Spectromicroscopic Measurements of Self-organized InAs Nanocrystals

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Introduction:

Motivation:

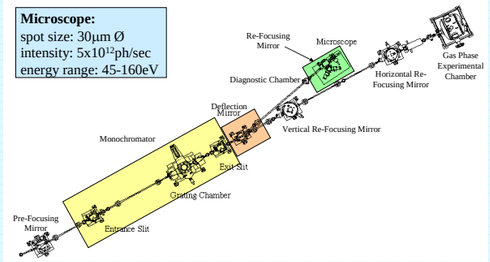
Nanocrystals
- quasi zero-dimensional quantum effects
- semiconductor lasers

Self organization during lattice-mismatched epitaxy:
- small high-quality uniform crystals

Few papers on single quantum dots; most experiments average over several objects (size fluctuations)

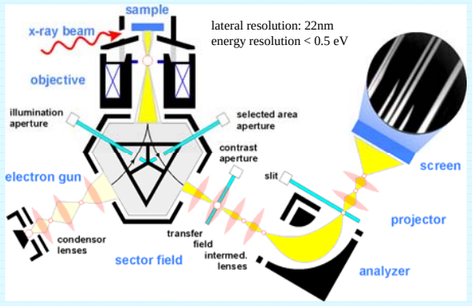
Purpose of this work:
- Electronic structure of a single InAs nanocrystal
- Photoelectron spectroscopy with high spatial resolution
- Feasibility study

SPELEEM / Gas Phase beamlines:



The SPELEEM:

(Spectroscopic photoemission and low energy electron microscope)

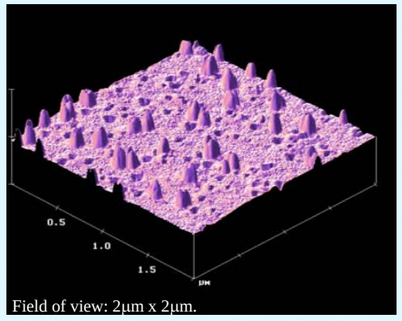


Sample preparation:

- Substrate
  - GaAs(001) 0.5¡ off
- Nanocrystal fabrication process (in Tsukuba, Japan)
  - Surface cleaning, GaAs buffer layer growth, Se treatment, InAs growth by molecular beam epitaxy (MBE), annealing
  - As capping to protect samples during transfer in air
- Characterization
  - Integral photoelectron spectroscopy at beamline BL-1A at the Photon Factory, Japan
  - SPELEEM at beamline 6.2LL at Elettra

Capping and Decapping:

Atomic Force Microscopy (AFM):



Field of view: 2µm x 2µm.

AFM on an InAs / Se / GaAs heterostructure after capping and decapping: The InAs nanocrystals are still there! Island size, shape, and density remain unchanged.

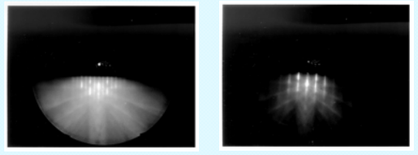
(Average island size: 100 nm. Average island height: 15 nm. Island density: 30 μm^{-2}, 3 x 10^9 cm^{-2}. RMS roughness: 5 - 10 nm.)

Integral Photoelectron Spectroscopy:

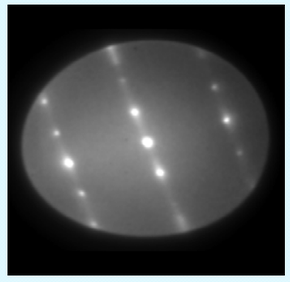
The measurements performed at the Photon factory in Tsukuba, Japan, demonstrate the reproducibility of the surface stoichiometry after capping and decapping.

For details, see: Y. Watanabe, S. Heun, Th. Schmidt, and K. C. Prince, Jpn. J. Appl. Phys., in press.

