Nanoscience – Photoemission 2 PEEM

Bruce C C Cowie

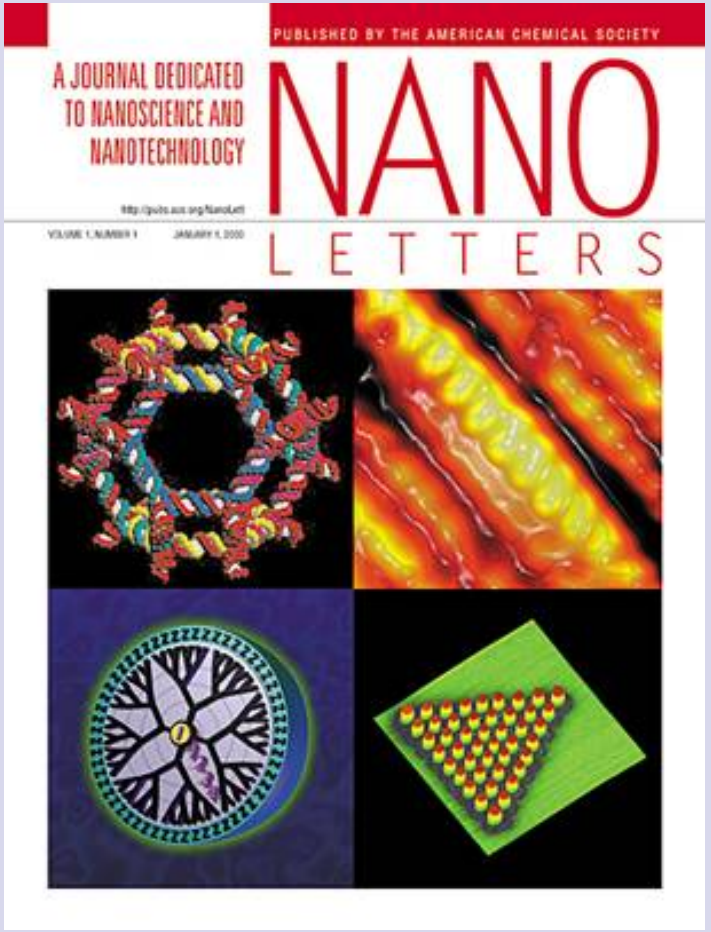
Australian Synchrotron

Introduction

- Nanoscience
- Some techniques to study nanomaterials
- LEEM and PEEM
- Some Applications of PEEM
- Future

Nanoscience

- Nano Letters
- Since 2001 Pages published Annually increased 4 fold
- In 2007 pages > 3000+
- About 8 Journals have Nano in the title!

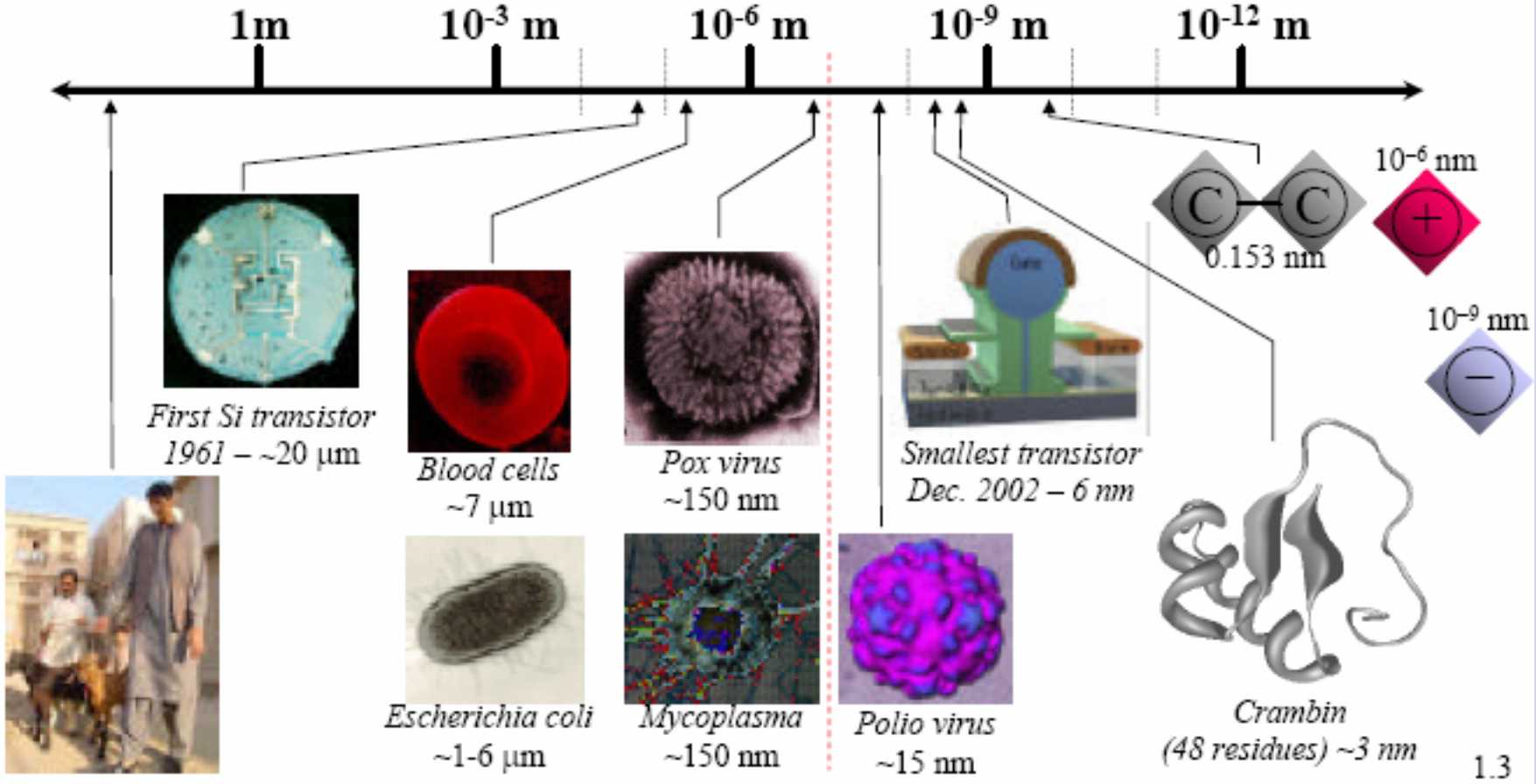


Nanoscience

- Why is it important?
  - Allows us to vary the properties of materials between atomic and bulk
  - Nanomaterials often have different physical properties
- What are the length scales for nanomaterials?
  - Often can be described as being in the range of countable numbers of atoms eg C_{60}
  - 1 Nanometre to 100's nanometres per particle
  - Not all dimensions have to be in nanometres!

What is the 'nanoscale'

- Nanoscale is generally held to span 1-100 nm (10^{-9} m).



- ***Dr Mark J. Biggs Institute for Materials and Processes*** *University of Edinburgh*

Brief History of Nano

- **Richard Feynman**
- – *There's plenty of room at the bottom* (1959) _
- Writing the Encyclopedia Britannica on a pin head

- **Norio Taniguchi**
- N. Taniguchi, "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974.
- semiconductor processing to make thin films and ion beam milling

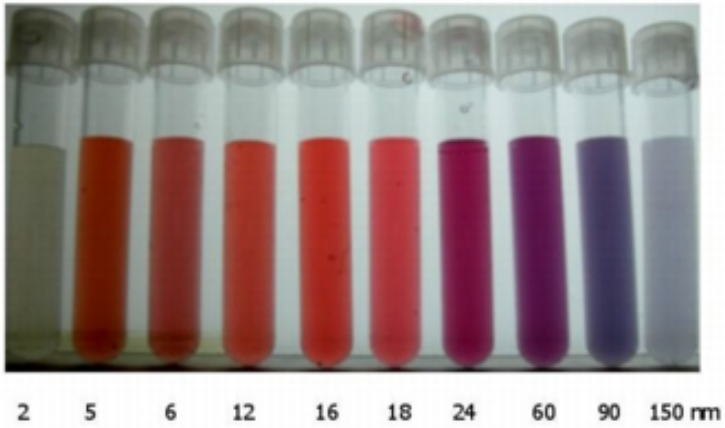
- **K. Eric Drexler**
- – *Molecular engineering: An approach …* (1981)
- Build from the Bottom up - Nano assembler machines
- Michael Crichton *Prey – "grey goo"*

The nanotechnology timeline NorthWestern University Part of DiscoverNano
http://www.discovernano.northwestern.edu/whatis/History/
Must see site

Nano has Different Properties

- Gold is gold - except when its nano gold
  - Definition of Gold **Merriam-Webster Dictionary**
  - a yellow malleable ductile metallic element
  - a variable color averaging deep yellow
- Known for 1000's of years in glass making
- Michael Faraday, *Philosophical Transactions of the Royal Society*, London, 1857

Different sizes of colloidal gold particles



Trends Biotechnol. 2006 Feb;24(2):62-7. Epub 2005 Dec 27.
Therapeutic possibilities of plasmonically heated gold nanoparticles.
Pissuwan D, Valenzuela SM, Cortie MB.
Institute for Nanoscale Technology, University of Technology Sydney, Broadway NSW 2007, Australia.

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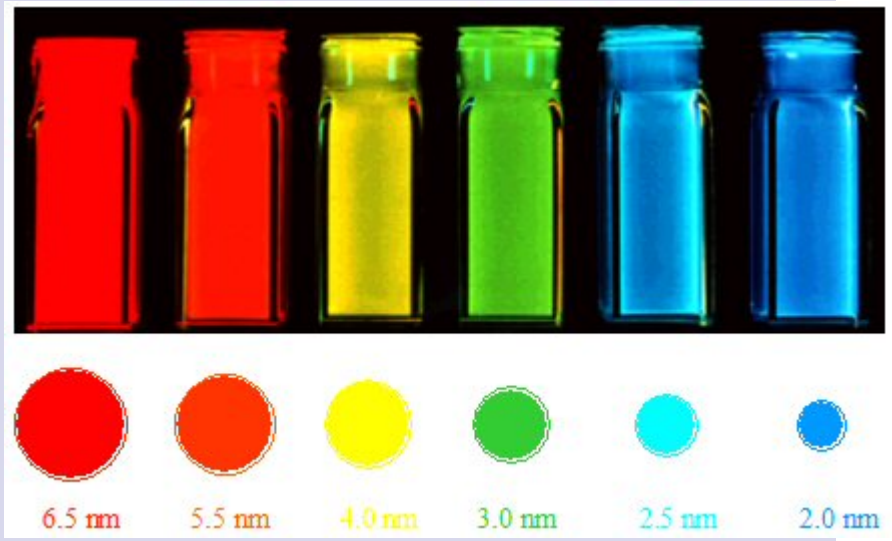
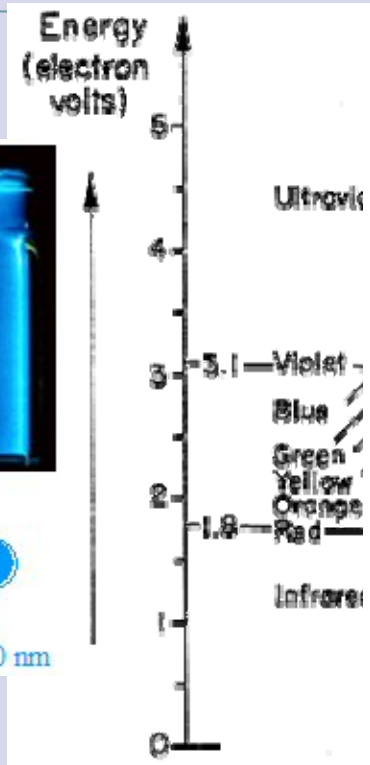
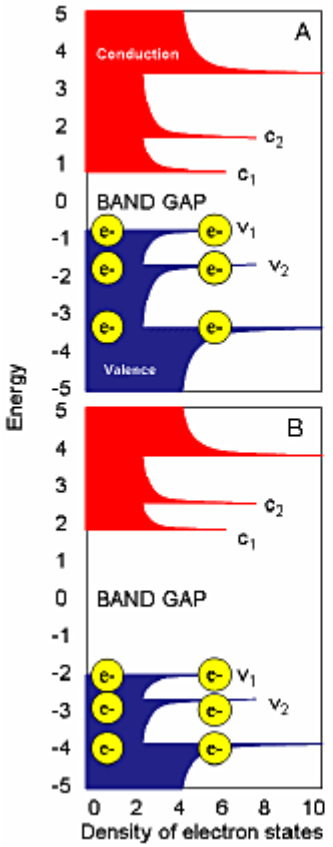
Size Matters (at least for Semiconductors)







Semiconductor	Exciton Bohr Diameter
CdSe	106Å
Band gap Energy	
1.74 eV	

Bukowski, Tracie J. and Simmons, Joseph H. (2002) 'Quantum Dot Research: Current State and Future Prospects', Critical Reviews in Solid State and Materials Sciences, 27:3, 119 - 142

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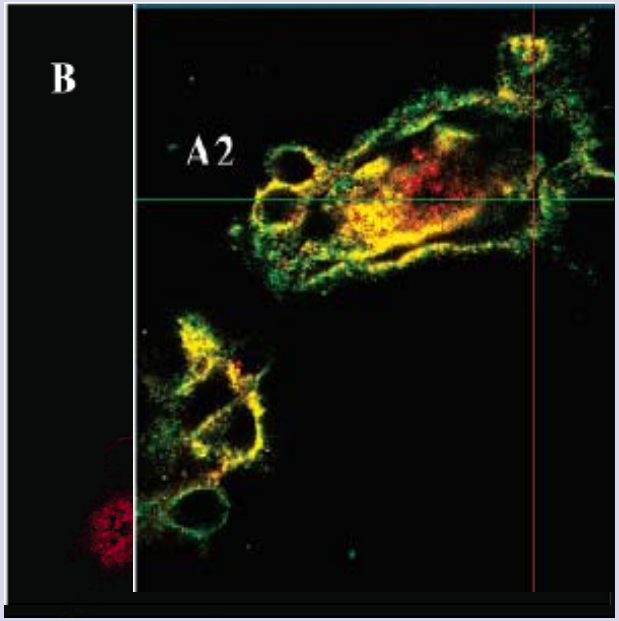
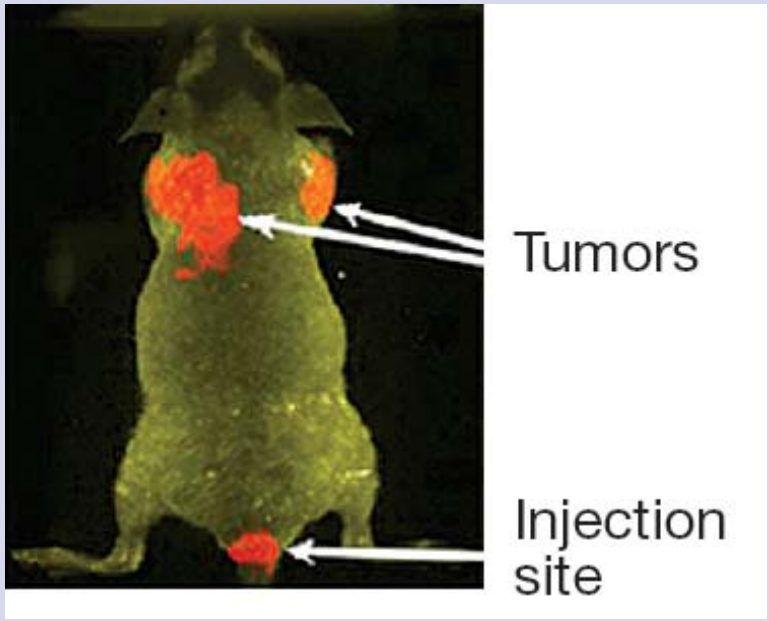
Applications of Quantum Dot markers

- Labeling Antibodies to Viral Proteins - Respiratory Virus



E. Bentzen et al Nano Lett., Vol. 5, No. 4, **2005**

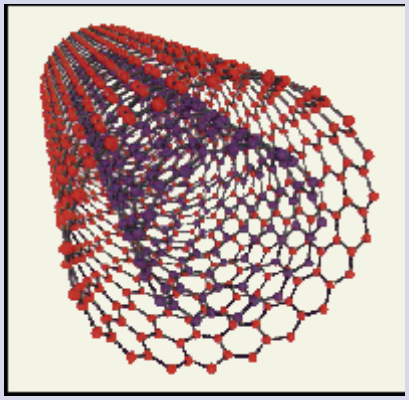
- Labeling Antibodies to Prostrate Cancer



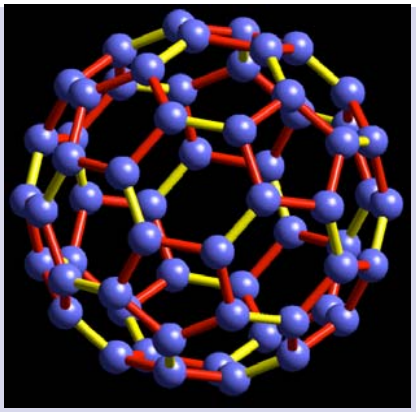
Gao X, Cui Y, Levenson RM, Chung LW, Nie S. 2004. *In vivo* cancer targeting and imaging with semiconductor quantum dots. Nat Biotechnol 22(8):969–976.

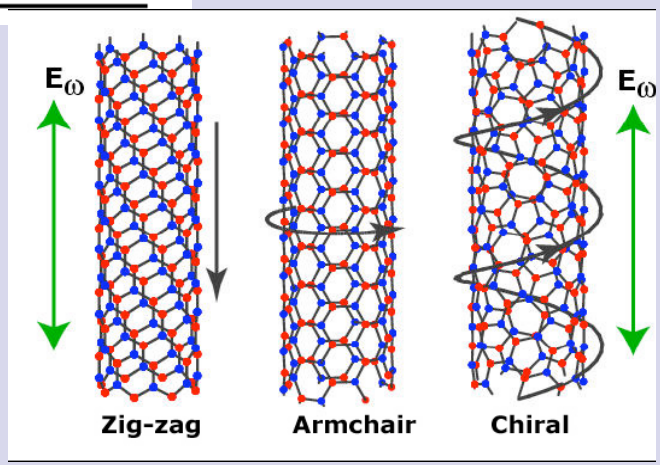
New Material Properties

Material	Young's Modulus (GPa)	Tensile Strength (GPa)	Density (g/cm3)
Single wall nanotube	~800	>30	1.8
Multi wall nanotube	~800	>30	2.6
Diamond	1140	>20	3.52
Graphite	8	0.2	2.25
Steel	208	0.4	7.8
Wood	16	0.008	0.6



- Carbon Nanotubes
- Already being added to polymers to strengthen car bumpers (Toyota)
- Replacement for copper wire?

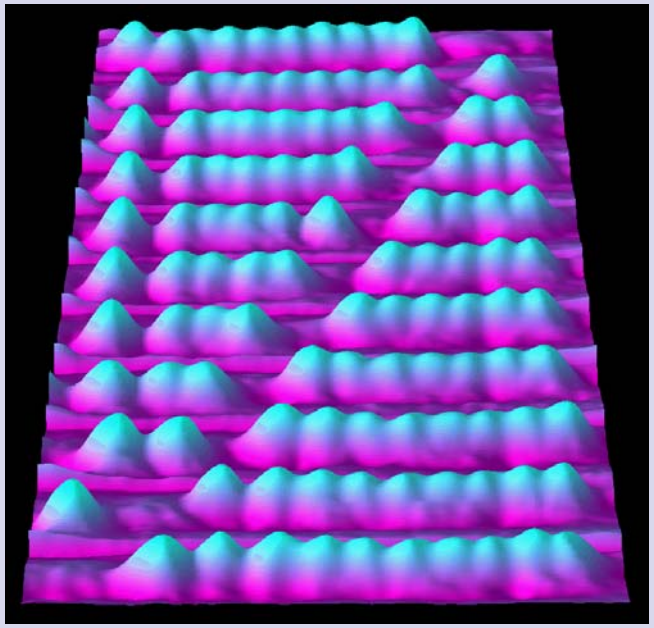




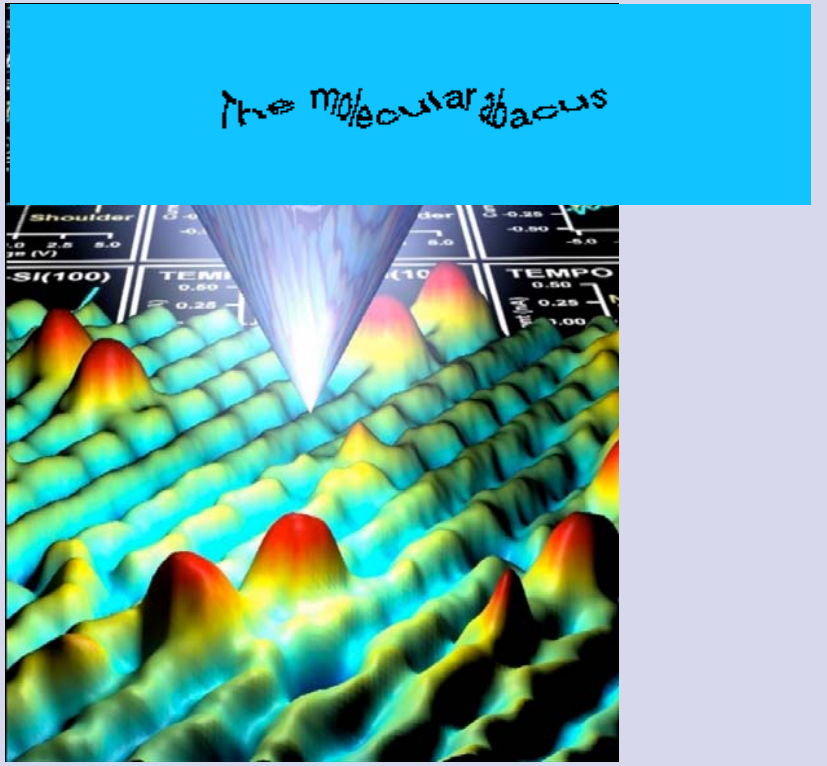
Carbon Nanotubes http://physicsweb.org/articles/world/11/1/9/1/world%2D11%2D1%2D9%2D6

Techniques for Nanoscience

- Scanning Tunnelling Microscope (STM)



C_{60} on Copper

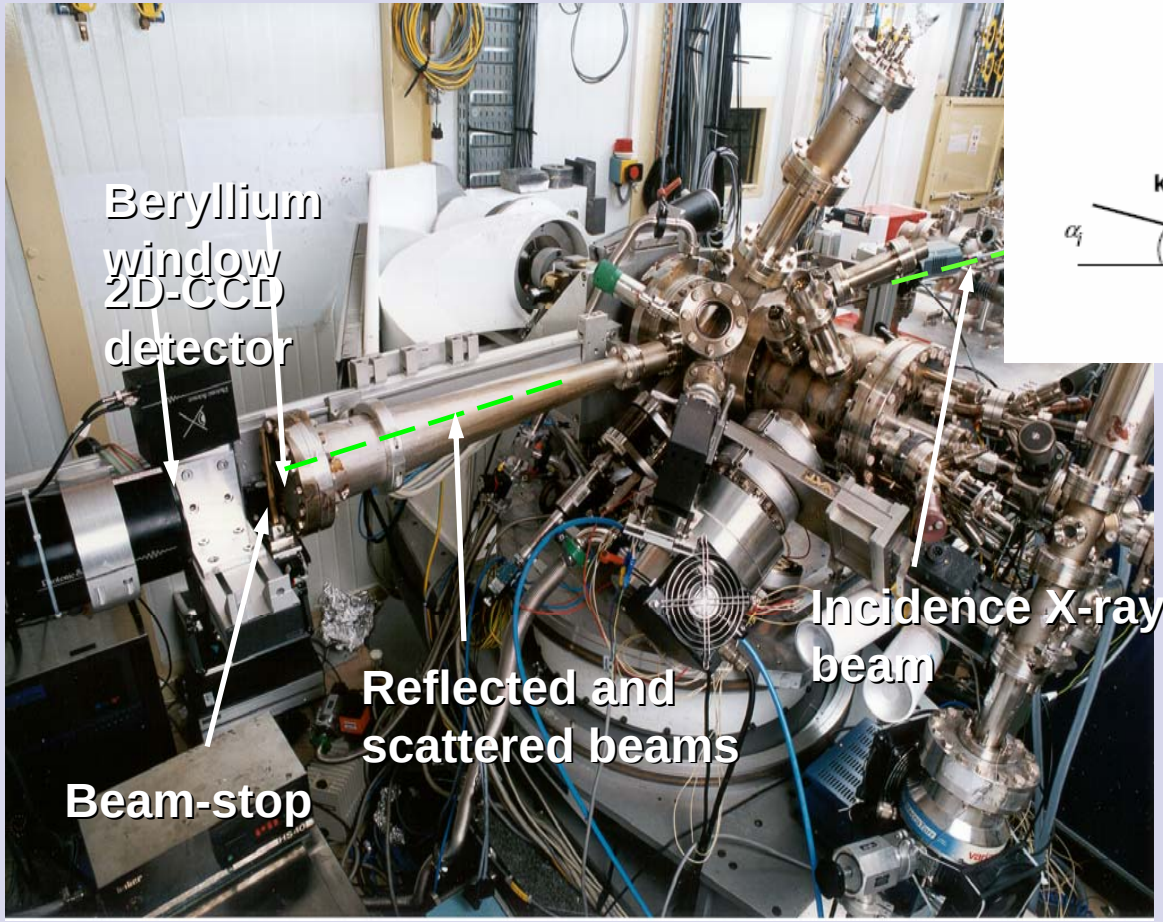


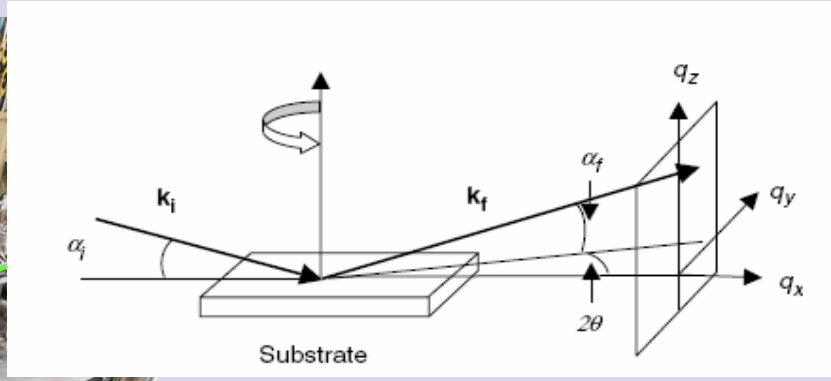
http://www.research.ibm.com/atomic/nano/roomtemp.html

Problem with Scanning Probe systems

- Not element specific
  - You have to know what you are looking at
- Relatively slow
  - Operational temperature range

Small Angle X-ray Scattering Grazing Incidence SAXS





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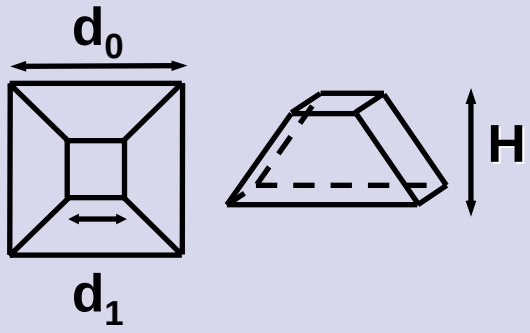
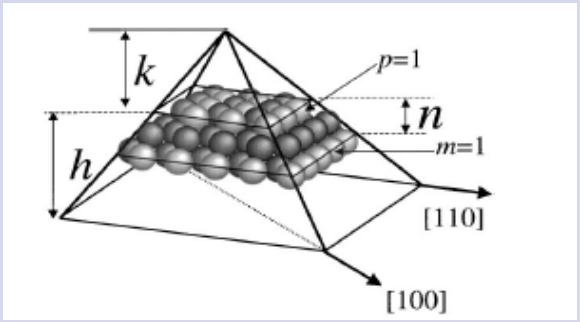
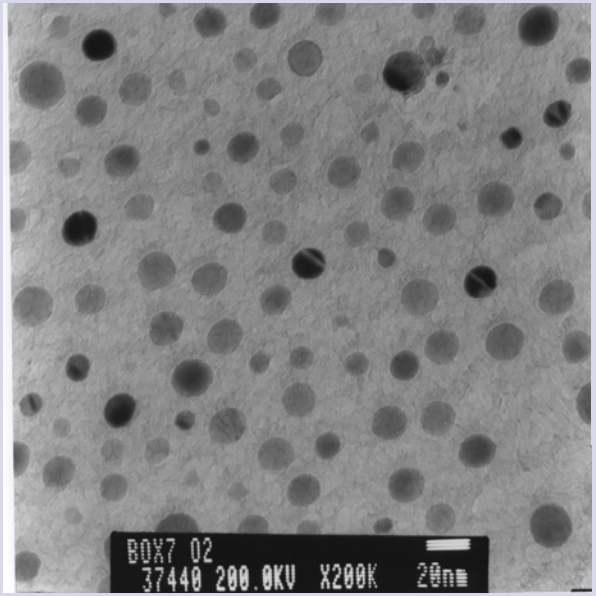
Surface science variant Grazing Incident (GISAXS)

