elettra SPELEEM

Core level photoelectron spectroscopy from individual heteroepitaxial nanocrystals on GaAs(001)

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NTT

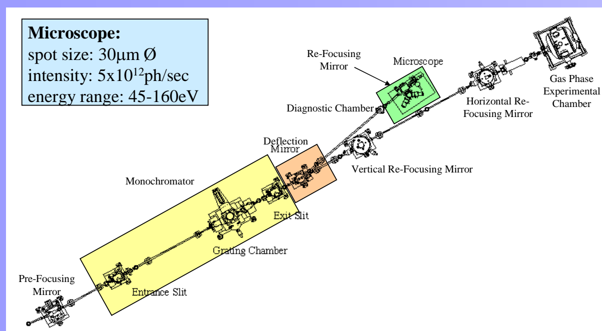
Introduction:

Nanocrystals formed by self-organization during strained-layer epitaxy
- Quasi zero-dimensional quantum effects (quantum dots)
- Semiconductor lasers and memory applications
- No lithography: cost-effective way

BUT:
- Size fluctuations: need for nano-scale spectroscopy
- Segregation and interdiffusion observed for Ge/Si and for InAs/GaAs

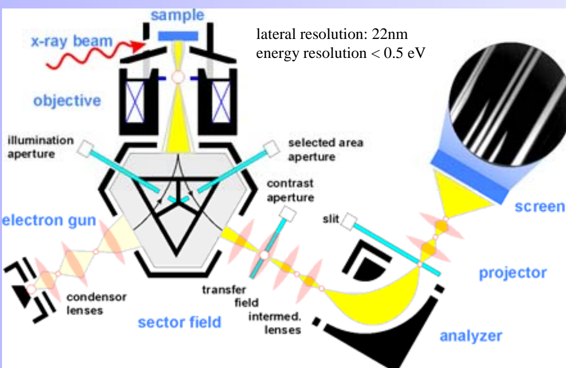
Purpose of this work:
- Photoelectron spectroscopy with high spatial resolution
- Determination of the elemental composition of the nanocrystals
- Electronic structure of a single InAs nanocrystal

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 (forming a 2-3 ML-thick film of Ga_2Se_3 on top of bulk GaAs), deposition of nominally 2 ML of InAs by MBE

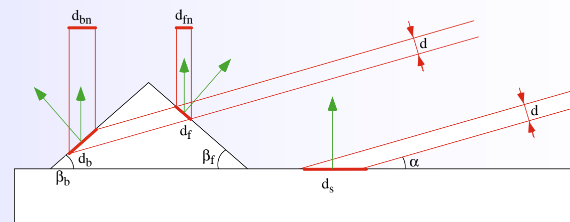
As capping to protect samples during transfer in air

Characterization with SPELEEM at beamline 6.2LL at Elettra

Lattice constants at room temperature:

GaAs	InAs	Ga_2Se_3	In_2Se_3
5.653 Å	6.058 Å	5.429 Å	5.82 Å

Sample topography vs. photoelectron yield:



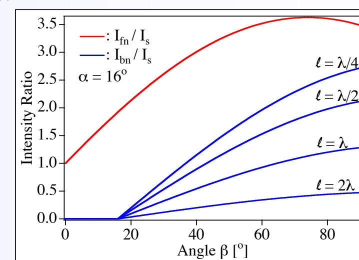
For emission along the sample normal: photoelectron intensity ratio from inclined to flat unit areas of the sample:

$$\frac{I_{fn}}{I_s} = \frac{\sin(\beta_f + \alpha)}{\sin \alpha}$$

In transmission:

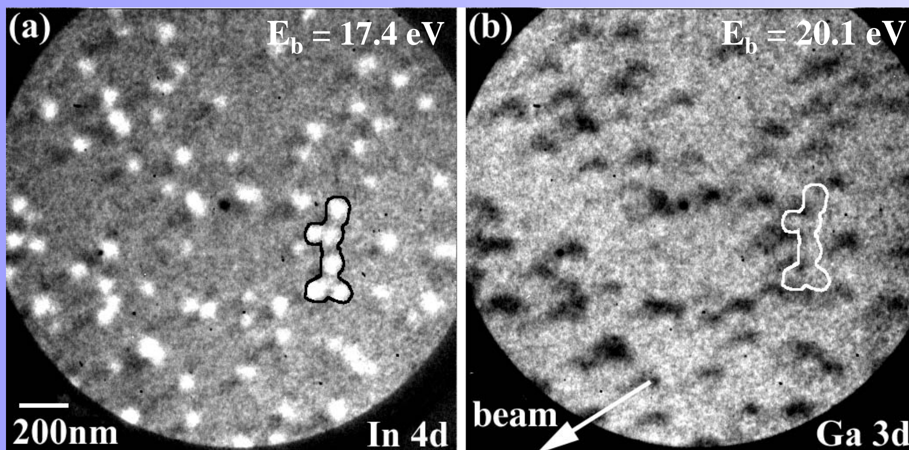
$$\frac{I_{bn}}{I_s} = \frac{\sin(\beta_b - \alpha)}{\sin \alpha} e^{-\ell/\lambda}$$

with λ: x-ray attenuation length

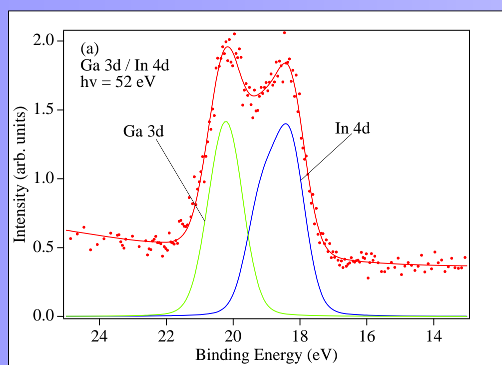


XPEEM:

hν = 52 eV
FoV = 2 μm



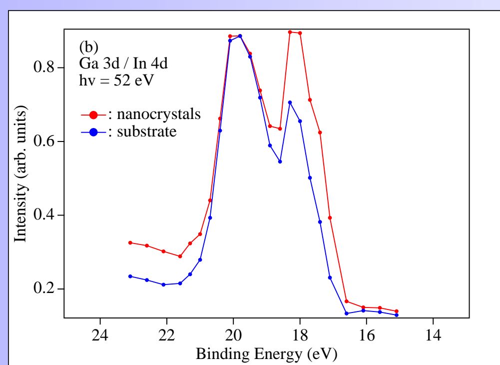
nanocrystal height from their shadow length: 22 nm



Integral spectrum

good agreement with literature values

↑ samples not changed by capping / decapping



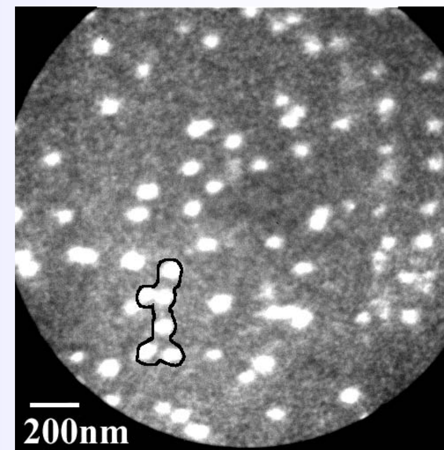
Laterally resolved spectra

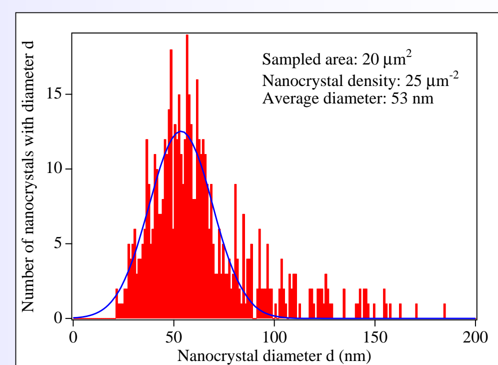
In on substrate ↑ SK growth mode

Ga on nanocrystals

LEEM:

E = 26.5 eV
FoV = 2 μm





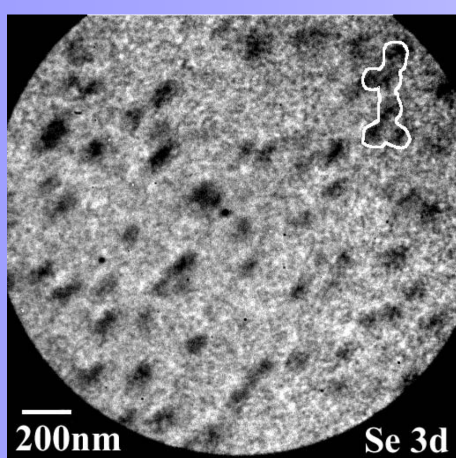
Volume of nanocrystals: 6 x 10^5 nm^3 per μm^2

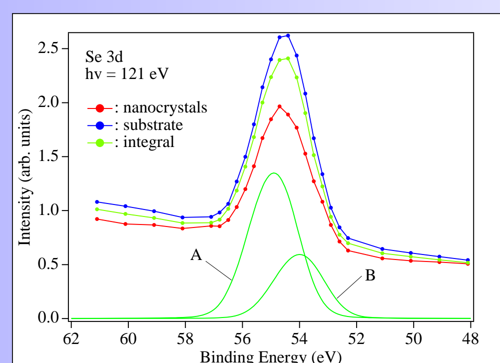
2 ML InAs correspond to 6 x 10^5 nm^3 per μm^2

SK growth mode ↑ nanocrystal volume is greater than expected, additional material from another source (Ga_2Se_3)

XPEEM:

Eb = 54.7 eV
hν = 121 eV
FoV = 2 μm





Se on nanocrystals

A: Se in Ga_2Se_3 coordination; B: Se near the surface

Intensity ratio A / B = 2.26; clean Se/GaAs: A / B = 1.51

↑ less B species after deposition of InAs

↑ some material moved from surface to nanocrystals

Discussion:

- Growth at 200°C: GaAs inert
- Reaction between InAs and Ga_2Se_3
- Formation of a quaternary unlikely (As and Se from different chemical groups)
- Alloying on cation sublattice (strain minimization)
- Phase separation on anion sublattice (like in $InAs_xSb_{1-x}$)
- No bulk inclusions of Ga_2Se_3 in the InAs nanocrystals (10% lattice mismatch)

Summary:

- During initial stage of growth, an $In_xGa_{1-x}As$ wetting layer is formed which is capped by $(In_yGa_{1-y})_2Se_3$.
- $(In_zGa_{1-z})_2Se_3$ covered InAs nanocrystals are formed on this surface.