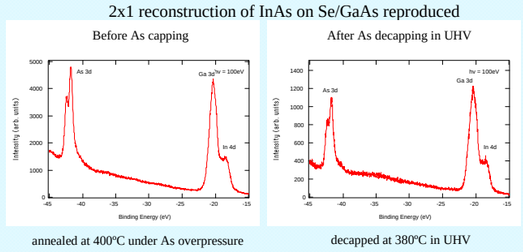
Electron Diffraction:



With RHEED in the MBE-chamber:
InAs / Se / GaAs surface reconstruction after growth: 2x1



After capping and decapping, LEED with the SPELEEM:
2x1 reconstruction of InAs on Se/GaAs reproduced

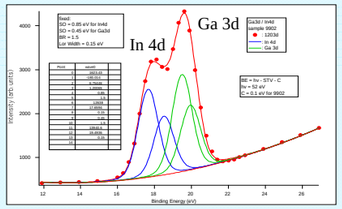


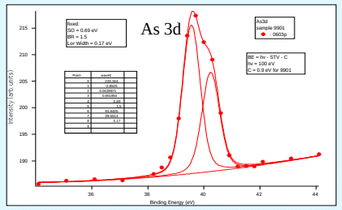
annealed at 400ºC under As overpressure

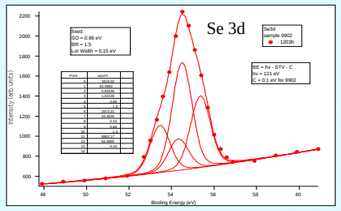
decapped at 380ºC in UHV

Spectromicroscopy with the SPELEEM:

Integral photoelectron spectra:





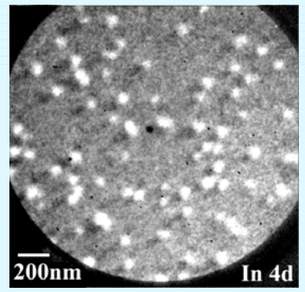


Spectra obtained by integration of series of SPELEEM images.

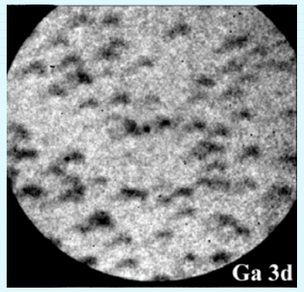
Ga 3d and In 4d peaks are clearly resolved. This implies that chemical contrast can be obtained in XPEEM.

Good agreement between spectra from SPELEEM and from Photon Factory.

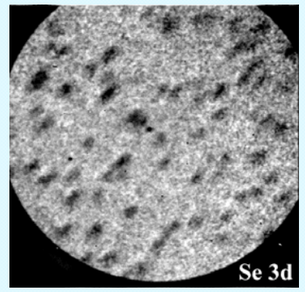
Soft x-ray photoemission electron microscopy (XPEEM):



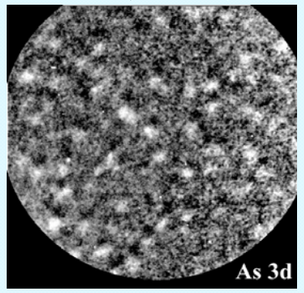
hv = 52 eV, E_b= 17.4 eV, FoV: 2µm



hv = 52 eV, E_b= 20.1 eV, FoV: 2µm



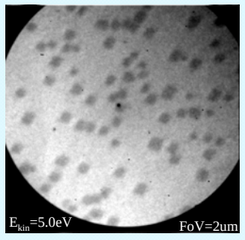
hv = 121 eV, E_b= 54.7 eV, FoV: 2µm



hv = 121 eV, E_b= 40.7 eV, FoV: 2µm

In the image obtained at the photoelectron kinetic energy corresponding to the In 4d core level, InAs nanocrystals appear brighter than the Se-terminated GaAs-substrate. The contrast is inverted at the energy of the Ga 3d core level.

LEEM:



Summary:

Results:

- Amorphous As-capping is effective in protecting InAs nanocrystal samples during transfer in air.
- Electronic properties and morphology of the samples are not changed by capping and decapping.
- LEEM and XPEEM images were obtained.
- Ga 3d and In 4d peaks were resolved.

Conclusion:

- It works !!!

Outlook:

- Photoelectron spectra of single nanocrystals (core levels and valence band)
- size effects ???

Proposed structure model: