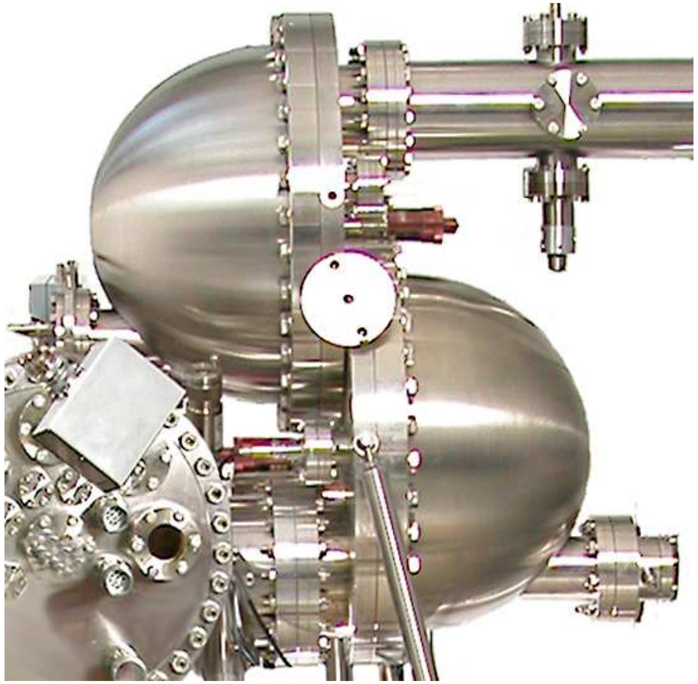


Energy filtered PEEM

Konrad Winkler

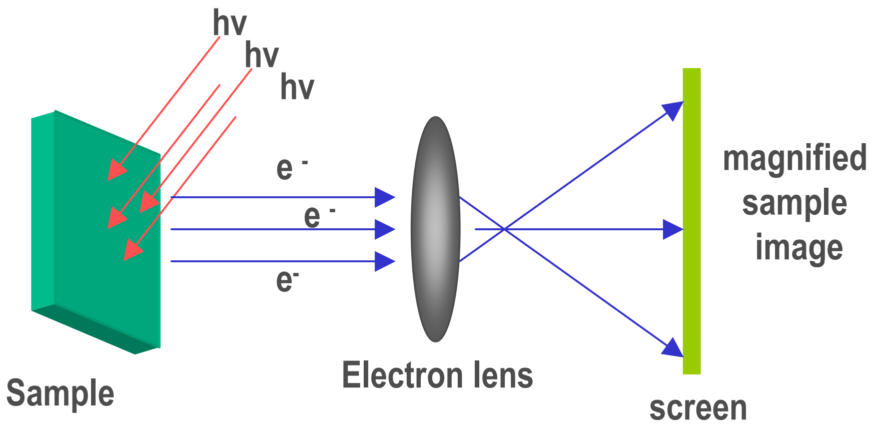
Omicron NanoTechnology GmbH

Germany

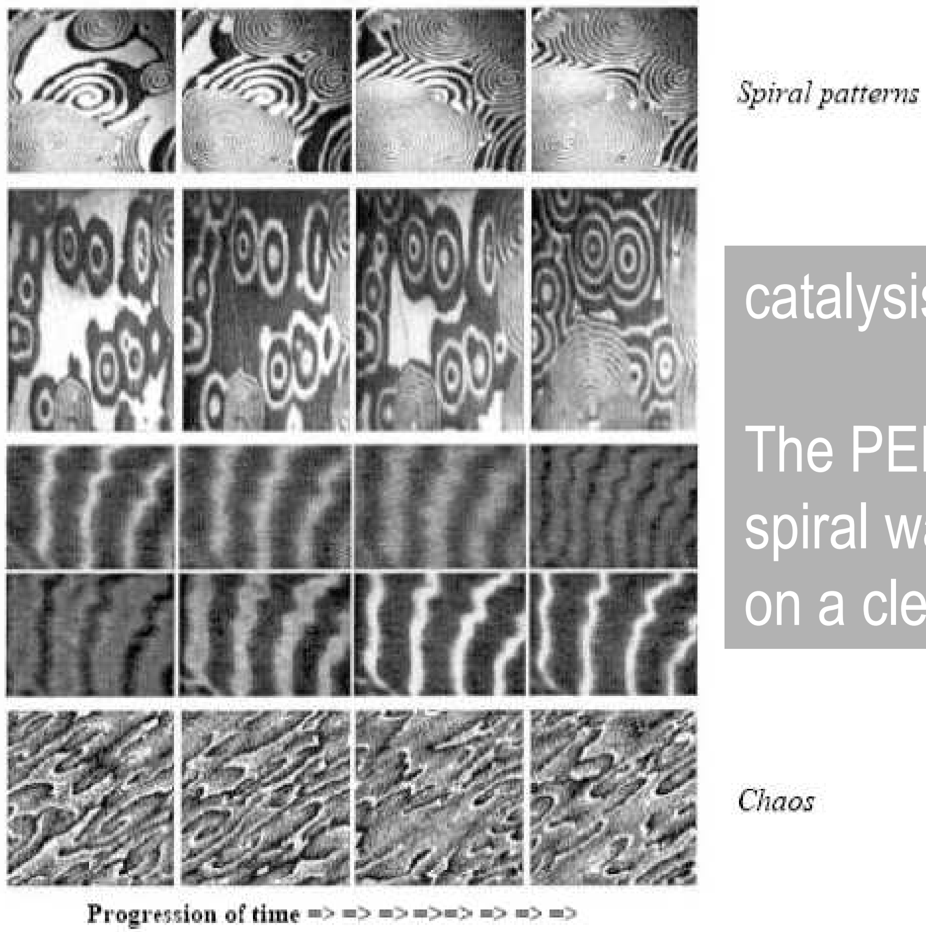
The Principle of PEEM

The Photoelectron Emission Microscope

- surface sensitive to the top most layer
- non destructive
- imaging lens system allows for massive parallel detection



A brief History



Platinum surface imaged by photoemission electron microscopy. Dark areas are rich in CO while light areas are O_2 rich. Note the oscillatory behavior of the domain extensions. Time scale ~10s, length scale ~0.1mm (The Surface Imaging Group, Dept. of Physical Chemistry, Fritz-Haber-Institute of the Max-Planck-Society, www.fhi-berlin.mpg.de/surfimag)

catalysis research:

The PEEM images show the formation of spiral wave paterns in catalytic CO oxidation on a clean Pt(110) surface

A brief History

- 1933 invented by Brüche
- 1971 Metioskope KE3 from Balzers
- 1970 -1990s PEEM has been utilised by several groups

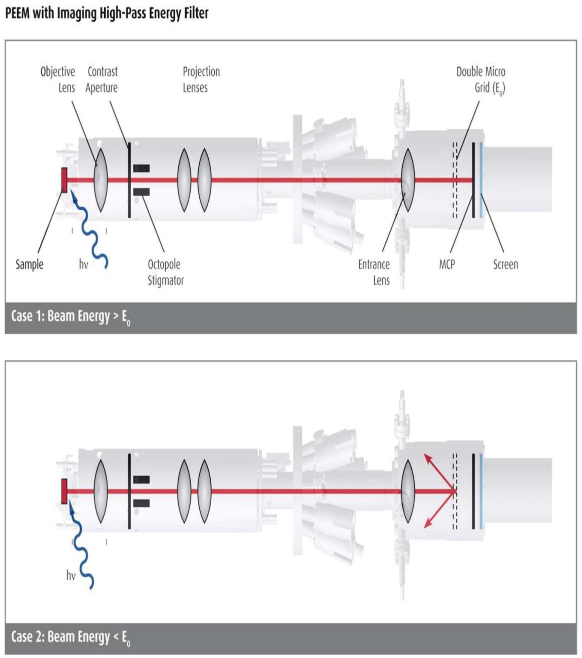
- Prominent is example Ertl: Nobel Prize in chemistry 2007

- around 1988: Tonner et al.: first Energy filtered PEEM
- followed by Ernst Bauer et al. in the early 90´s

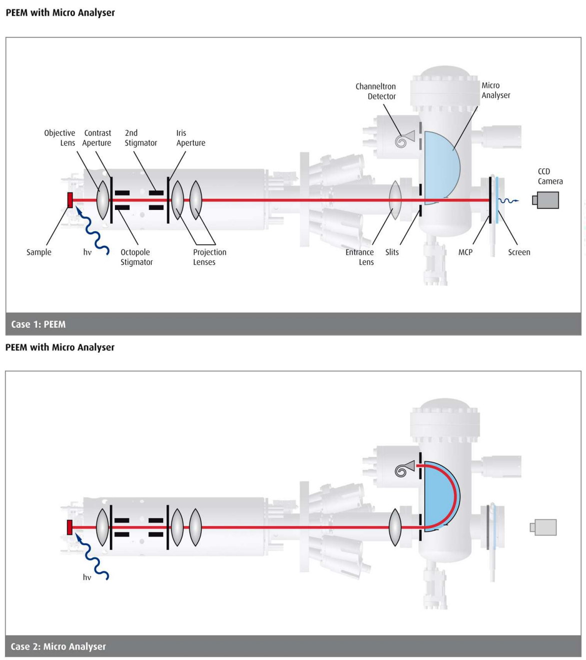
•Late 90´s several Energy filtered PEEM concepts have been commercialised

Energy filtered PEEM

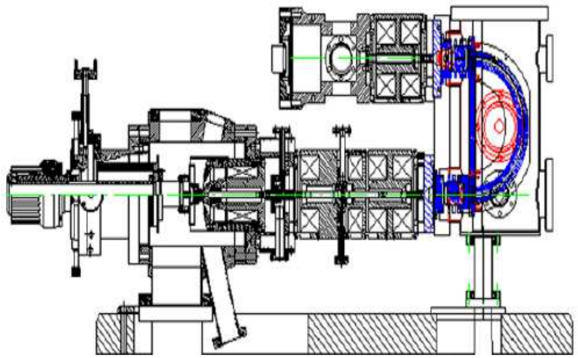
- High Pass imaging energy filter,
- Micro Spot electron spectroscopy,
- Band Pass imaging analyser



Staib
Focus



Focus



Elmitec

Energy Filtered Imaging

Omicron NanoTechnology

Such energy filters demand for very high photon flux densities when working with higher kinetic electron energies > 10eV

Lab Experiments: Ekin < 10eV

- Local work function analysis / Field emission
- Laser experiments / Plasmon
- Structure analysis / Growth processes

Synchrotrons:

