Ordering and Strain in Quantum Dot Molecules

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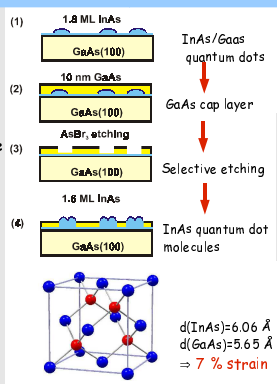
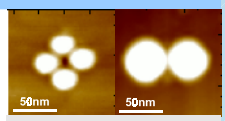
Quantum Dot Molecules

Introduction

Lateral quantum dot molecules have been proposed as building blocks for quantum computers. They can be produced by MBE growth. The nuber of the quantum dots is controlled by the substrate temperature.
Strain, surface migration and interdiffusion seem to be crucial for the understanding of the formation process.
We present grazing incidence X-ray diffraction results giving information about shape, size, strain, and interdiffusion of ordered and disordered InAs/GaAs quantum dot molecules.





- MBE growth of InAs/GaAs quantum dots
- Temperature-controlled island nucleation at the borders of nanoholes ⇒ quantum dot molecules
- Nanoholes by selective etching or electron beam lithography

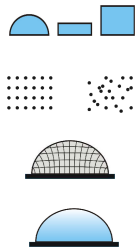
d(InAs)=6.06 Å
d(GaAs)=5.65 Å
⇒ 7 % strain

X-ray Scattering on QD's

Experimental

- GID and GISAXS on lateral quantum dot molecules
- X-ray energy 8 keV
- Focussed x-ray beam, 200x200µm
- Penetration depth 60 Å
- Sample protected from beam damage by He atmosphere

- Shape (GISAXS, GID, XRD)
  average shape, size distribution
- Position (GISAXS, GID, XRD)
  average distances, order vs. disorder
- Strain (GID, XRD)
  strain profile, averaged over all objects
- Interdiffusion (anomalous scattering)
  concentration profile, averaged over all objects



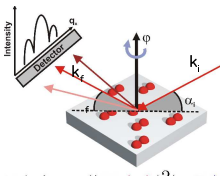
GISAXS on Bimolecules

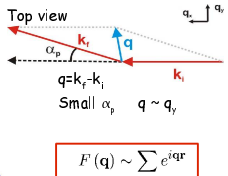
GISAXS

Grazing Incidence Small Angle X-ray Scattering

⇒ Information about

- Average shape of object
- Average distribution of objects
- For objects on surface and for buried objects





$$I(\mathbf{q}) \sim \langle |F(\mathbf{q})|^2 \rangle \, S(\mathbf{q})$$

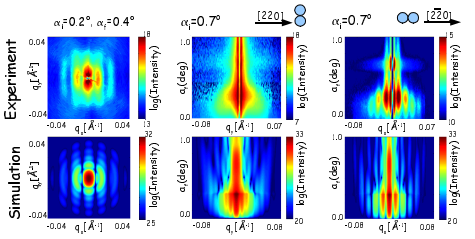
$$F(\mathbf{q}) \sim \sum e^{i\mathbf{qr}} \quad \text{for all r object}$$

Form factor
(FT of the shape of a single object)

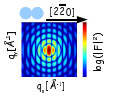
Total interference function
(FT of the correlation function of the positions)

Experiment

- Asymmetry between [110] and [1-10] due to alignment of the dots
- Narrow size distribution
- Good alignment in [1-10]
- Shape in good agreement with AFM observations



Model:
R_o=270 Å
R_i=130 Å
H=170 Å
R distribution: ± 0.1 R
H distribution: ± 0.2 H



Formfactor of 2 disks
- Size of disk → rings
- Distance of disks → stripes

Disordered Quad Molecules

Sample

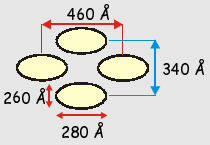
- 1.8 ML InAs on GaAs(001)
- Disordered holes produced by selective etching
- Hole diameter approx. 700 Å
- Hole depth 50 Å

Results

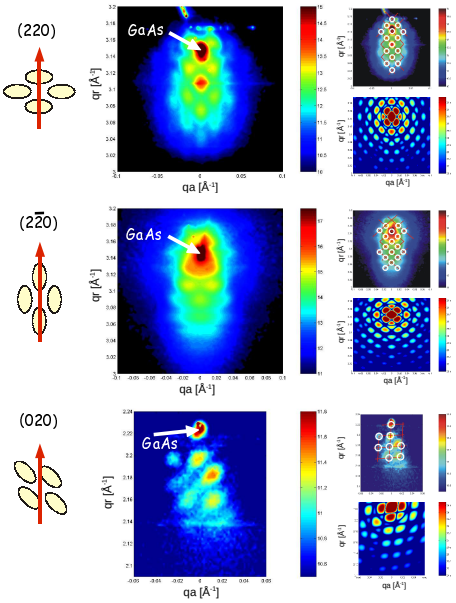
- Intensity oscillations due to shape and distance of the dots
- Main scattering intensity from the dots, not from the (partially?) filled hole
- Lateral lattice constant of the dots dominated by the substrate
- Slight strain relaxation (visible in radial intensity distribution)

Simulations

- No relaxation (d_{dot}=$d_{substrate}$)
- No interdiffusion
- Dot as disk
- Dots elongated along [2-20]



⇒ Model reproduces main experimental features



GID on Bimolecules

GID

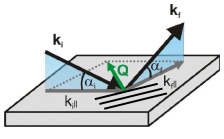
Grazing Incidence Diffraction

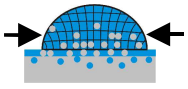
⇒ Information about

- Average shape of object
- Average distribution of objects
- Strain distribution

α_i, α_f small

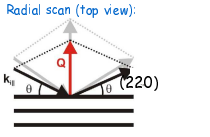
- Small penetration depth surface sensitive
- Scattering vector $q=k_f-k_i$ in the surface plane

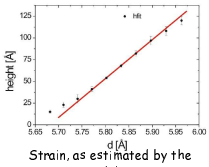




Substrate induces strain mainly parallel to the surface

Radial scan (top view):

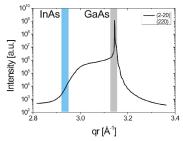


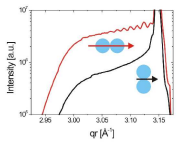


Strain, as estimated by the isostrain model

Experiment

- Lattice parameter distribution between d(InAs) and d(GaAs)
- Anisotropy between (220) and (2-20) due to alignment of dots
- Main part of dot strained
- Model: Nonlinear strain profile





Summary and Conclusions

Summary

- Bimolecule sample:
  - GISAXS: result for shape corresponds to AFM measurement
  - Anisotropy (GISAXS and GID) due to alignment of dots
  - Lattice parameter distribution between d(GaAs) and d(InAs)
  - First simulations: nonlinear strain profile
- Quadmolecule sample:
  - Strain distribution similar to bimolecules
  - Distance between dots in [110] and [1-10] are not equivalent

Conclusions

- Strain distribution similar to single quantum dots grown on a flat surface
- Bi- and quadmolecules show similar strain profiles

Future projects

- GISAXS on quadmolecules
- qr/qa maps on bimolecules
- Detailed modelling of the data
- Anomalous scattering in order to study the concentration profile
- Systematic study of different growth stages of the quantum dot molecules

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