Truncated pyramids







TEM images Ag/MgO(001), 300 K

C. Revenant et al. / Nucl. Instr. and Meth. in Phys. Res. B 246 (2006) 112–117

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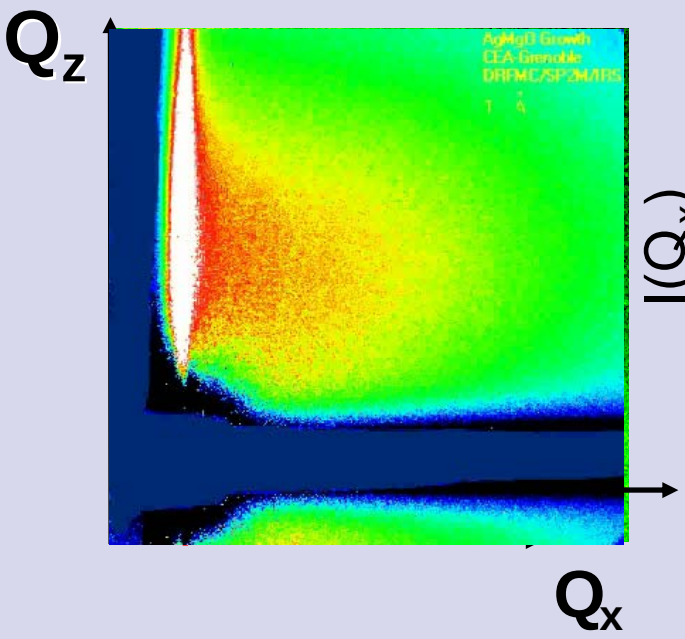
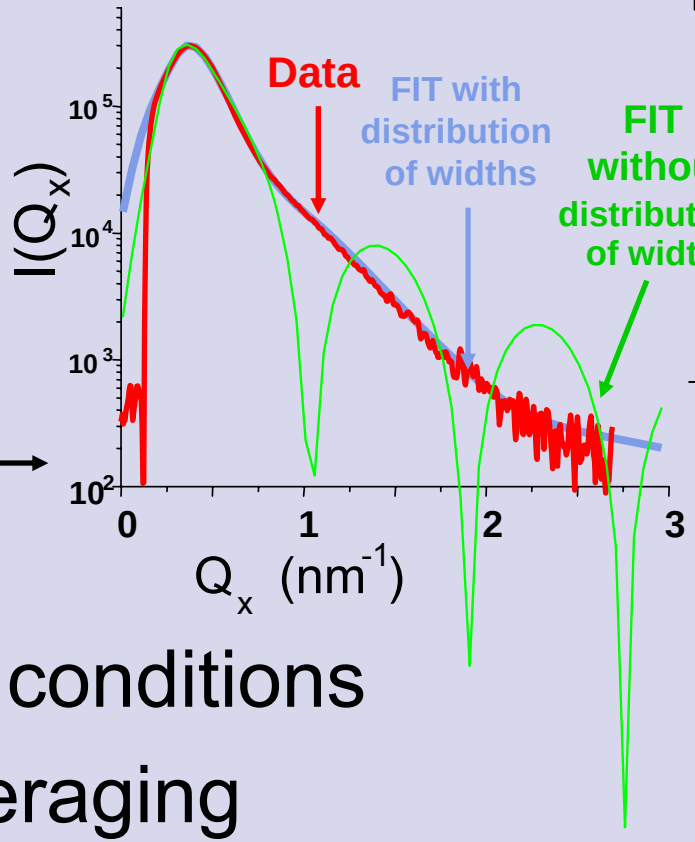
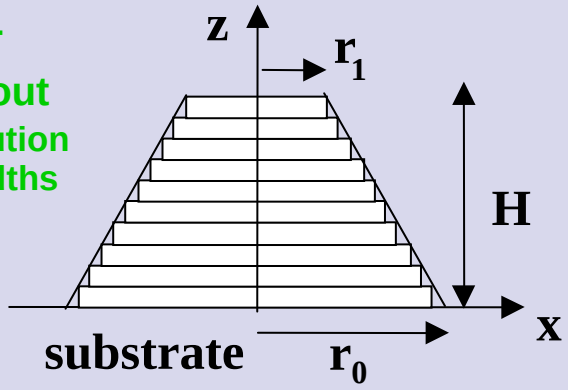
SAXS allows “realtime”





Parallel cross-section **Truncated pyramid**

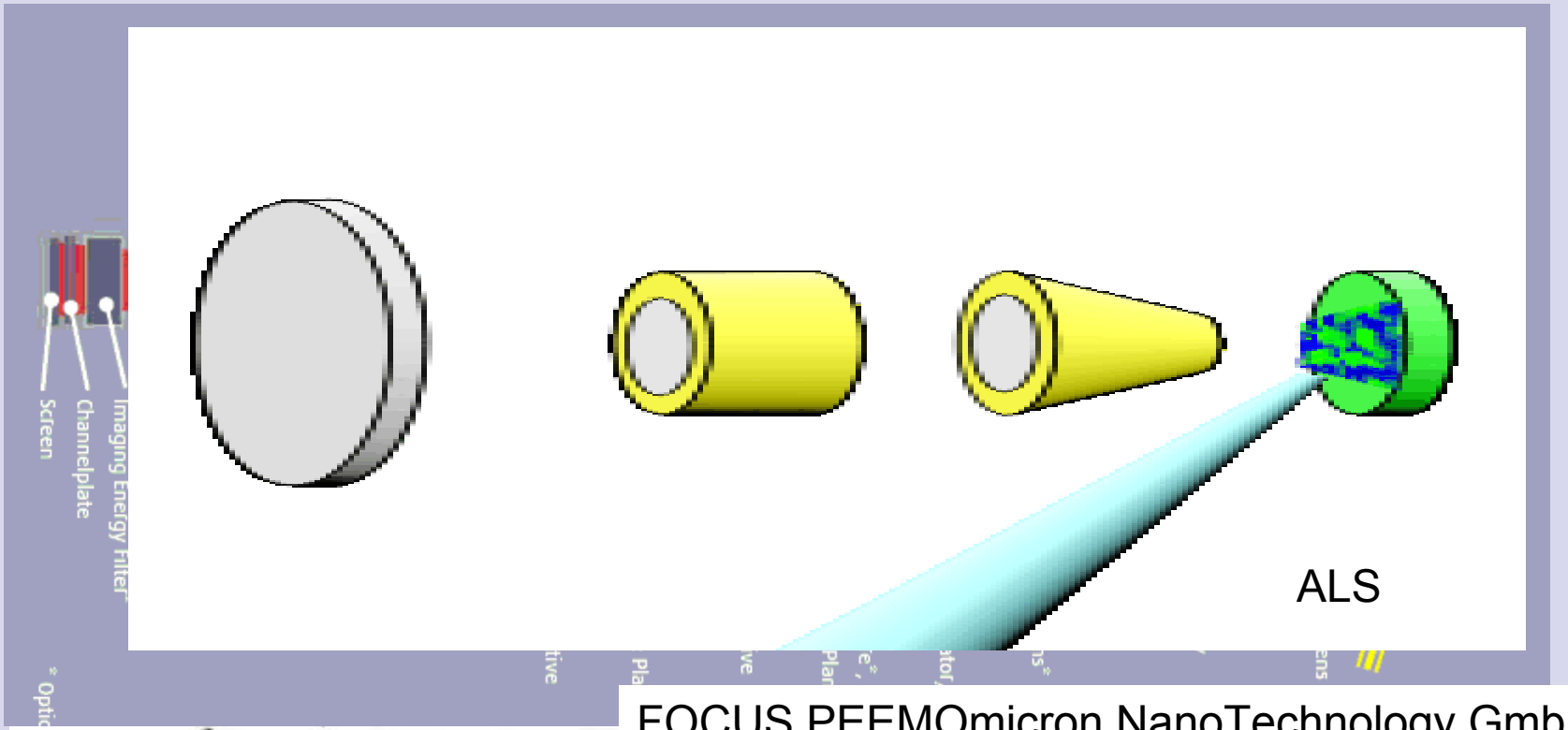


- Under growth conditions
- Ensemble Averaging

FITS :

r_0=11 nm
r_1=5.8 nm; H=5.1 nm
Distributions:
$(FWHM)_x$ = 16 nm;
$(FWHM)_z$ = 3 nm

Photoemission Electron Microscope / Low Energy Electron Microscope



FOCUS PEEMOmicron NanoTechnology GmbH

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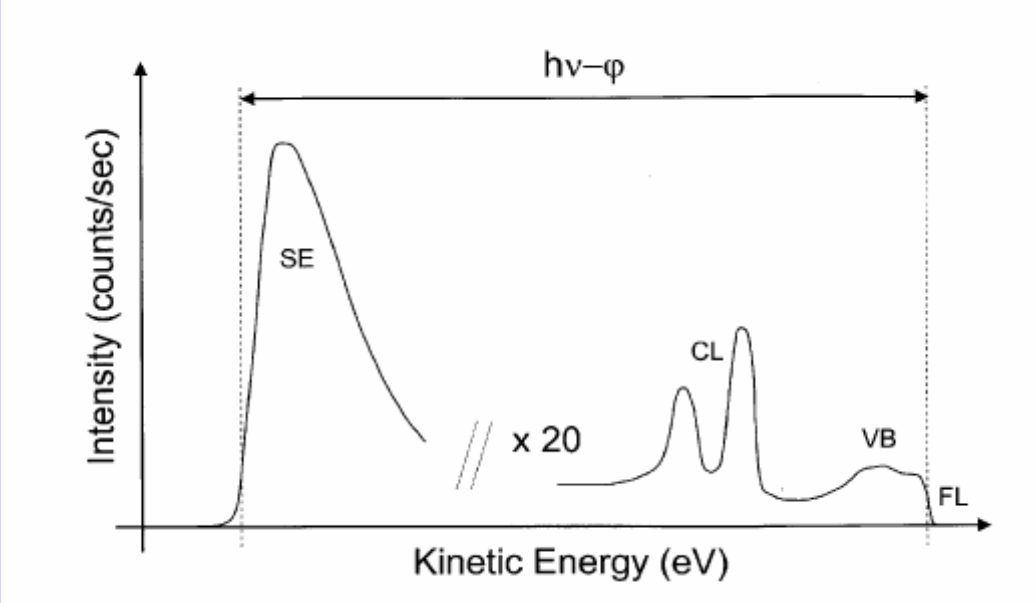
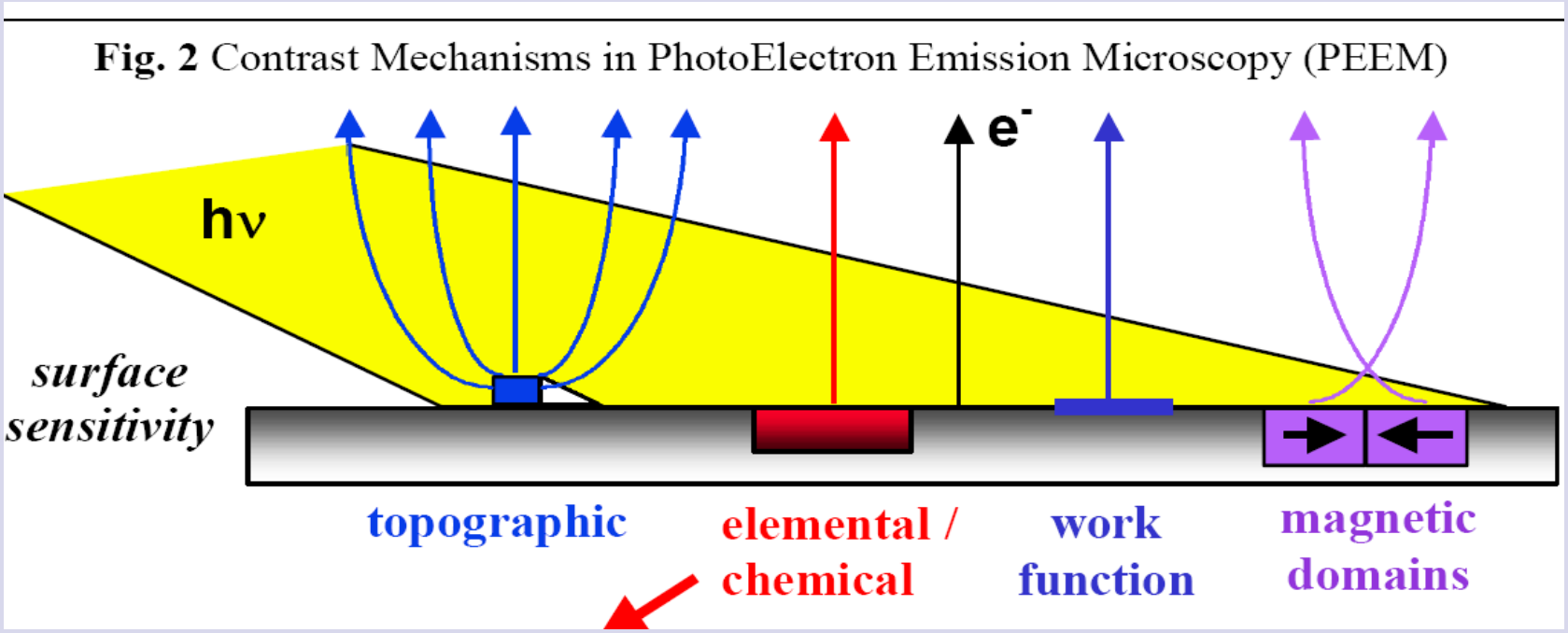
Photon generated Image Contrast

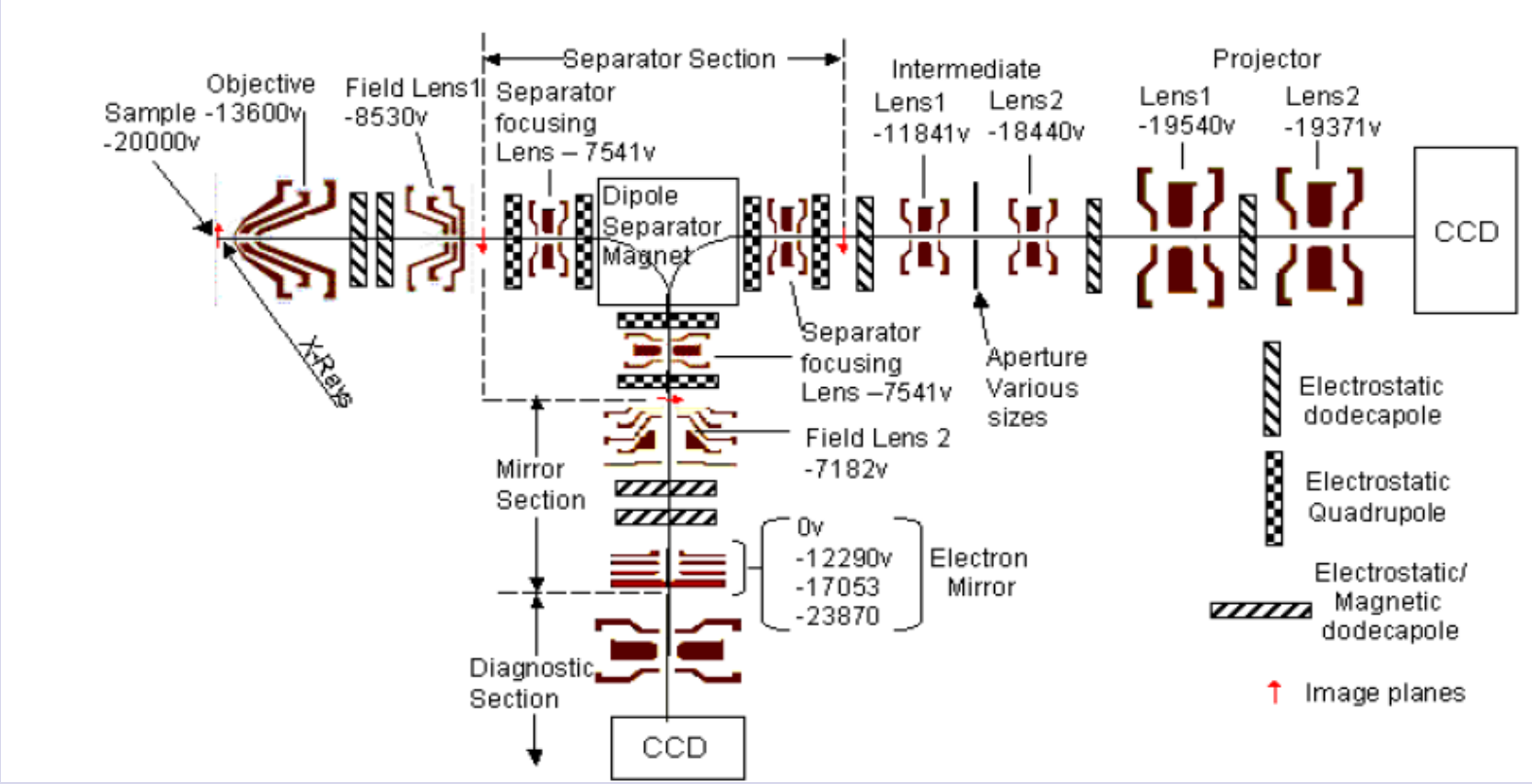
- Low energy secondary electrons
  - TV rate imaging
- Core level electrons
  - Chemical state determination
  - Slower scan rates 60 sec



S. Günther et al. / Progress in Surface Science 70 (2002) 187–260



PEEM3 ALS



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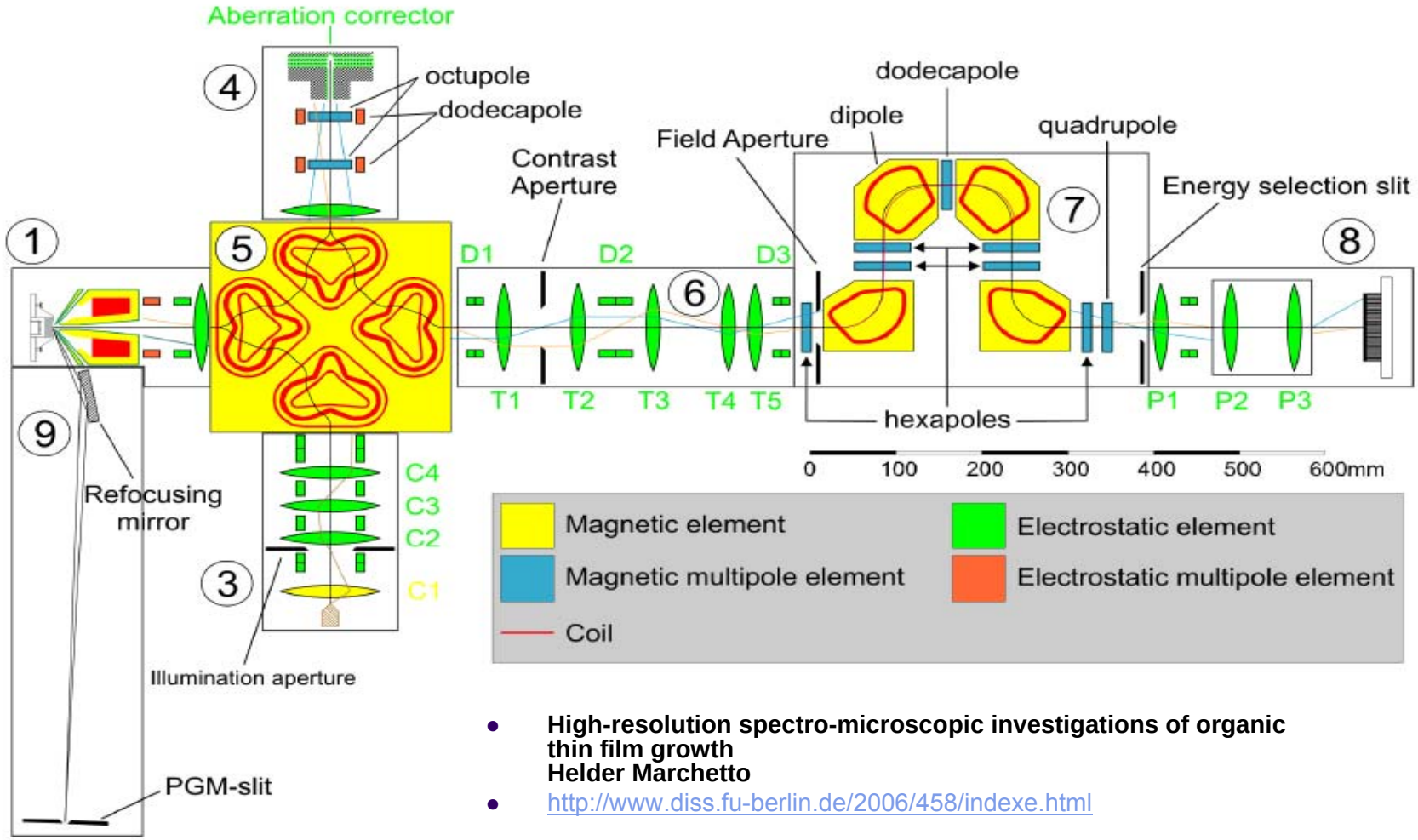
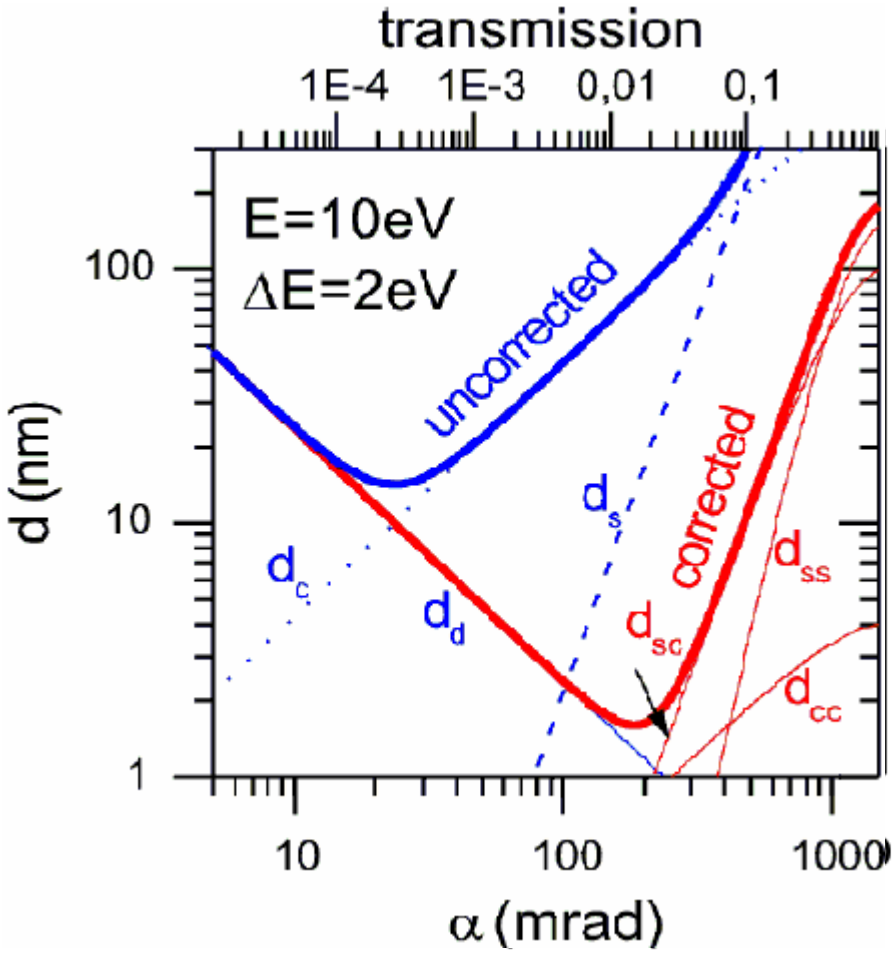
SMART PEEM/LEEM BESSY