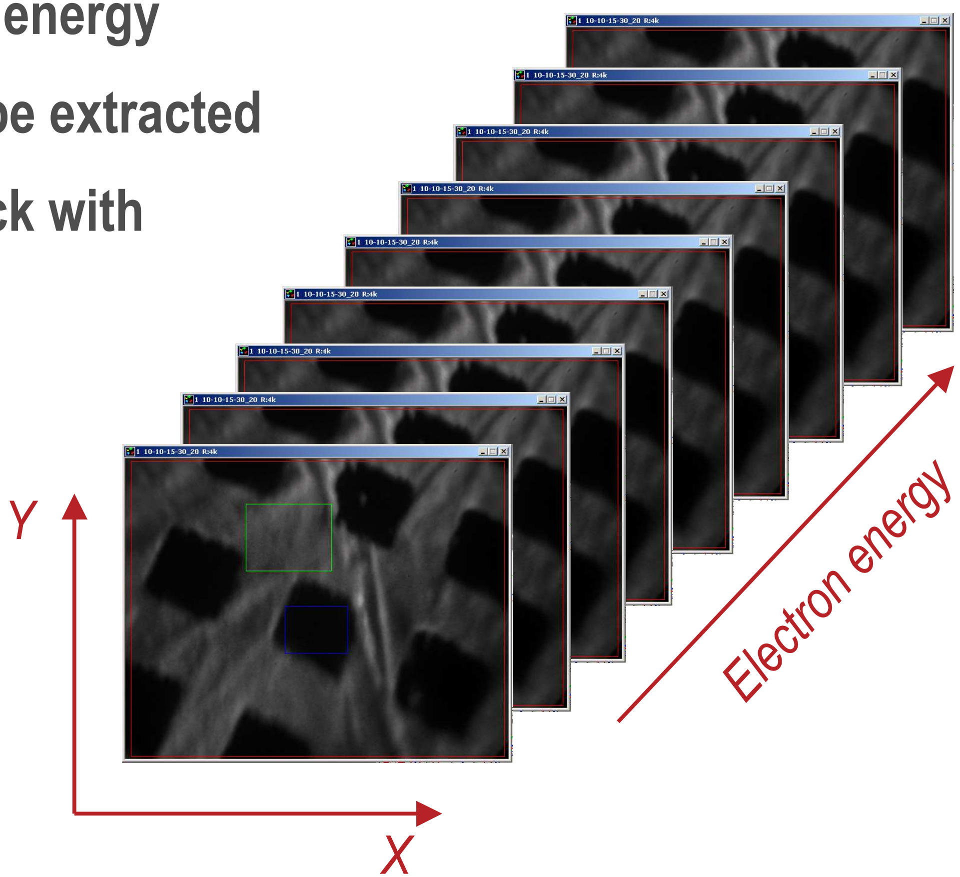
XAS experiments and XMCD using pol. Light	Ekin << 50eV
Only limited nr. of XPS experiments	Ekin > 50eV

Energy Filtered Imaging

Data Acquisition:

Multi-Dimensional Data Sets (Intensity I(X, Y, E_{kin}))

- The Energy filtered PEEM image is a local area map at single energy
- Local spectra can be extracted from image an stack with images recorded at different energies



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Data Analysis:

Sample: Ag evaporated on Ta, hv =700 eV

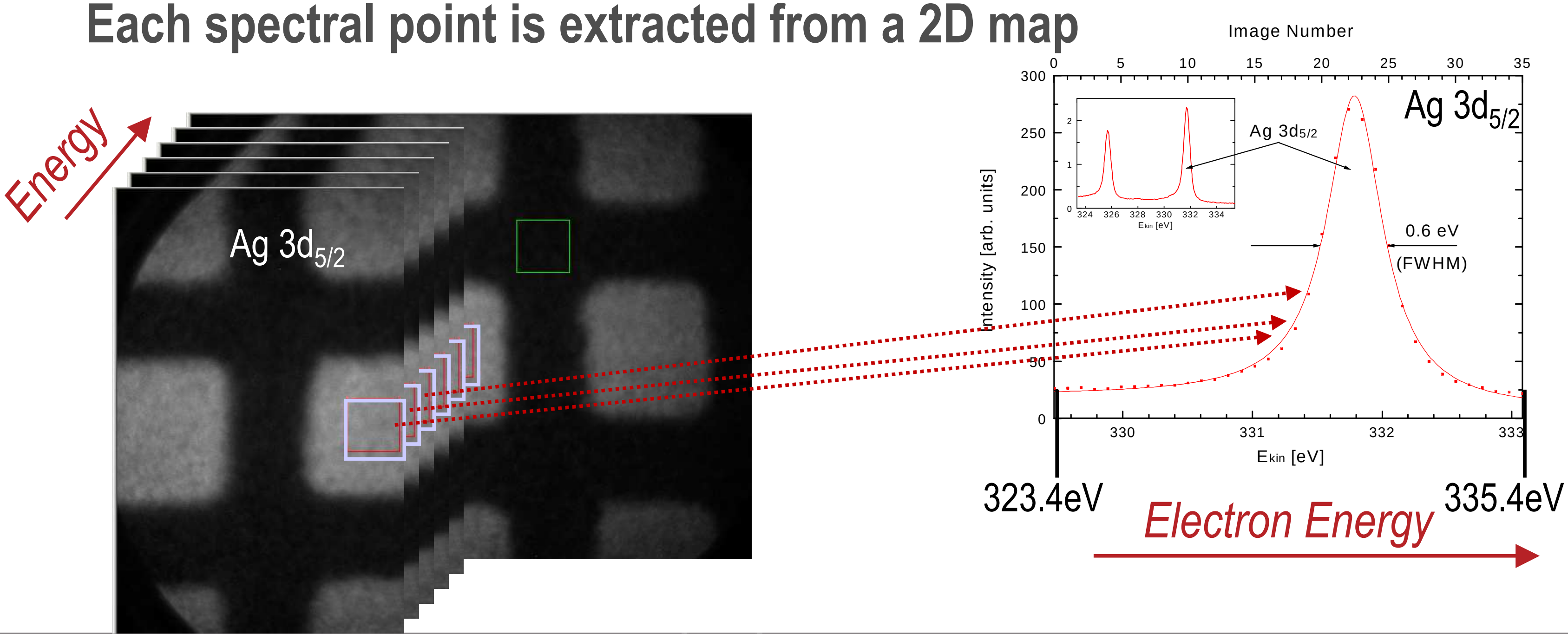
- Image stack:

  36 images across Ag 3d, field of view of 35 µm

- Spectrum

  "Grey level" averaging within a 3 x 3 µm area

  Each spectral point is extracted from a 2D map



Aberration correctors in Photoemission Microscopy

Recent PEEM development: two main directions

A) The mirror corrector

+ ultimate PEEM / LEEM resolution in the sub 10nm range
+ increased transmission
- increased complexity of the instruments
- limits of the energy filter remain

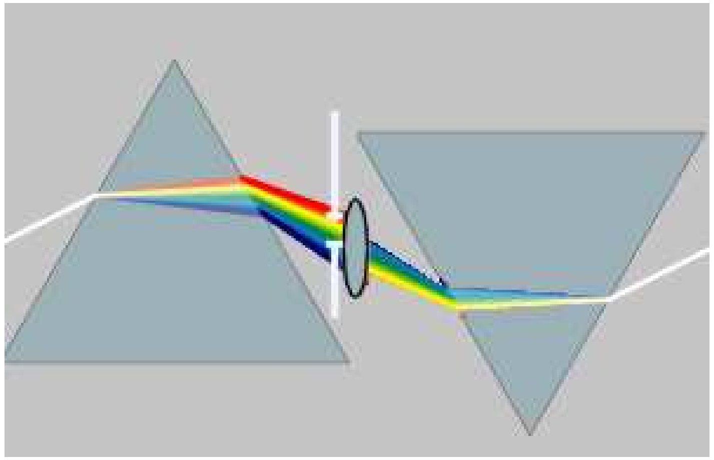
Bessy: SMART	operational
ALS PEEM III	ongoing commissioning
Commercial solutions	soon available

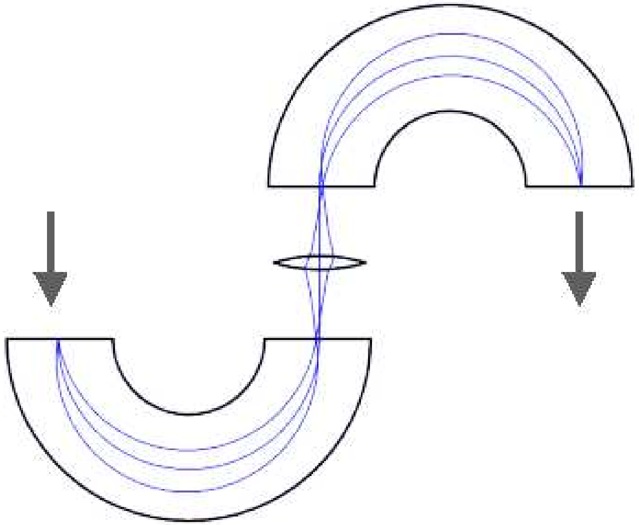
Aberration correctors in Photoemission Microscopy

B) The aberration corrected hemispherical energy filter

Aberrations introduced by the first analyser are compensated by second analyser

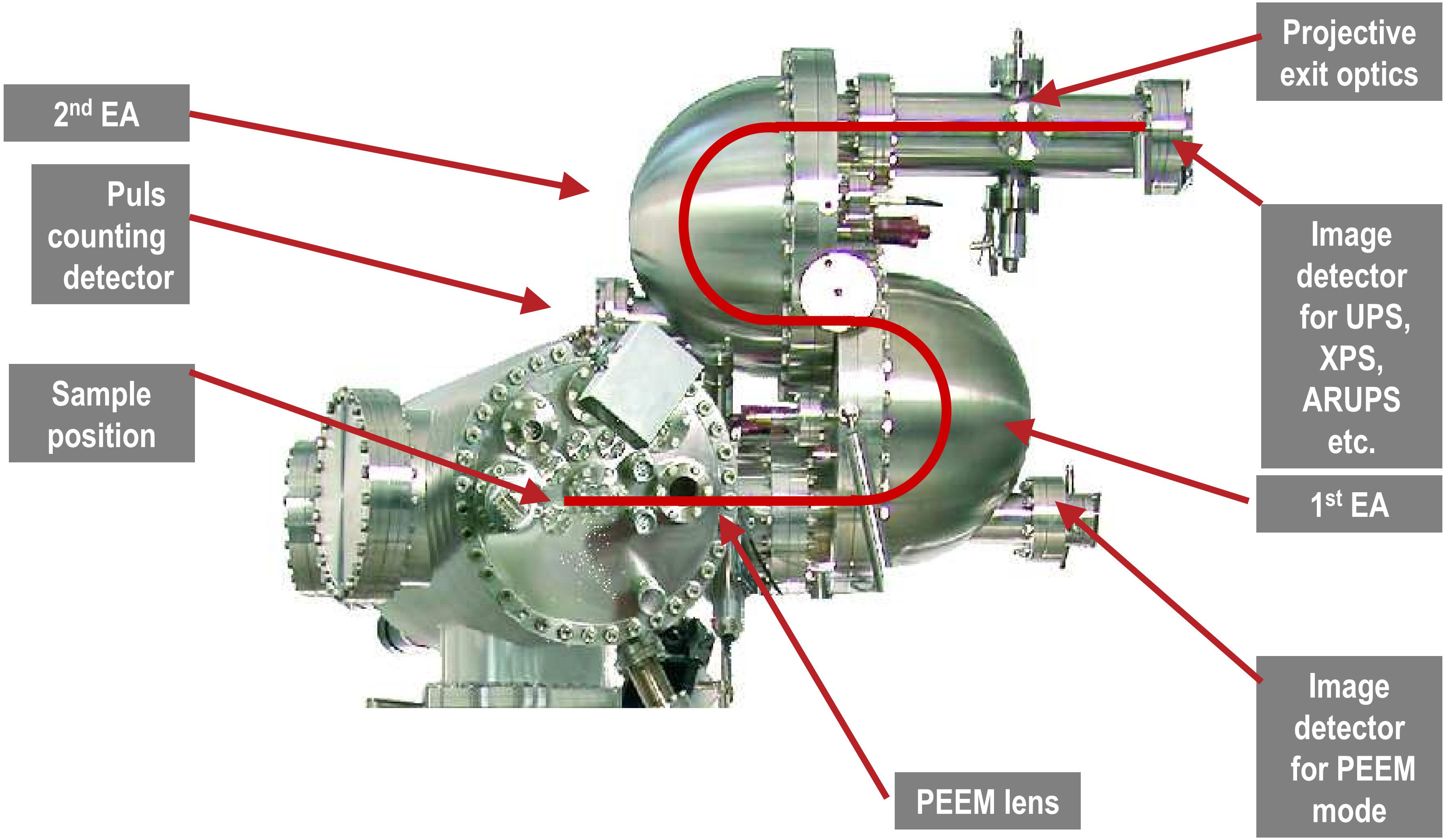
+ very high transmission (larger slits)
+ excellent energy resolution (smaller pass energy)
- no increase in lateral resolution





Instrument View

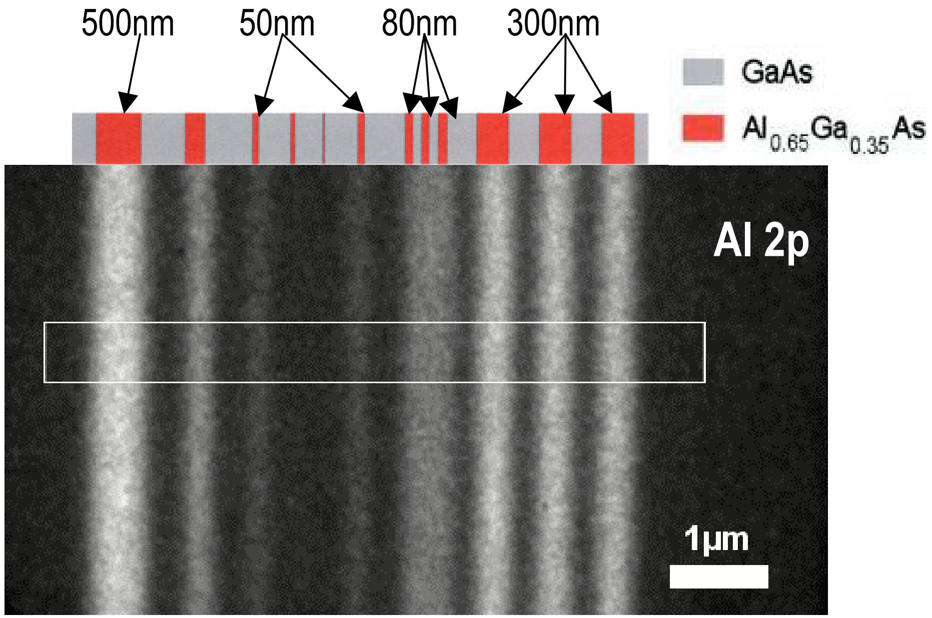
NanoESCA



Synchrotron Results (BESSY II UE 52 SGM)

- Imaging Al 2p Corelevel
- Calibrated sample from BAM
- Semiconductor heterostructure GaAs/AlGaAs (BAM L002)
- Beamline UE 52 SGM
- hν = 150 eV, Ekin = 77 eV
- Edge resolution

  120nm @ 57% Contrast



M. Senoner et al. *Jurnal of Surface Analysis* **12**, pp 78-82 (2005).

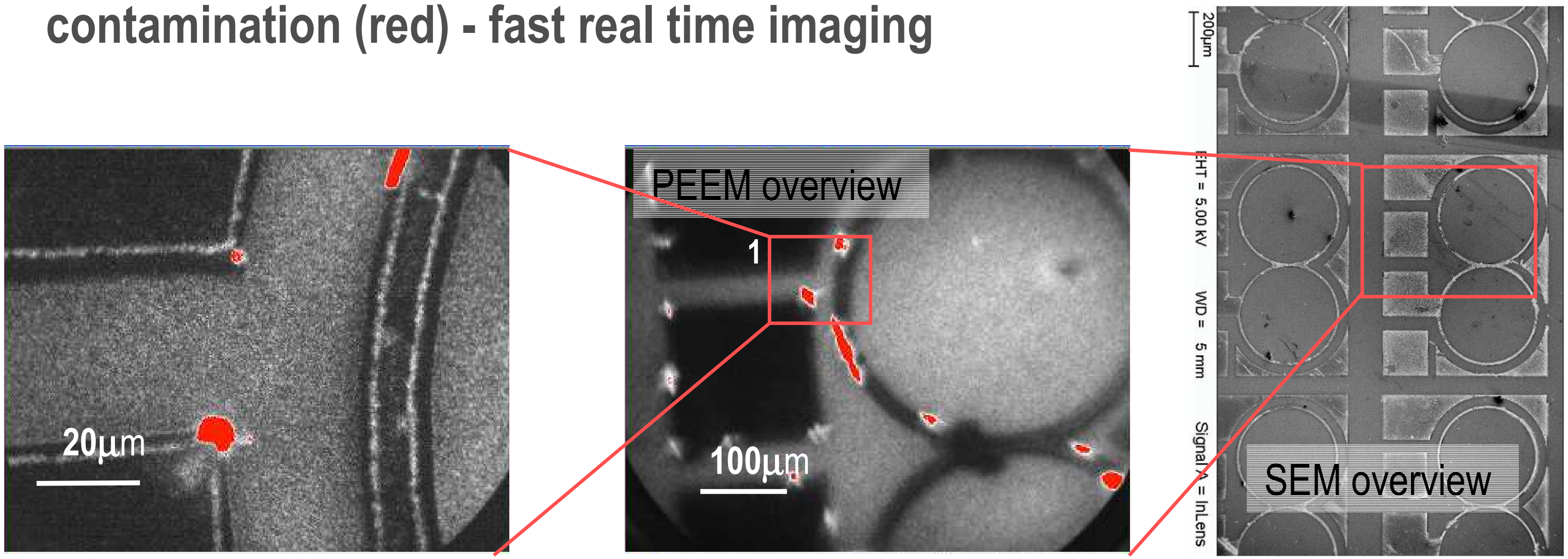
Imaging XPS

Synchrotron Results (ESRF ID08)

Sample: electrochemical coated with pMAN (polymethacrylonitril)

- Mercury arc lamp illumination

- PEEM mode: find good area with little contamination (red) - fast real time imaging



O. Renault et al., *Surface Science*. **601, 2007**

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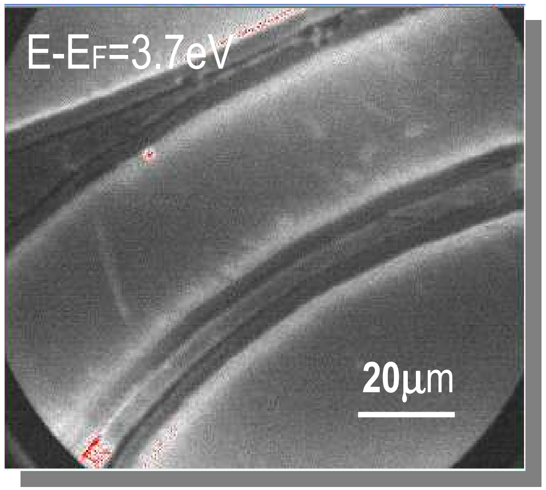
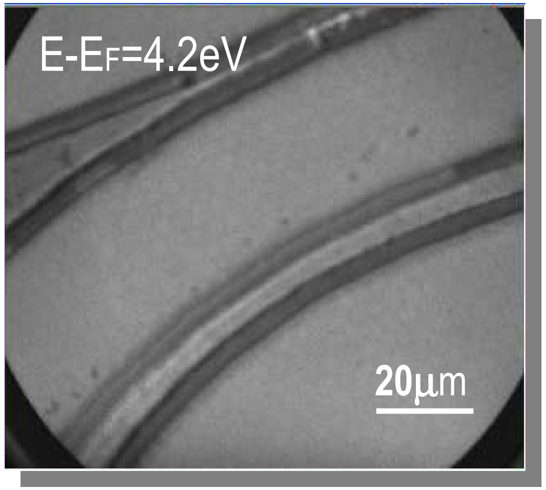
Synchrotron Results (ESRF ID08)

pMAN sample

- SE imaging with Work- function contrast
- Contrast changes selected analyser energy
- Strong indication for localised chemical compounds

