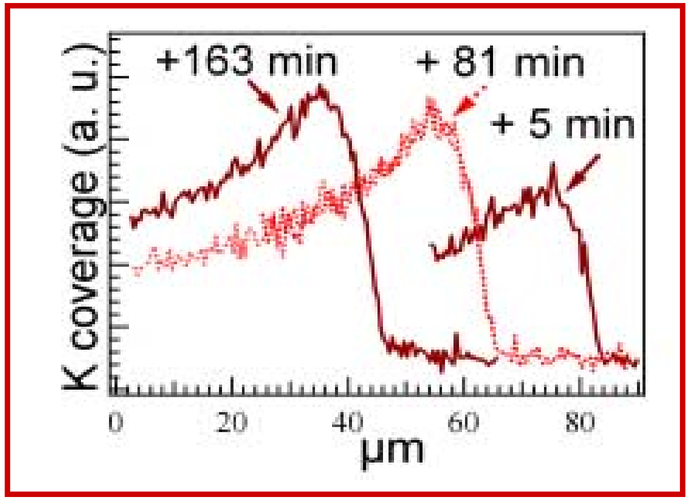
O 1s





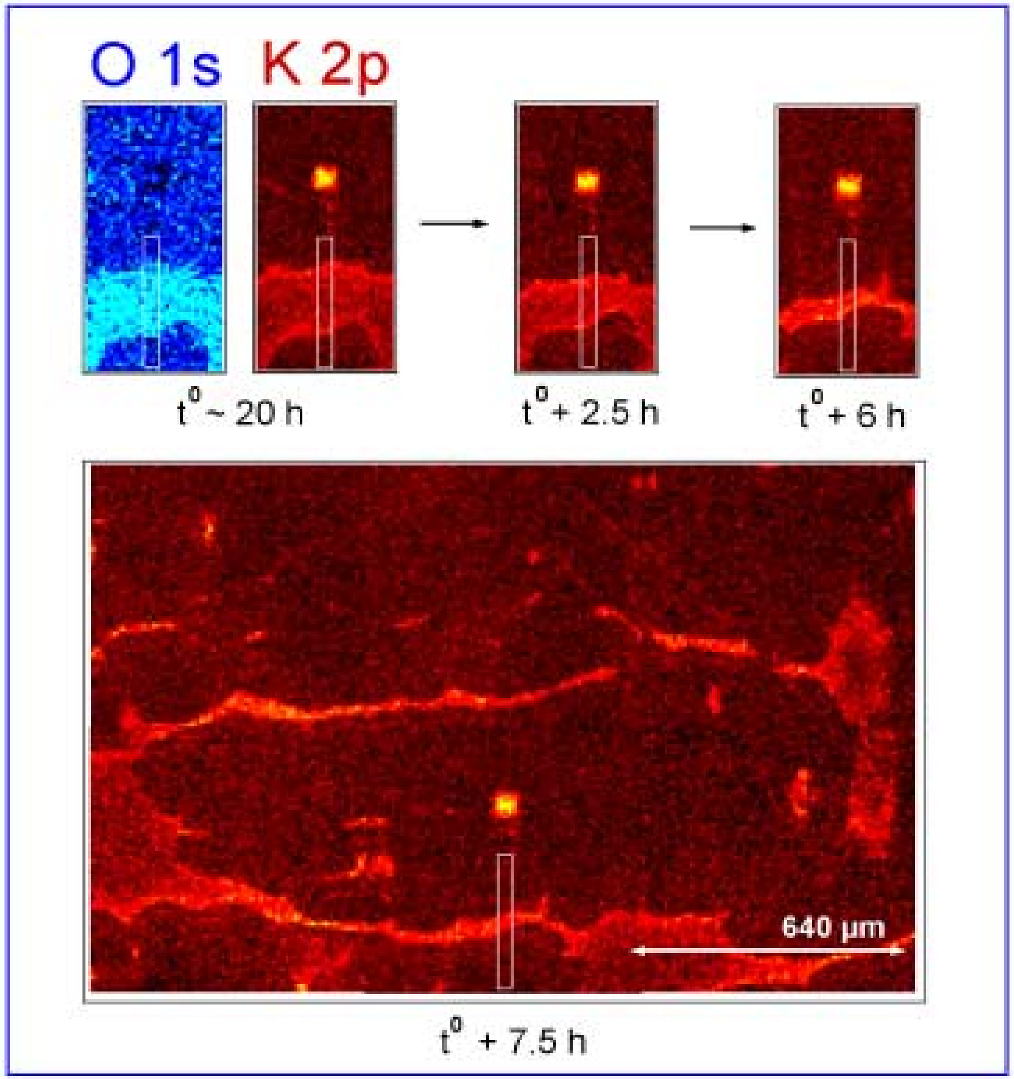
K 2p

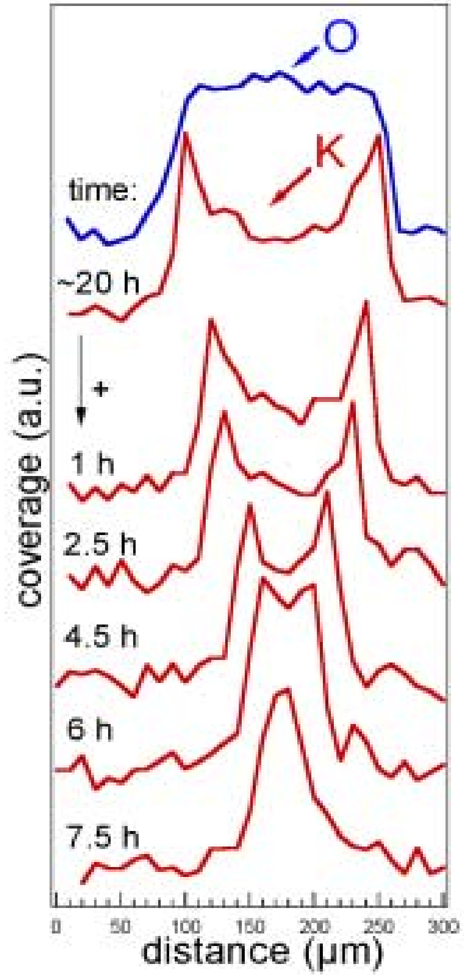




H. Marbach, to be published, S. Günther et al.J. Electron Spectrosc. Relat. Phenom 114-116 (2001) 989.

Applications XPS-SPEM: imaging chemical reactions





H. Marbach, to be published, S. Günther et al.J. Electron Spectrosc. Relat. Phenom 114-116 (2001) 989.

Conclusions: Microspectroscopy - Spectromicroscopy

adding lateral resolution to X-ray spectroscopy helps to characterize samples in, e.g.:

biology

materials science

semiconductor surfaces

polymer science

surface chemistry

magnetism

it combines

high spatial resolution with **full chemical characterization**

Acknoledgement:

Many thanks to:

M.Kiskinova, B. Kaulich, L. Gregoratti, A. Barinov, F. Nolting, Th. Schmidt, S. Heun, H. Ade, H. Marbach, R. Imbihl