- **High-resolution spectro-microscopic investigations of organic thin film growth**
  Helder Marchetto
- http://www.diss.fu-berlin.de/2006/458/indexe.html

Aberration Correction



$$d = \sqrt{d_{\mathrm{d}}^2 + (d_{\mathrm{s}}/2)^2 + d_{\mathrm{c}}^2}$$

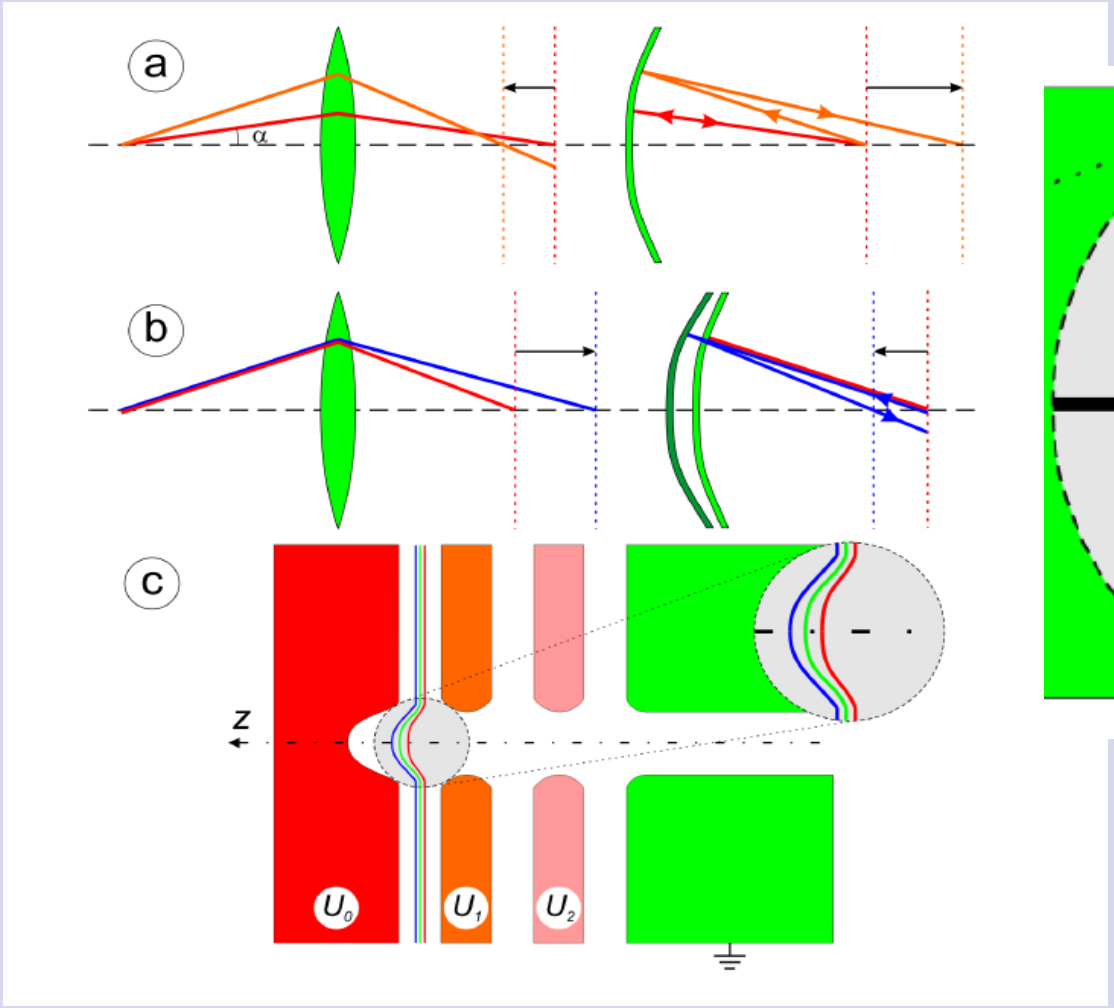
$$d_{\mathrm{s}} = C_{\mathrm{s}} \sin^3 \alpha$$

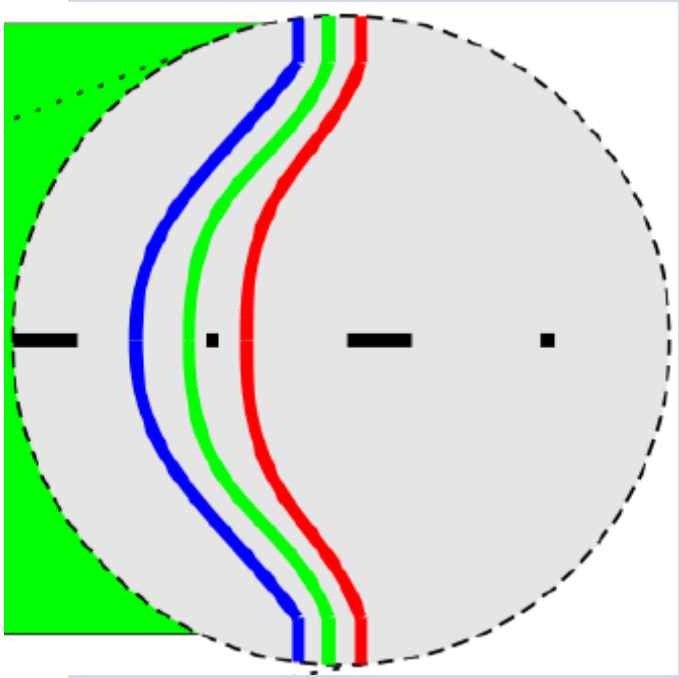
$$d_{\mathrm{c}} = C_{\mathrm{c}} \frac{\Delta E}{E_0} \sin \alpha$$

$$d_{\mathrm{d}} = 0.61\, \lambda / \sin \alpha$$

- **PhD Thesis**
  Helder Marchetto

Aberration Correction Electron Reflection Mirror





- PhD Thesis
  Helder Marchetto

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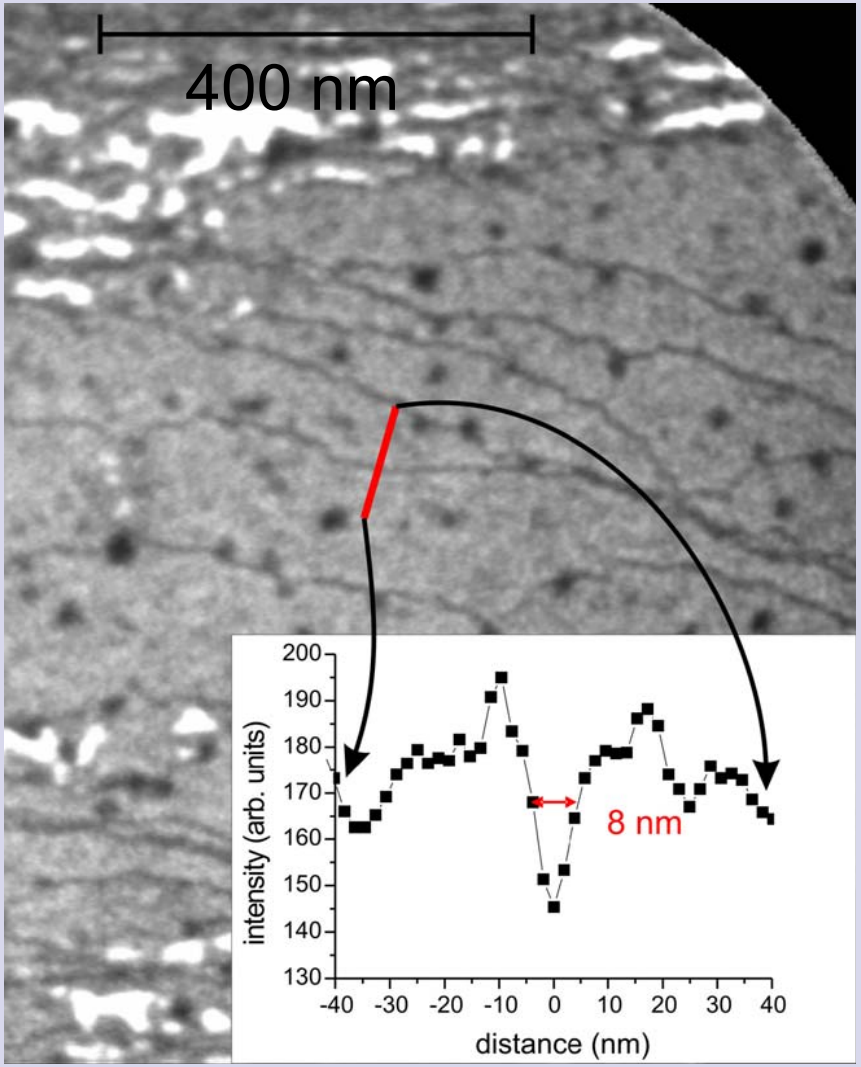
Lateral resolution in Leem after Aberration Correction

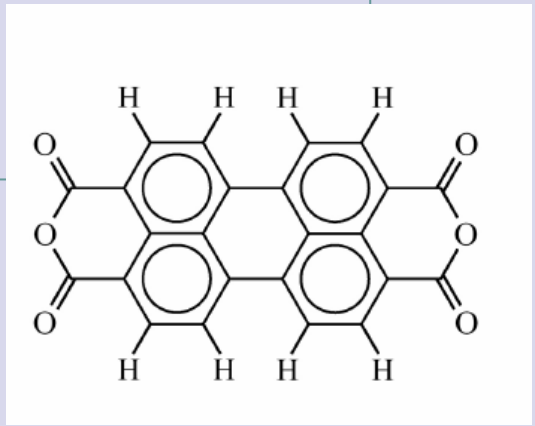


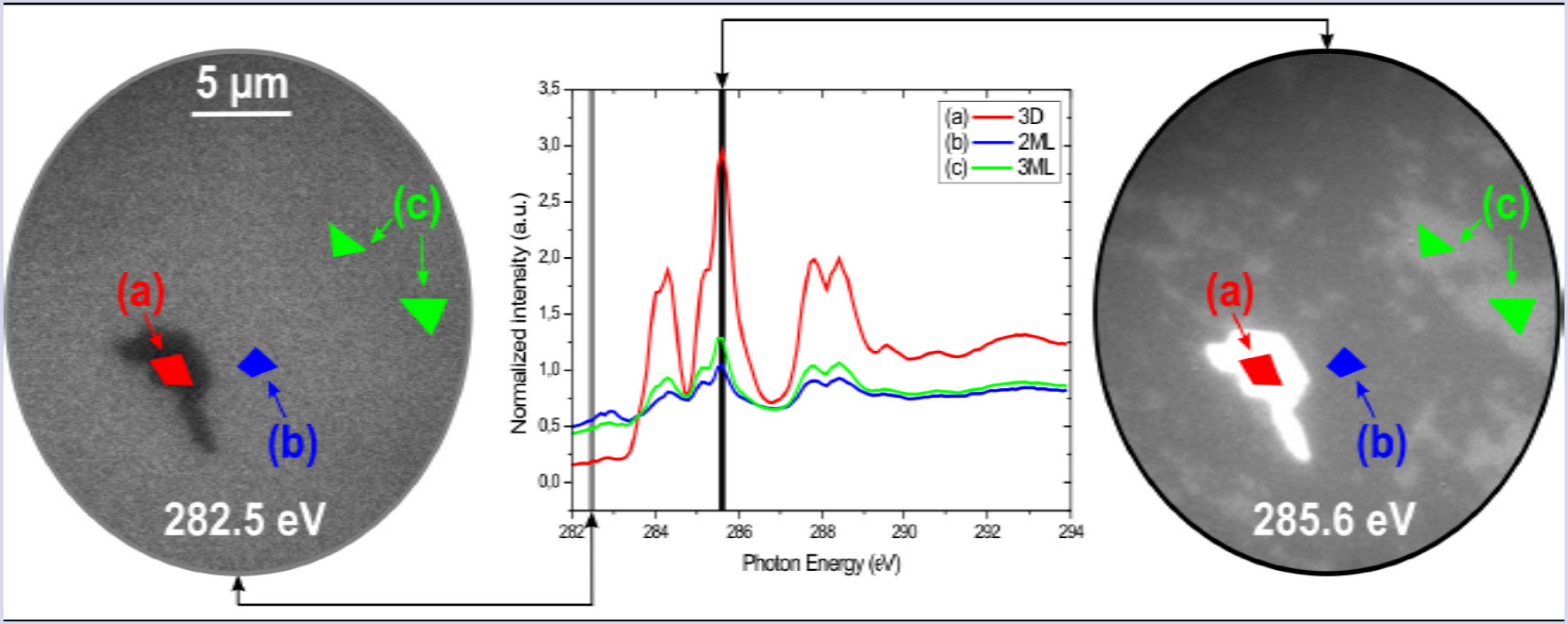
- Step edge Imaging on Au (111) Electron Kinetic Energy 18 eV

- **PhD Thesis**
  Helder Marchetto

Adsorption of PTCDA Ag(1 1 1)

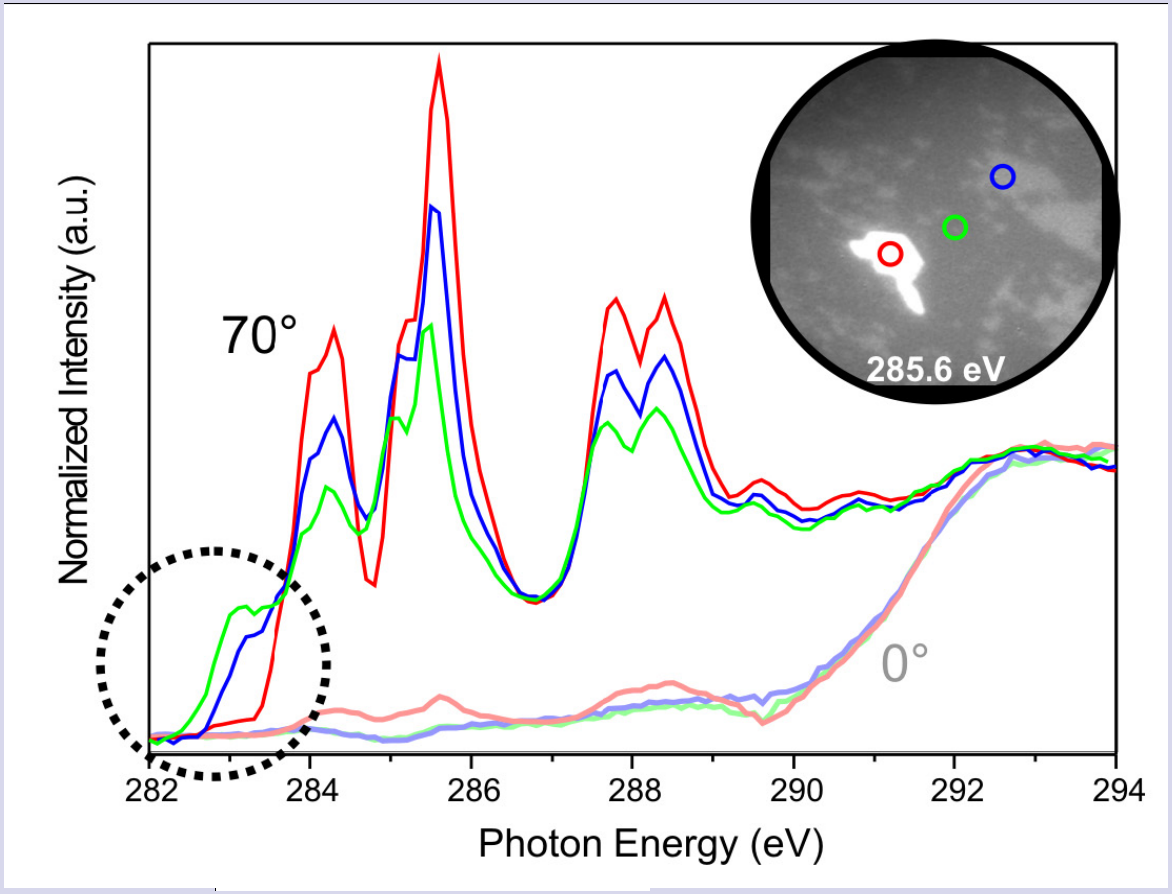
- Nominal total deposition of 5 ML





H. Marchetto et al. / Chemical Physics 325 (2006) 178–184

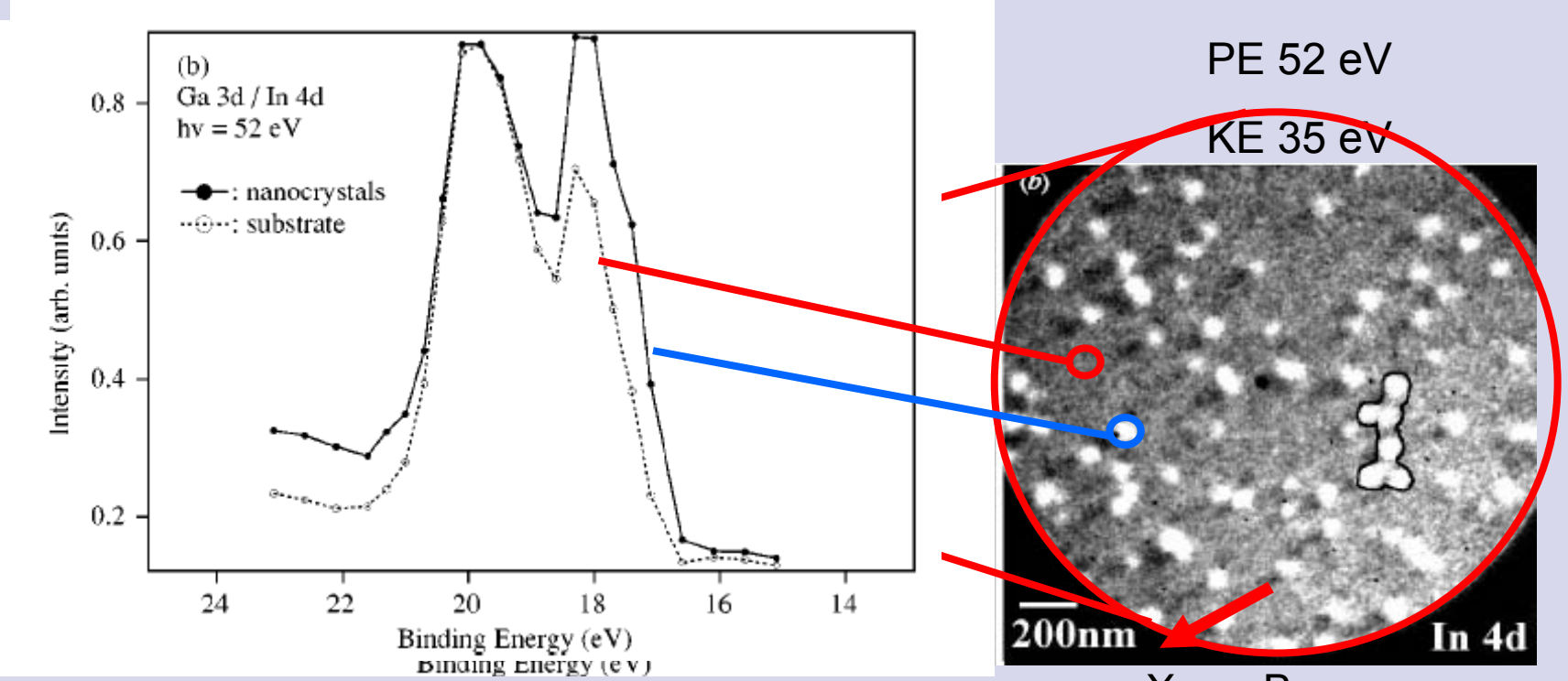
Variable Polarization Contrast



- All layers are flat to the surface Including the multilayer islands

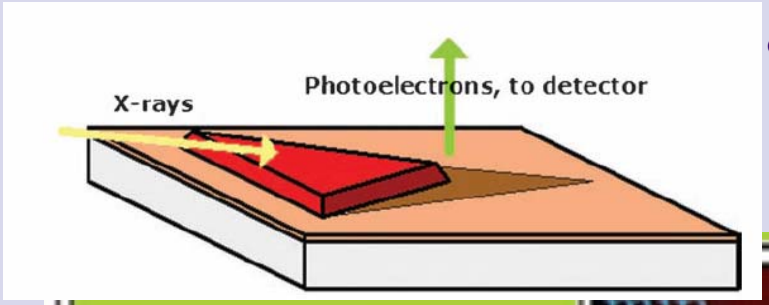
InAs Nanocrystals on GaAs(001)

- Used SPELEEM at Elettra



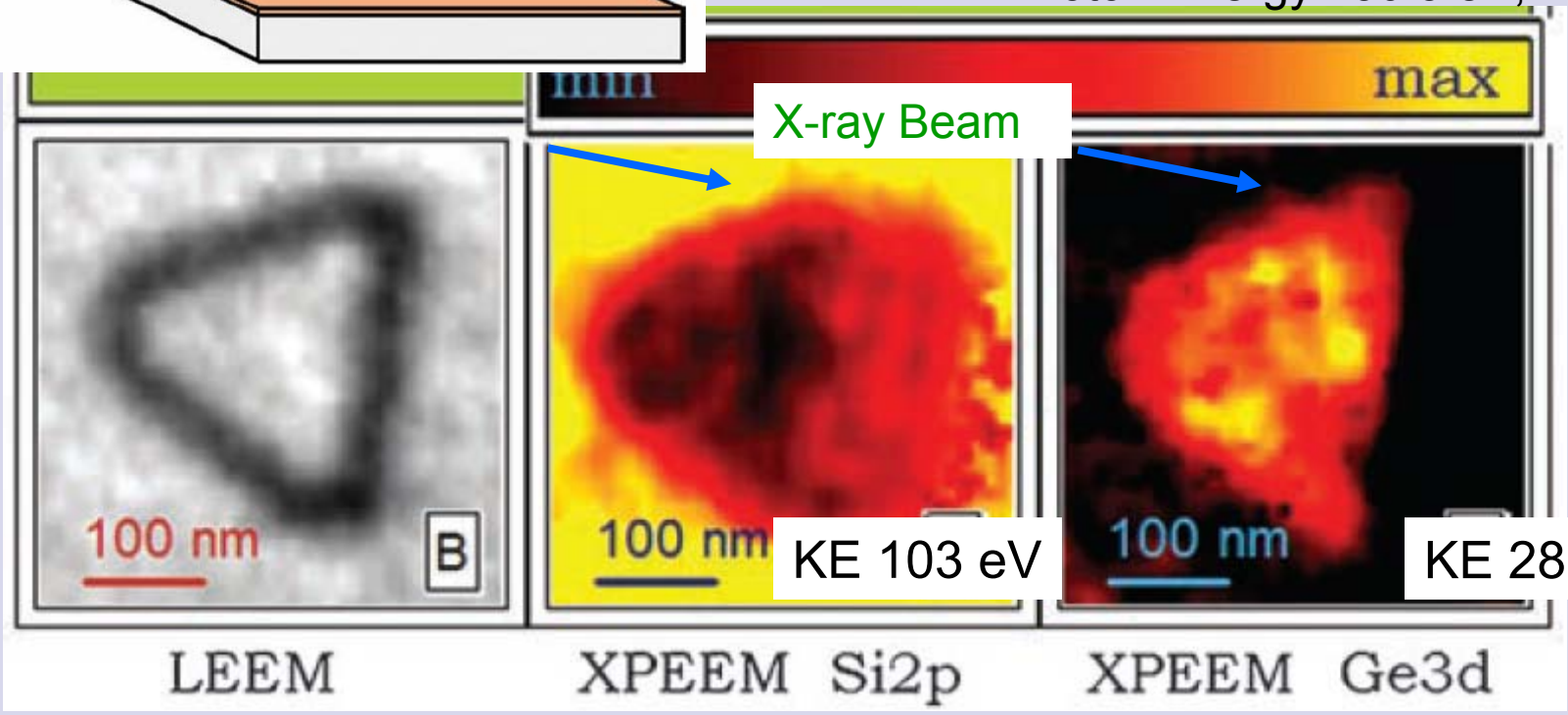
S. Heun et al Phys Rev B, 63, 125335

Ge(Si) Nanostructures



- Shadow Height estimated island height 25nm

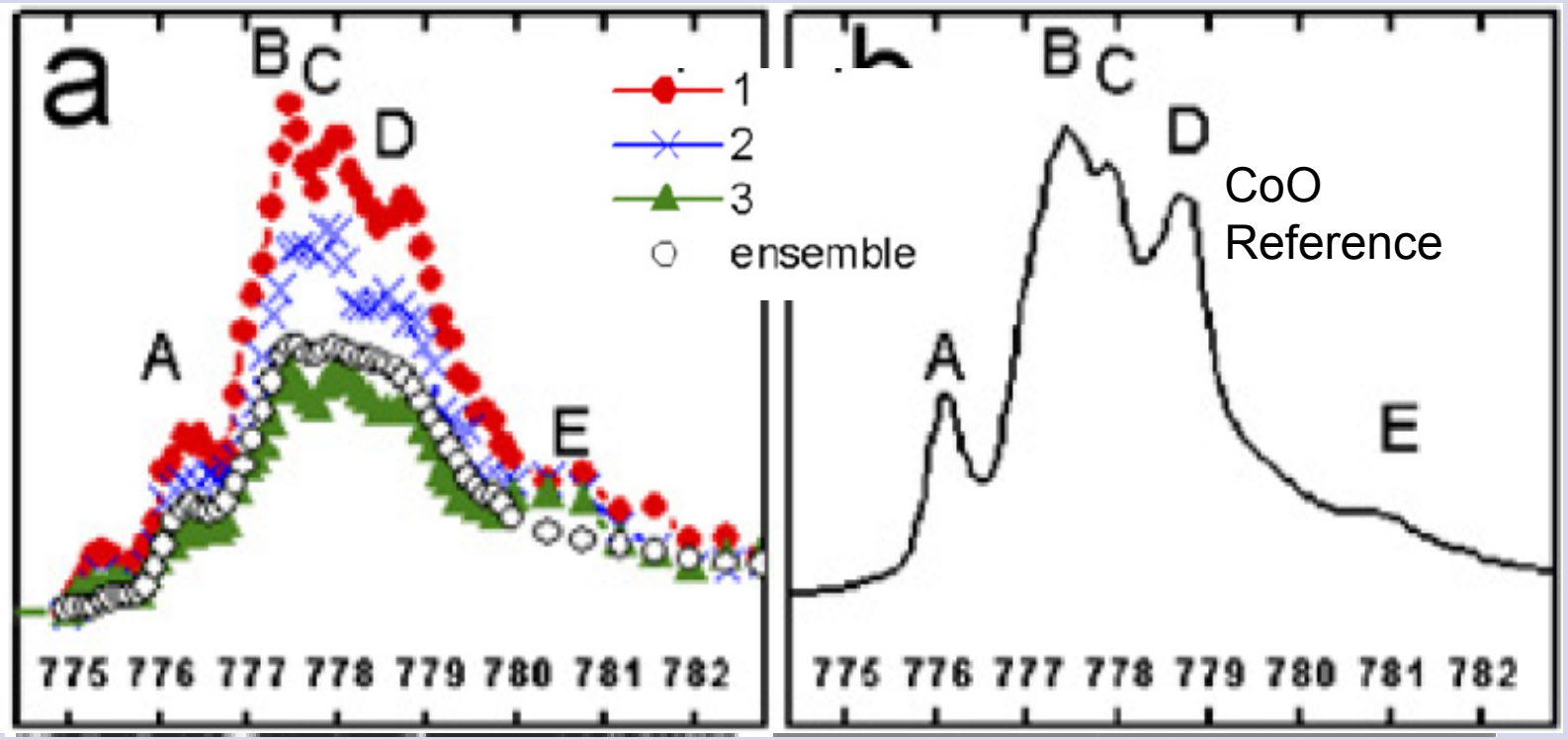
Photon Energy 130.5 eV,



F. Ratto et al small 2006, 2, No. 3, 401 – 405

Co 8nm particles on Silicon

- PEEM resolution 50 nm Individual particles have to be well spread out



A. Fraile Rodriguez et alJ. of Magn. and Mag. Mat. 316 (2007) 426–428

Commercial Instruments are the key to increased uptake

- Staib Instruments
- Omicron
- ELMITEC GmbH – Aberration Compensated LEEM/PEEM
- SPECS

Future Aberration Corrected PEEM

- Spectroscopic measurements
  - NEXAFS is enough (ALS)
  - Micro XPS is a very useful addition
  - LEEM – very useful for setting up aberration corrections for PEEM
  - 20 microns is fine with much higher transmission
- Only problem – 10 years and counting since Aberration correction was first proposed!