Morphology, Composition and Strain: TEM Image Contrast of Self-assembled Quantum Dot Structures of Semiconducter Materials

P. Werner, K. Scheerschmidt, N.Z. Zakharov, M. Grundmann, A. Taurino**, R. Schneider****

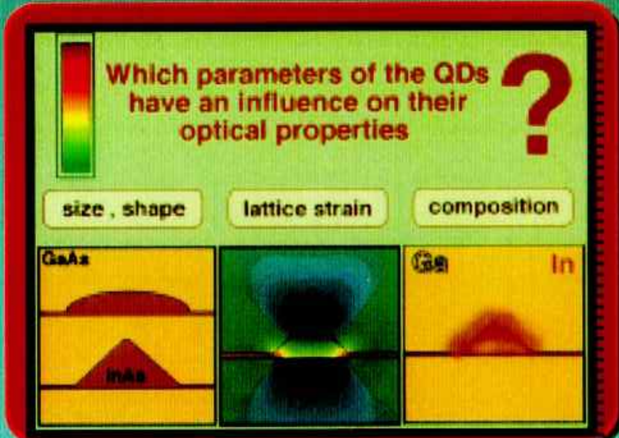
*MPI für Mikrostrukturphysik, Halle   *TU Berlin,   **CNR, Inst. For Advanced Electronic Materials, Lecce/Italy*
****Humboldt Universität Berlin*

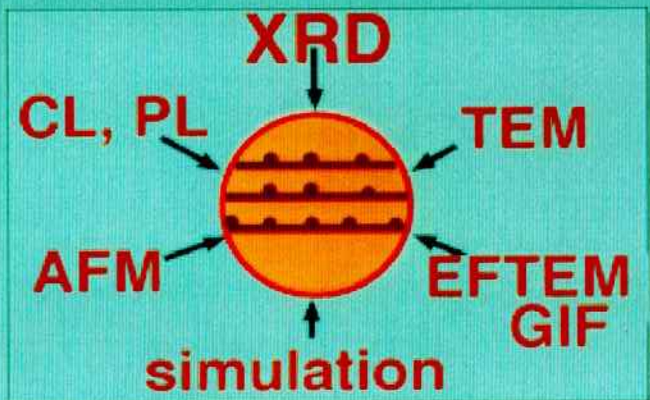
Introduction

Self-assembled quantum dot (QD) structures, either InAs/GaAs based or SiGe/Si-based systems, are characterized by novel electronic and optical properties. Especially the ability to arrange QD's in self-assembled 3-dimensional arrays opened the possibility for new electronic devices, such as QD-lasers and detectors.

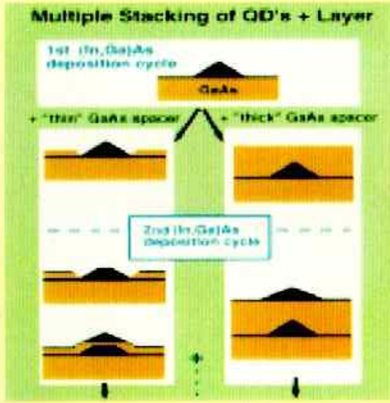
The formation and alignment of such small islands (size 10...30 nm) is based on the Stranski-Krastanow growth mode, which is a complex process between local lattice strain and diffusion kinetics. The electronic properties, especially the energy of quantum states do not only depend on the size, but also on the shape, the local strain and the chemical composition of the islands.

We demonstrate the application of different TEM techniques to investigate these parameters: conventional diffraction contrast technique, HREM and energy-filtered TEM. For a qualitative and quantitative image analysis contrast simulations are necessary. Especially molecular dynamics structure calculations demonstrate the influence of the shape (pyramid, spherical shape) and strain of islands on the TEM image contrast.

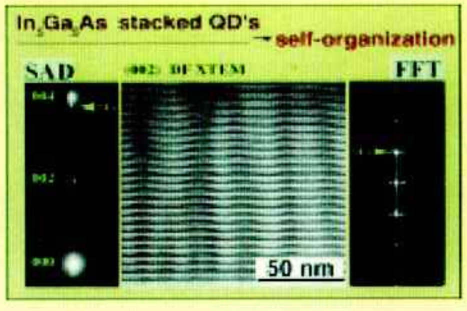




Growth

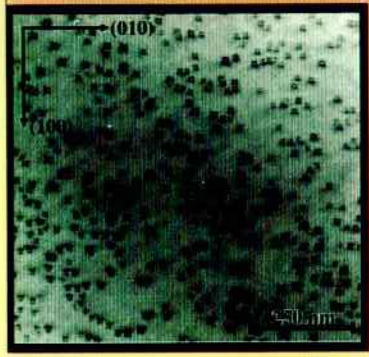


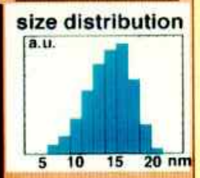
Scheme of the island growth by MBE or MOCVD. These techniques generate QD stackes as a form of "self-organization". Strong verticaland horizontal periodicities are demonstrated by SAD and FFT images.

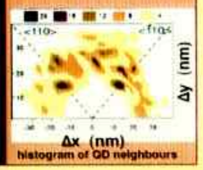


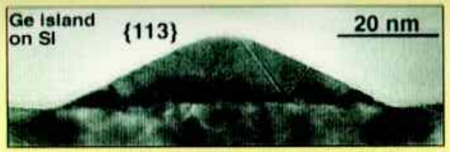
Morphology

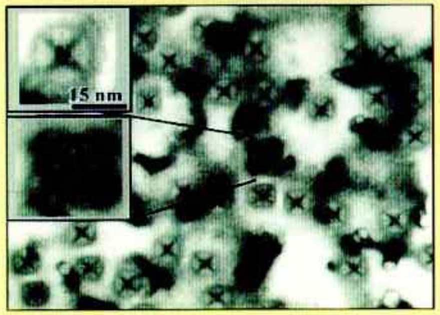
TEM plane-view of InAs QD's on (001) GaAs





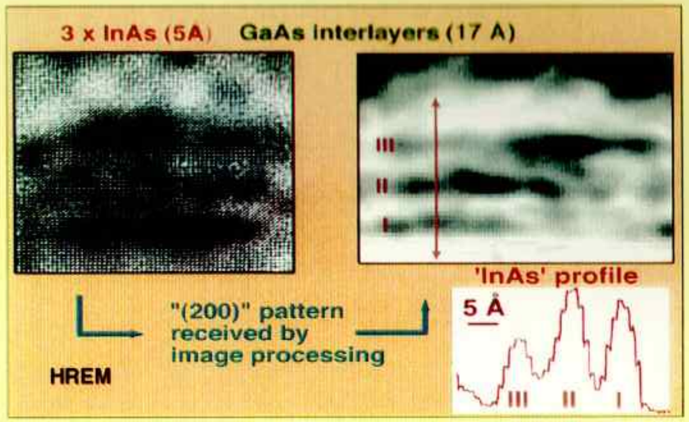






In plane-view bright-field mode islands are mainly visible by their strain fields. Examples of two islands of different size imaged in <001> on-axis.

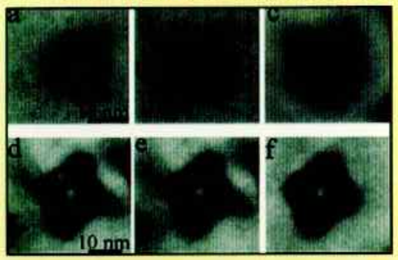
Chemical composition



Starting from HREM cross-section images, different image processing software is available to determine chemical composition. In this case: the indium "In" distribution profile) within 3 stacked **InAs** islands.

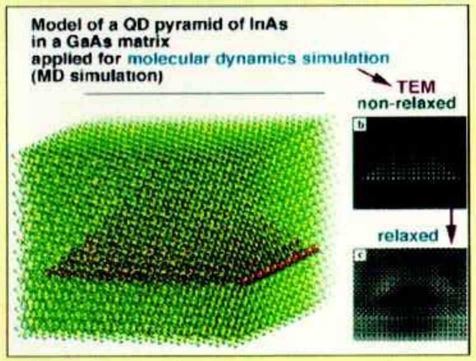
Lattice strain

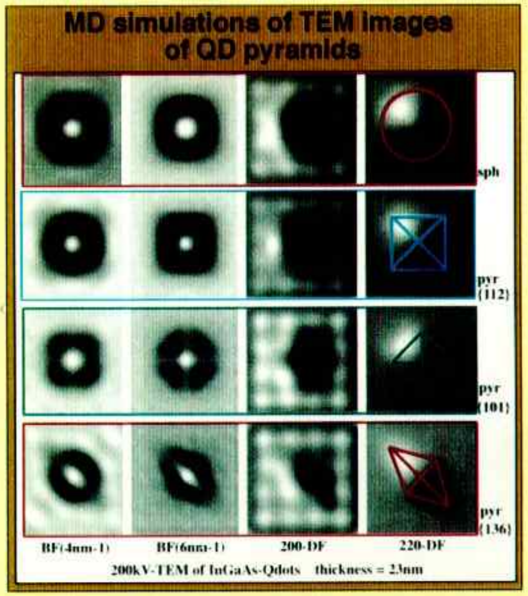
Experimental: capped InAs islands of different size



small capped island

large capped island





An appropriate tool to interpret experimental image contrast are image Simulations by molecular dynamics calculations (MD) including shape and strain of the islands, in this case of pyramids of different shape and surface planes.

EF TEM

"0-loss" image of a cross-section sample of a single QD layer of InAs in a GaAs matrix.

"chemical mapping" by GIF filter: On the right: line scan of the Ga content showing 2 minima within the QD

GIF image showing the In content within the island. right: "In" line scan.