Synchrotron illumination hν = 700eV





Dream cea leti SPCSI

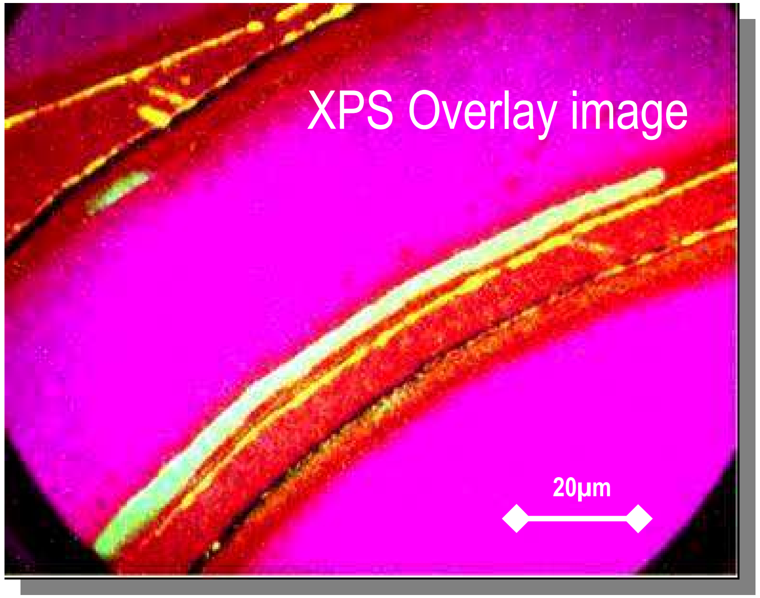
O. Renault et al., *Surface Science*. **601**, **2007**

Synchrotron Results (ESRF ID08)

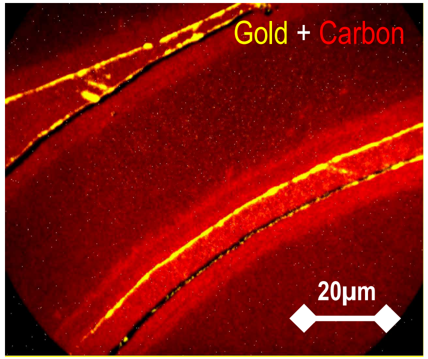
Understanding complex chemical map

XPS chemical state mapping O(x)

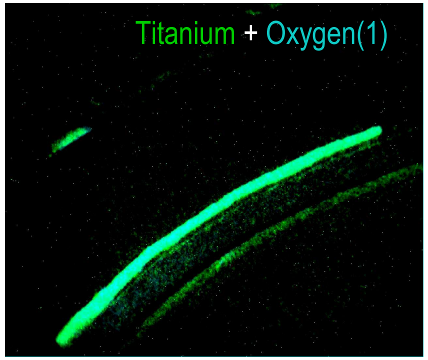
$h\nu$ = 700eV, ~5 min per image



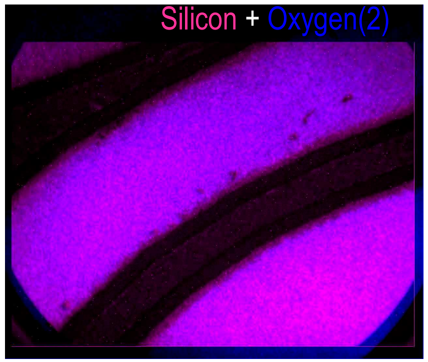
Au $4f_{7/2}$, 84 eV
C 1s, 284.2 eV



Ti $2p_{3/2}$, 453.8 eV
O 1s, 543.1 eV



Si $2p_{3/2}$, 99.4 eV



O. Renault et al., *Surface Science*. **601**, **2007**

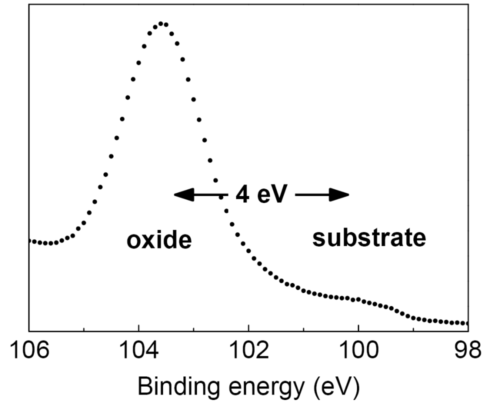
Synchrotron Results (ELETTRA)

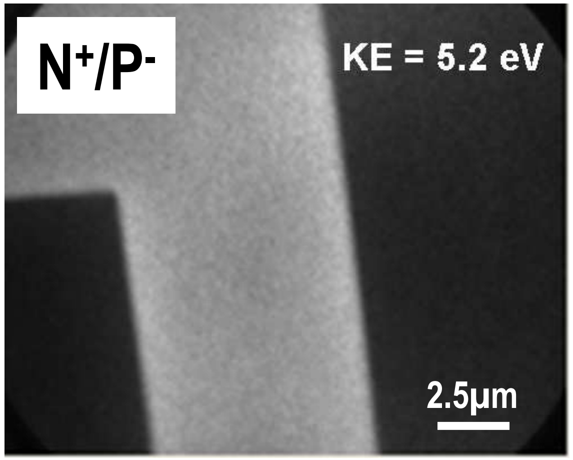
highly p and n doped Si patterns

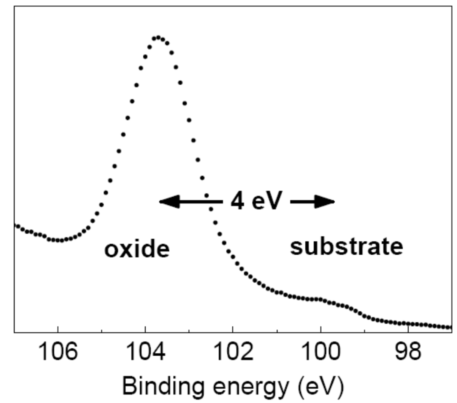
Threshold images of N^+/P^- and P^+/N sample,

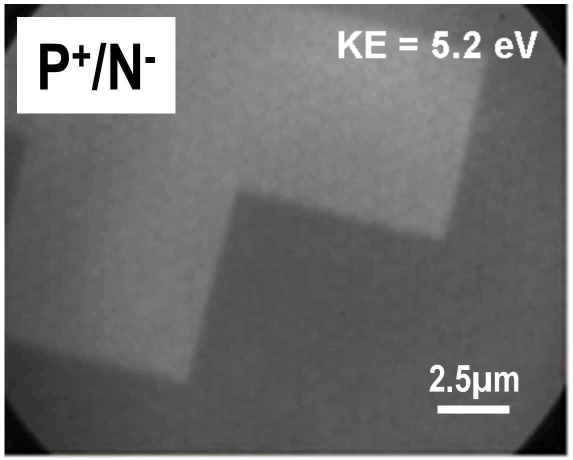
Si 2p
small spot pulse counting spectra (spectra averaged over the field of view, 25µm)

hν = 127eV







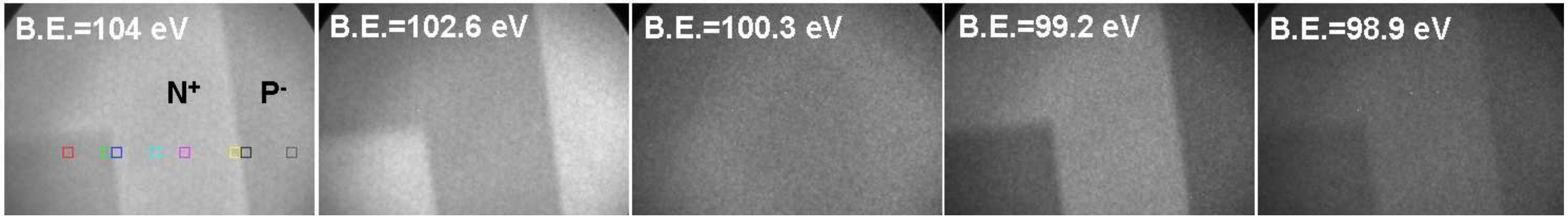


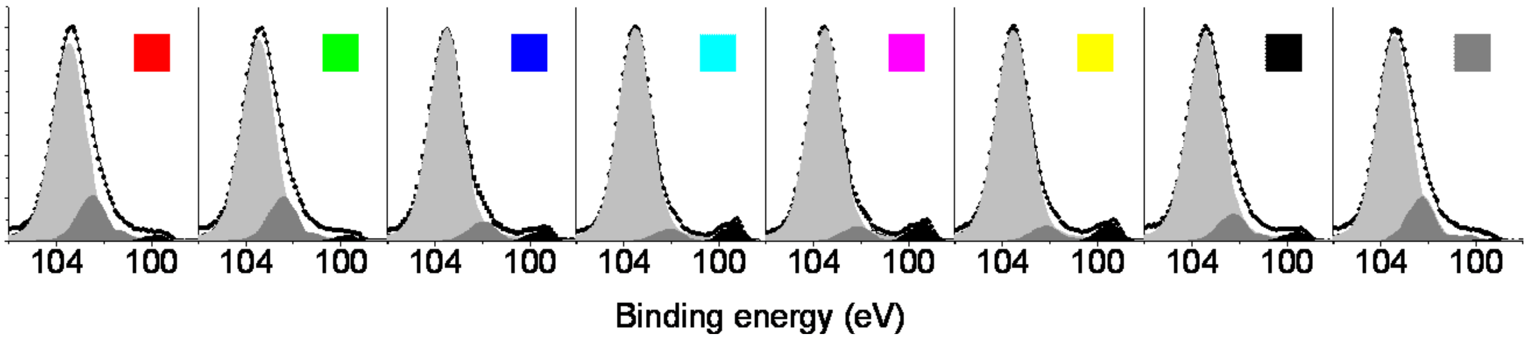
leti cea **N. Barrett et al**. *J.Phys.:Condens. Matter, to be published* **2009**

Synchrotron Results (ELETTRA)

highly p and n doped silicon patterns hν = 127eV
Local spectra are extracted from a 400x400nm area of interest

Poster Session: We 025
M. Lavayssière





N. Barrett et al. *J.Phys.:Condens. Matter, to be published* **2009**

Imaging XPS

lab source results

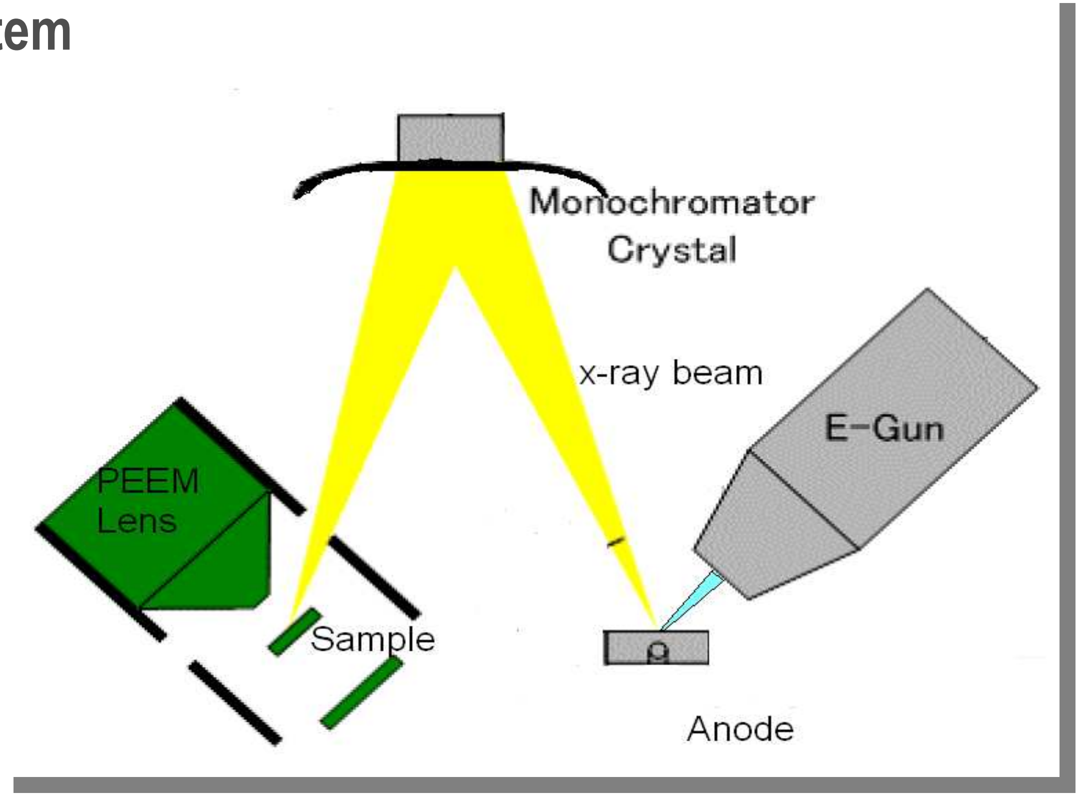
Variable x-ray spot 20-200µm

Static x-ray spot

Imaging analyser lens system

Highest photon density

$h\nu$ = 1486.7eV



Imaging XPS

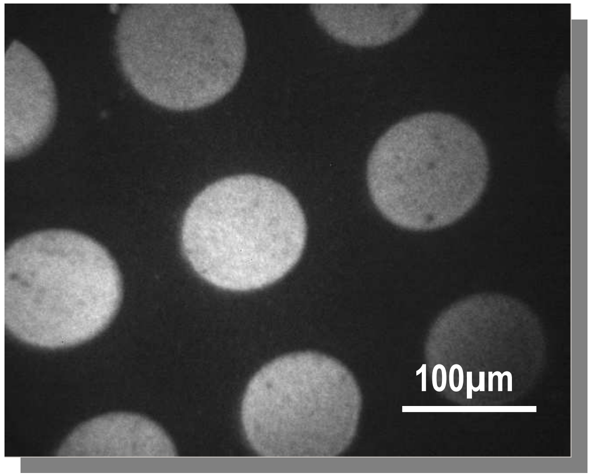
lab source results

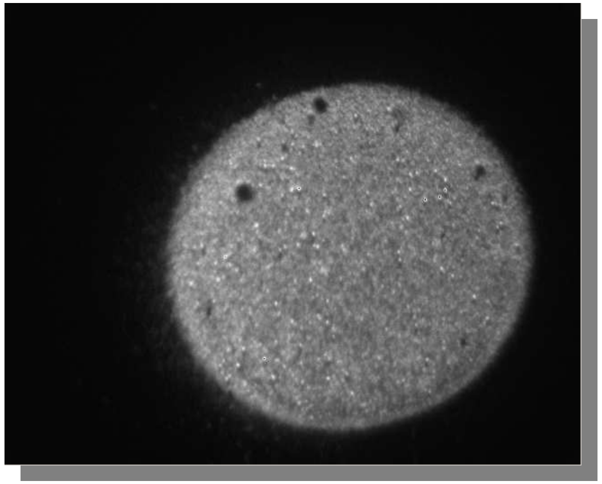
Sample: Layered Hydrogel

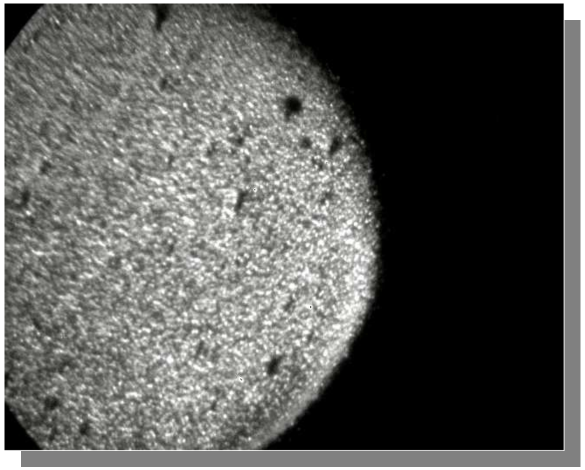
bulk: copolymer of carboxyl/hydroxyl terminated crylate/methacrylate

top (patterned) layer: amine terminated methacrylate

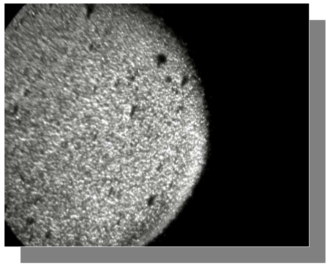
PEEM navigation on sample 600µm to 127µm field of view







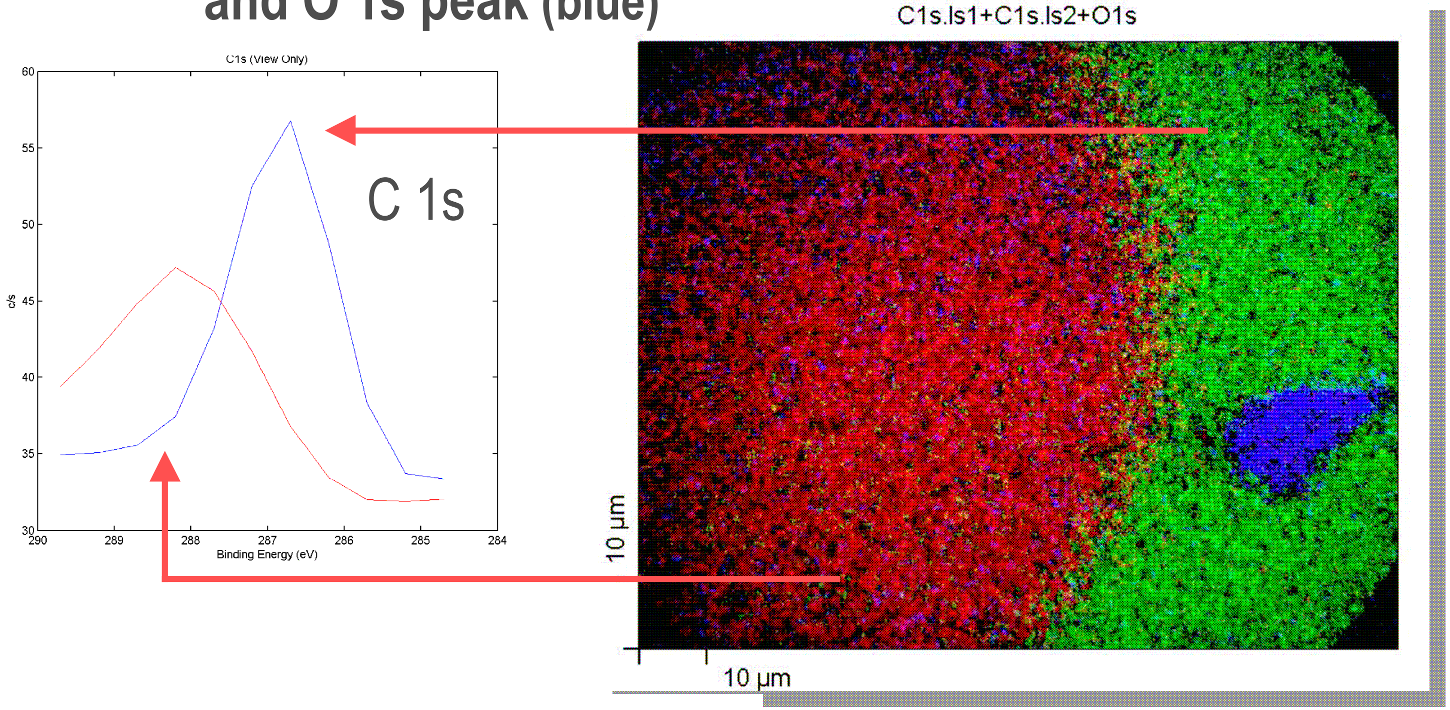
Escher et al, *submitted to J. El. Spec. Rel. Phenom* **2009**



Sample: Layered Hydrogel

High resolution XPS Core level imaging

RGB overlay C 1s two modifications (red and green) and O 1s peak (blue)



Escher et al, *submitted to J. El. Spec. Rel. Phenom* **2009**

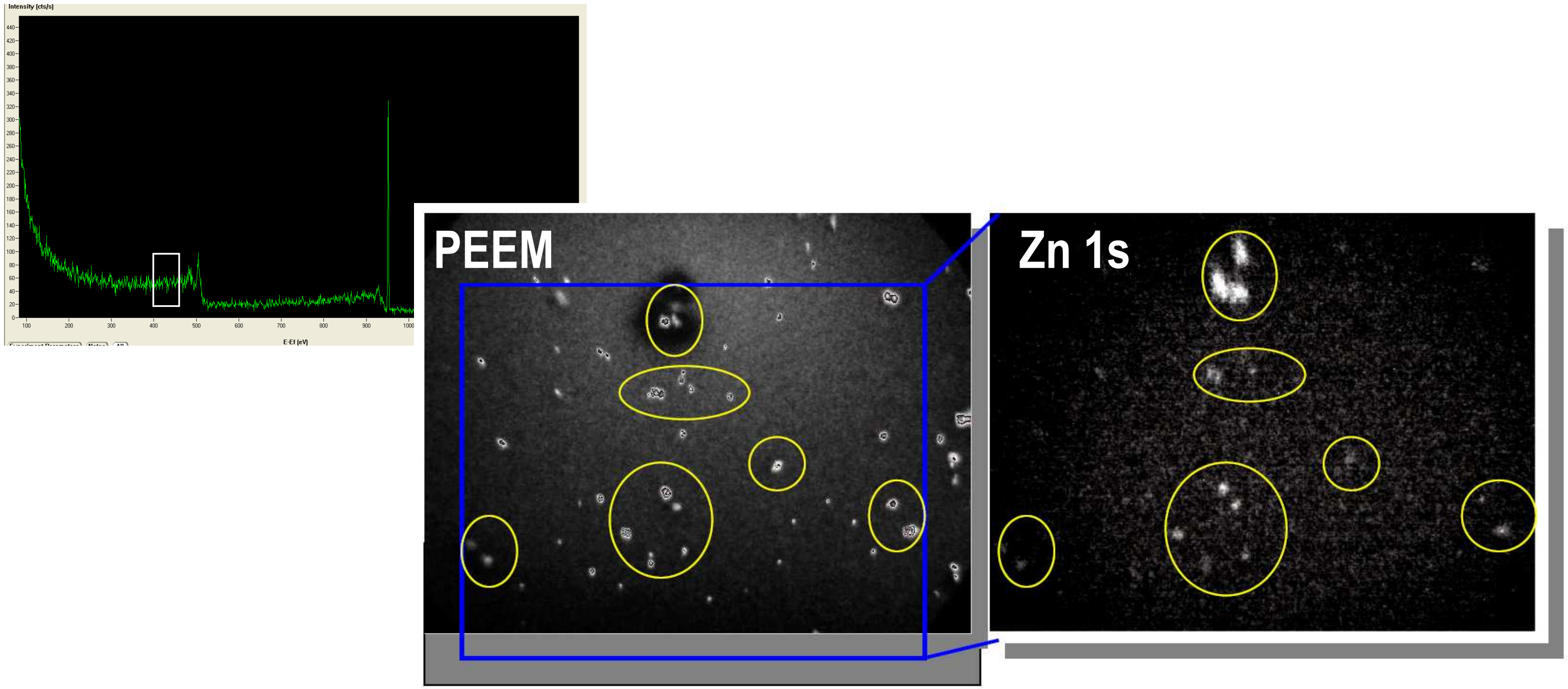
Imaging XPS

lab source results

Sample ZnO nano-particles

Small coverage of particles: weak Zn signal in small spot spectroscopy

Particle size down to <1µm are clearly visible in imaging XPS

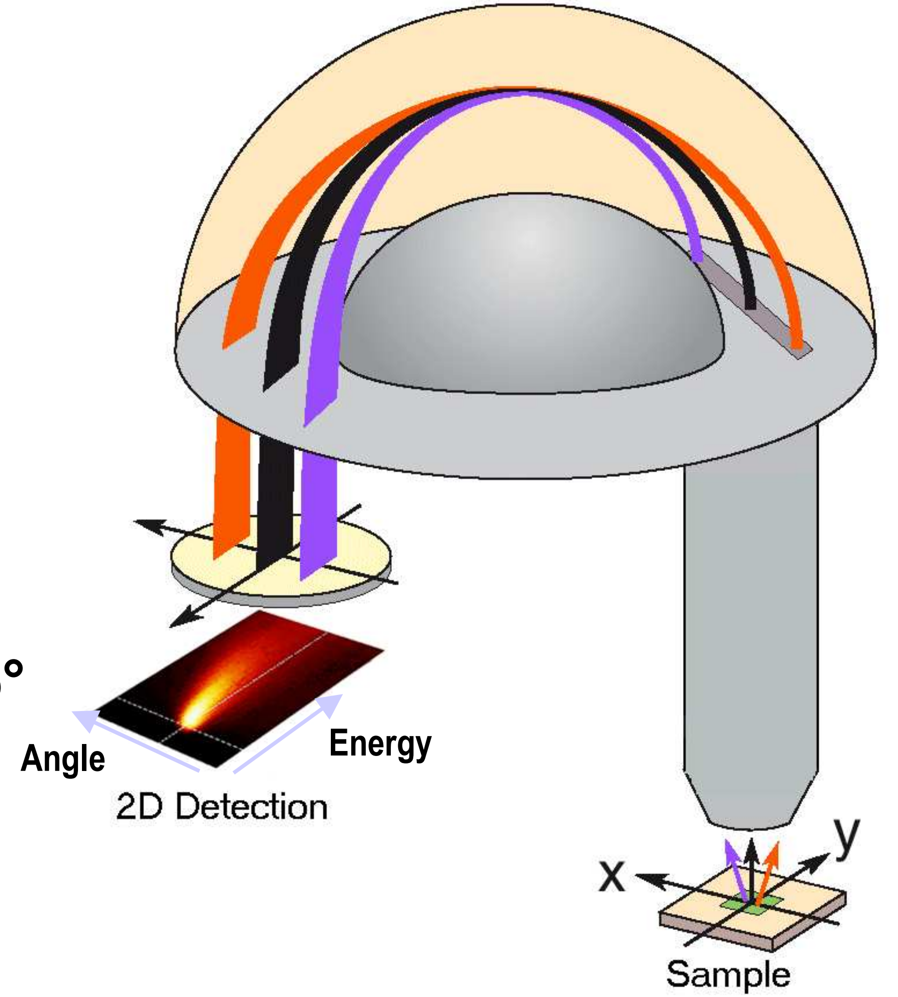


Standard ARUPS Hemispherical Analyser with 2D detector

2 D Detectors for EA image the dispersive plane (energy spectrum) and angles simultaneously

+ Very high angular resolution
+ Very high energy resolution

- Poor control of the analysed area
- Mechanically rotated system
- Limitted angular acceptance up to ±15°



NanoESCA

Aperture at k-space image

Inactive Trans Lens

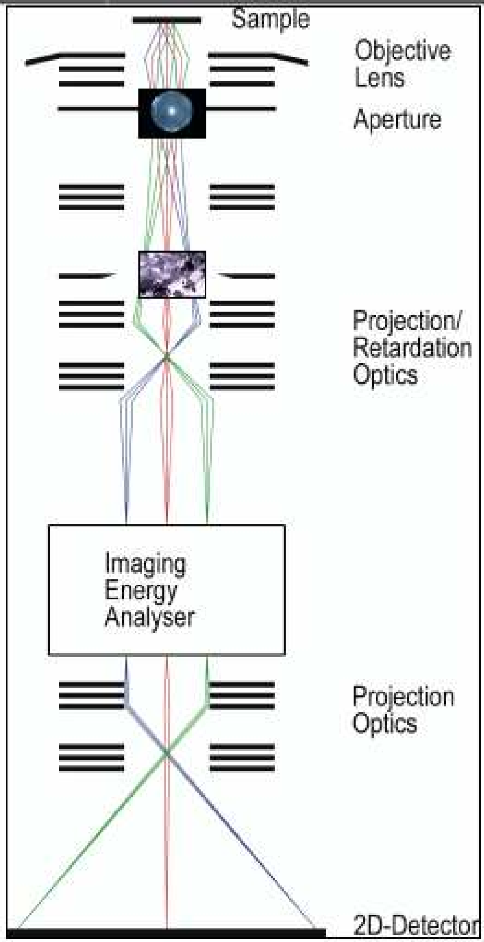
Intermediate image

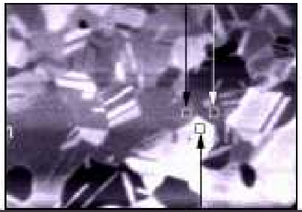
Image magnification

Aberration corrected energy analyser

Energy filtered real space image

real space imaging





Angular resolved UPS

NanoESCA + Transfer lense = Momentum Microscope

k - space imaging

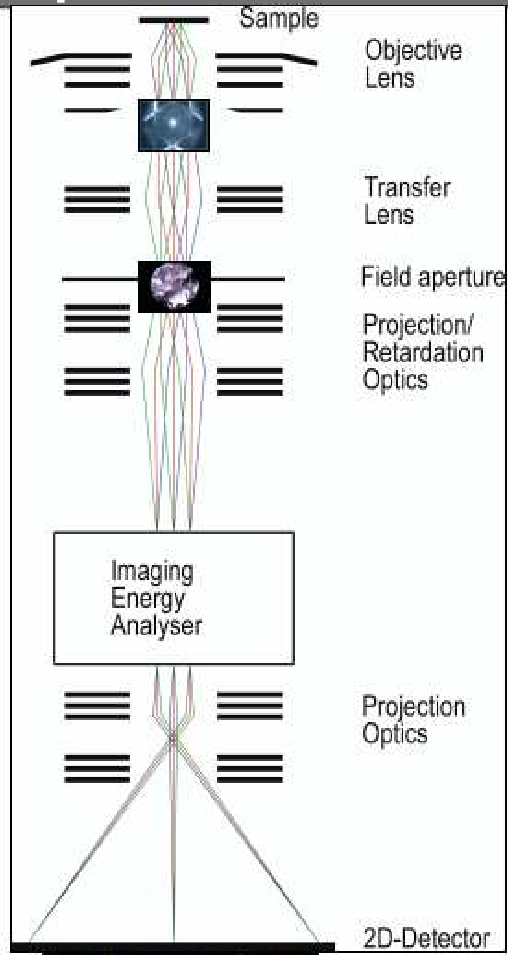
Full k-space image

Active Trans Lens

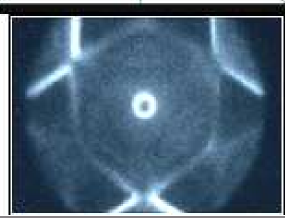
Active aperture at intermediate image

Optimised lens design for
k-space imaging

Aberration corrected energy analyser



Energy filtered k-space image

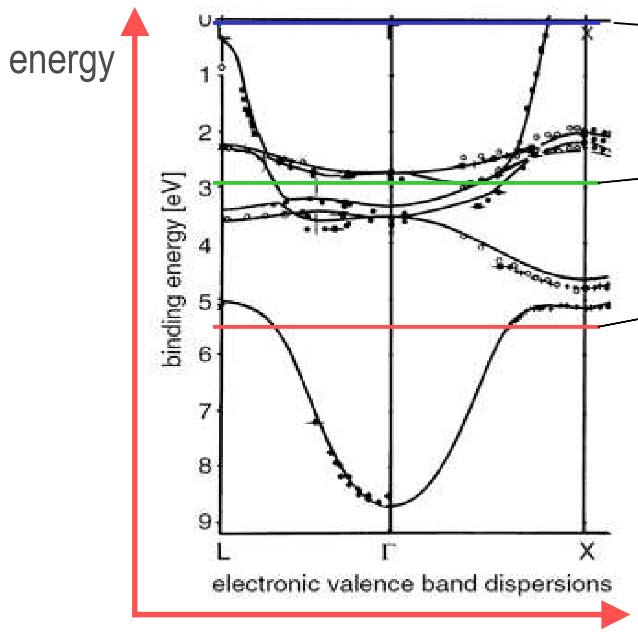


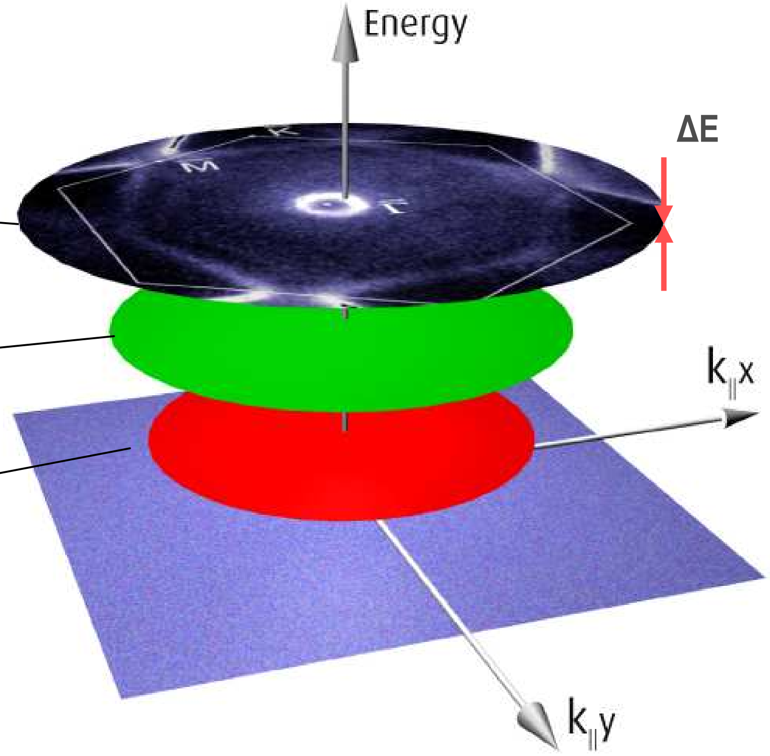
Omicron NanoTechnology

NanoESCA for fast k-space mapping

Energy slices in “Band structure” space

The Instruments energy resolution defines thickness of energy slide





Single shot image of the Cu(111) Fermi Surface

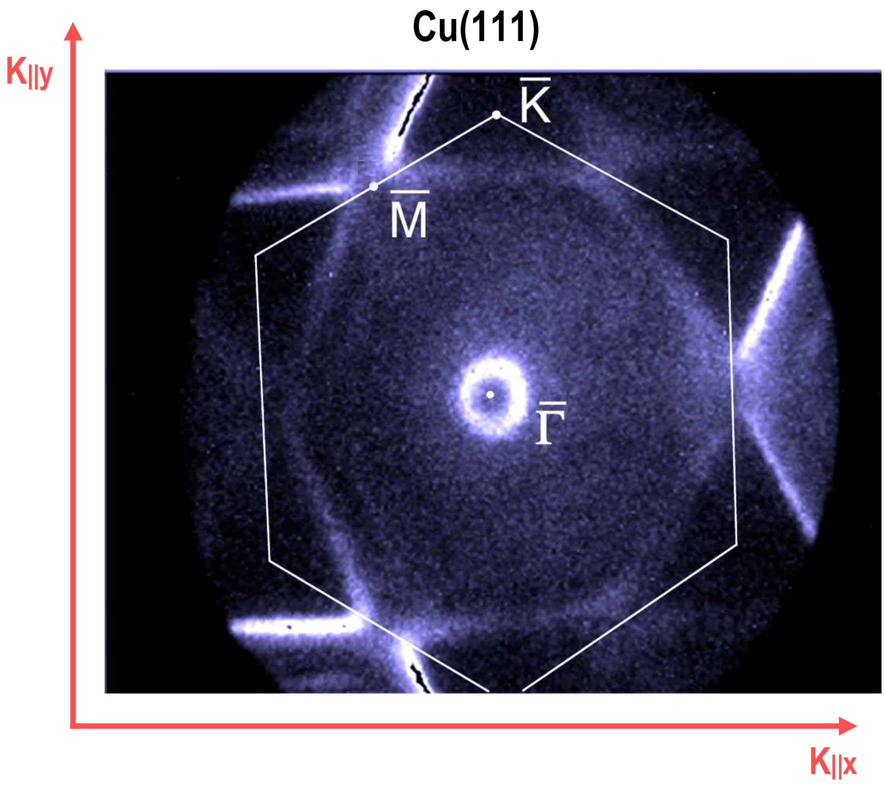
Acquisition time 60sec

He I excitation, hv = 21.2 eV

VUV source HIS 13

With a standard ARUPS set-up it will take many hours

Large angles are very difficult to image

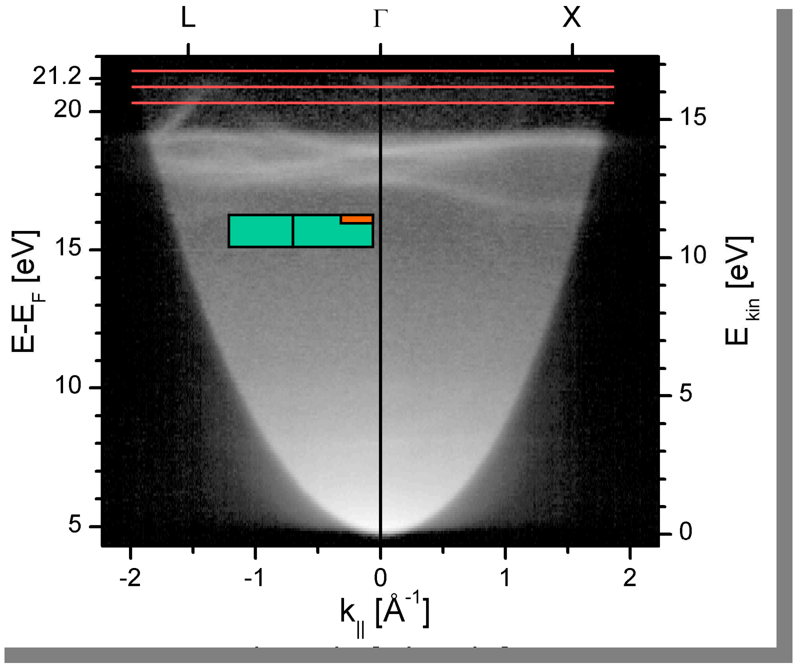


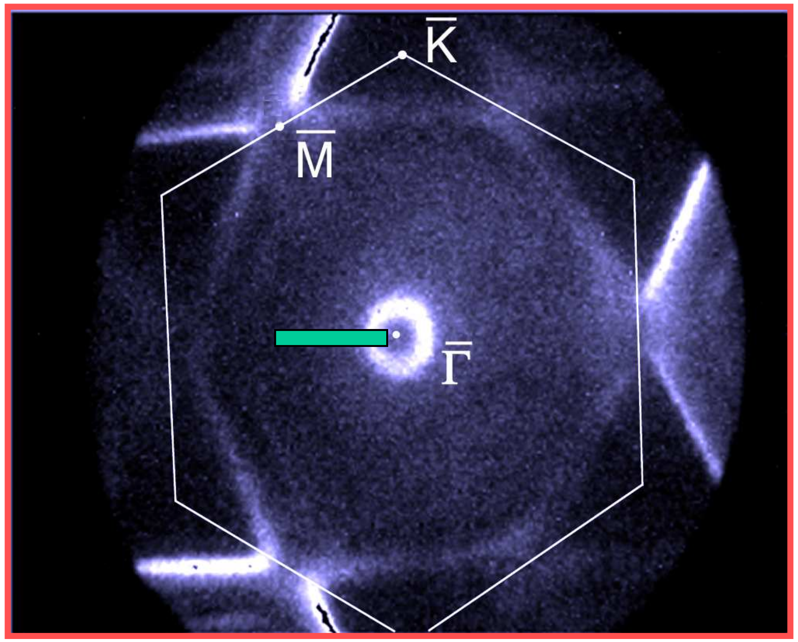
B. Krömker et al. *Rev Sci Instrum.* **79**, **2008**

Angular resolved UPS

A scan in k-space: Cu (111)

Data I(kx,ky) at fixed Energy
Green and red box indicate a single shot from a standard ARUPS set-up with limitations at large emission angles





B. Krömker et al. *Rev Sci Instrum.* **79, 2008**

Angular resolved UPS

A scan in k-space: Cu (111)

120 angular images,

ΔE per image: 50meV

60 sec per image,

2h total acq. time

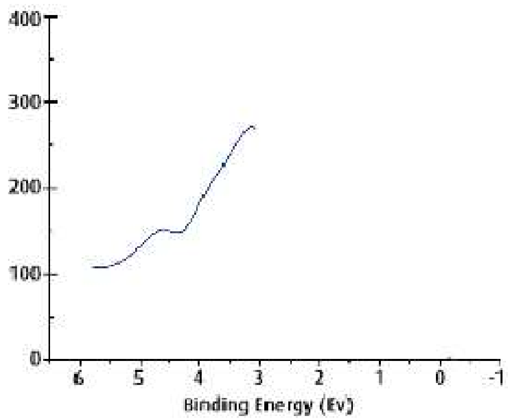
UPS Spectrum extracted

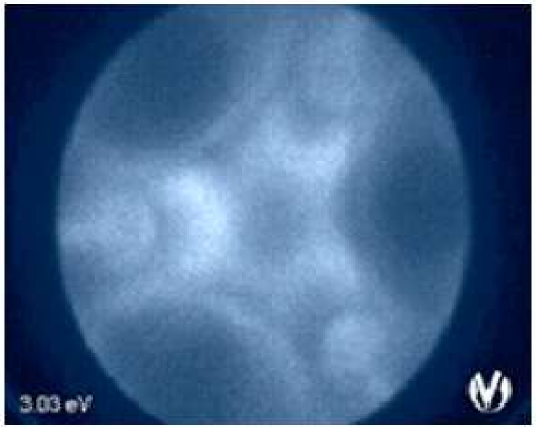
from total intensity of each

angular image

see also at

http://www.omicron.de/nanoesca/





120 images

A scan in k-space: Cu (111)

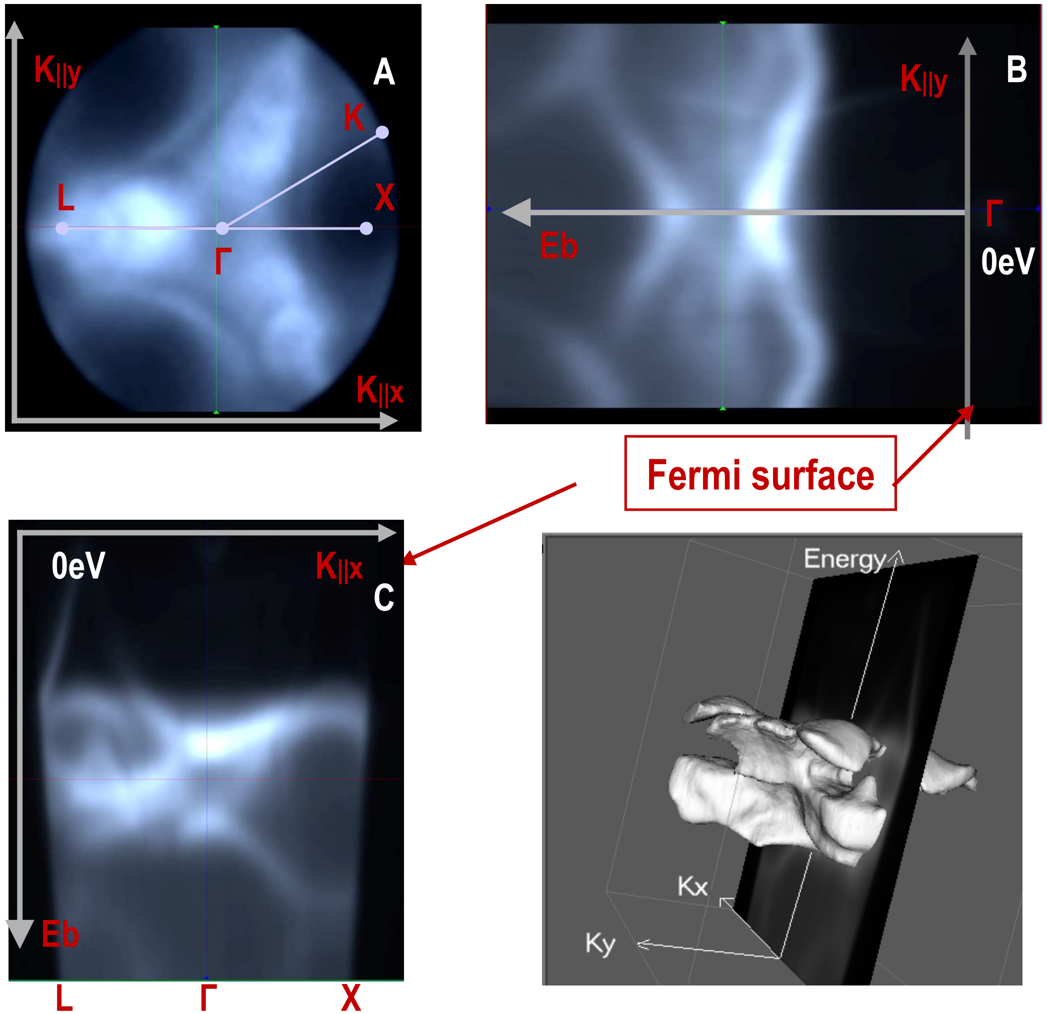
Visualisation of the 120 angular images and analysis:

Cuts through image stack can be changed online.

A) Cut at constant Energy, I(kx,ky)

B) & C) Band structure

cuts along along Energy axis I(E,kx) and I(E,ky)



Angular resolved UPS

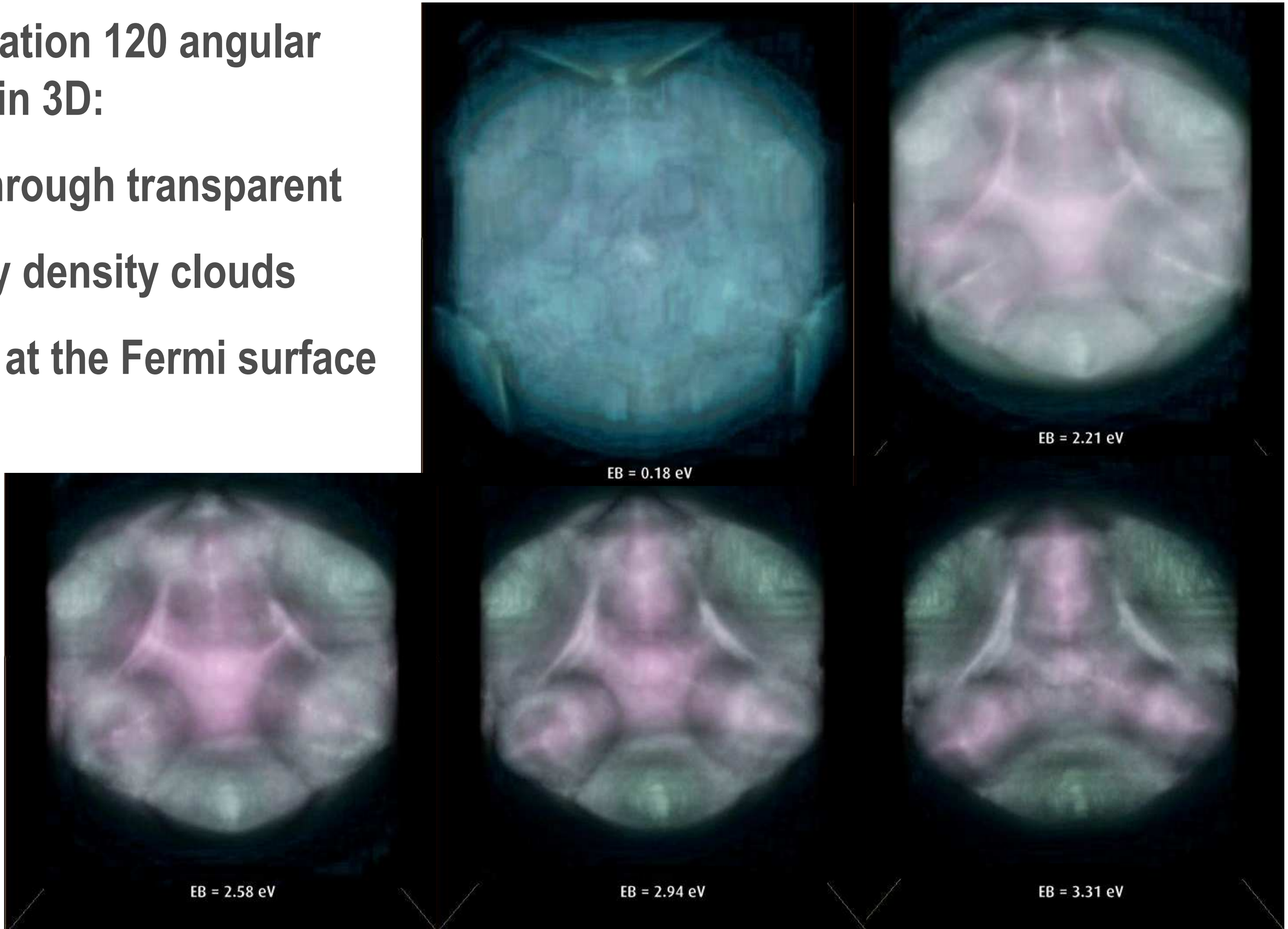
A scan in k-space: Cu (111)

Visualisation 120 angular images in 3D:

Flight through transparent

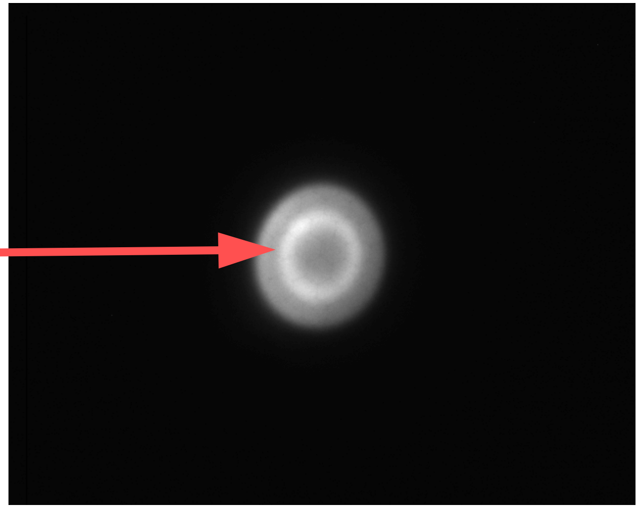
Intensity density clouds

starting at the Fermi surface



Cu (111) - Shockley Surface State

Cu(111)



Shockley Surface State is visible with a Mercury arc lamp (hν ~ 4.9 eV)

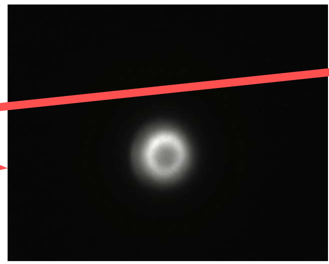
Cu(111) surface state

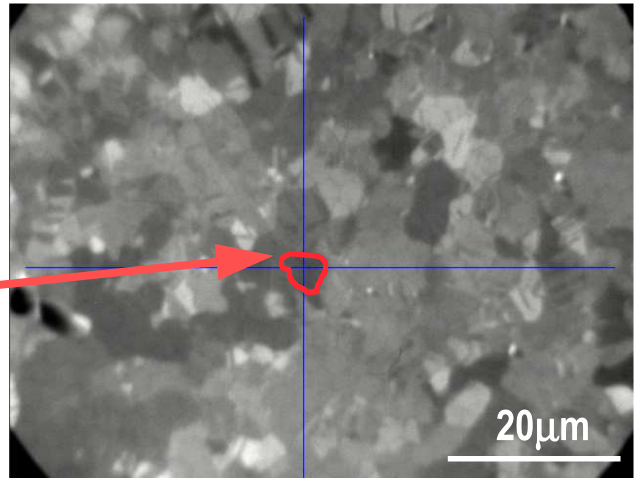
Combined real space and k-space imaging

Sample: Cu film with preferred (111) orientation and work function of 4.9 eV

O. Renault *et al.*, Surf. Interf. Anal. **38**, 375 (2006)

Single Cu grain





Thank you very much for your attention!