HL 56 Quantum dots and wires: Preparation and characterization III

Time: Friday 11:00–13:15 Room: POT 51

HL 56.1 Fri 11:00 POT 51

Understanding Growth of InAs/GaAs Quantum Dot Nanostructures in Atomic Detail — •Thomas Hammerschmidt, Peter Kratzer, and Matthias Scheffler — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany

The experimental and theoretical investigations of the last decade lead to a good understanding of many aspects of quantum dot (QD) growth. One of the remaining challenges is the discrimination of kinetic and thermodynamic effects. We focus on the question which aspects of QD growth can be understood within thermodynamic reasoning. In particular, we identify the driving force for the experimental findings of a sequence of shapes with increasing QD size, and of growth correlations in QD stacks. Recently, we developed an interatomic potential of the Abell-Tersoff type that accounts for the energetic balance of strain relief and QD side-facet formation during QD growth, and enables us to systematically study the energetics and atomic structure of realistic QD nanostructures. Based on recent atomically resolved STM images we set up InAs QD nanostructures in atomic detail, apply our potential to relax them, and compare the resulting total energies. We find that the experimentally observed critical coverage for the 2D to 3D growth transition and the shape sequence of 'hut'-like QD's dominated by {317} facets and 'dome'-like QD's dominated by {101} can be attributed to three distinct stability regimes. Furthermore, we can explain the vertical growth correlations in QD stacks by quantitatively calculating the size of the critical nucleus in different lateral positions.

HL 56.2 Fri 11:15 POT 51

Strain-enhanced charge carrier confinement in nanostructures fabricated by cleaved edge overgrowth — •Jörg Ehehalt[1], Robert Schuster[1], Christian Gerl[1], Harald Hajak[1], Elisabeth Reinwald[1], Matthias Reinwald[1], Dieter Schuh[1], Werner Wegscheider[1], Max Bichler[2], and Gerhard Abstreiter[2] — [1]Universität Regensburg — [2]Walter-Schottky-Institut TU München

The Cleaved Edge Overgrowth technique was used to fabricate quantum wires and quantum dot systems with precisely controlled sizes and positions. Conventionally two intersecting GaAs quantum wells lead to the formation of a quantum wire at the T-shaped junction with confinement energies of up to 54 meV.

However, a larger confinement is needed in order to examine excited states and observe quantum effects at higher temperatures. This can be achieved by introducing tensile strain between materials with different lattice constants. Micro-photoluminescence spectroscopy of purely strain-induced quantum wires shows confinement energies of up to 52 meV. By combining conventional T-shaped wires with strain-induced confinement, much larger confinement energies are possible. Simulations predict confinement energies of up to 108 meV.

These results are now to be applied to fabricate quantum wire lasers working at higher temperatures and lower threshold currents as well as quantum dot system, which will be used to study generation, detection and lifetimes of spin-polarized charges.

HL 56.3 Fri 11:30 POT 51

Atomic structure of GaSb/GaAs quantum rings and dots studied by cross-sectional scanning tunneling microscopy — •Rainer Timm[1], Andrea Lenz[1], Lena Ivanova[1], Holger Eisele[1], Ganesh Balakrishnan[2], Diana Huffaker[1,2], and Mario Dähne[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, D-10623 Berlin — [2]Center for High Technology Materials, University of New Mexico, Albuquerque, New Mexico 87106, USA

GaSb quantum dots in a GaAs matrix show a staggered type-II band alignment and are promising nanostructures for storage devices due to their large hole confinement energy [1]. Cross-sectional scanning tunneling microscopy is a powerful tool to obtain both structural and electronic information on such buried quantum dots with atomic resolution [2].

Here we present data on self-assembled GaSb/GaAs nanostructures, grown by molecular beam epitaxy. Independent of the amount of deposited GaSb ranging from 1 to 3 monolayers, we found distinctive quantum dots with truncated pyramid-like shapes with base lengths between 10 and 30 nm and 2 to 6 nm height as well as quantum rings, which have evolved from the dots by segregation of antimony out of the dot center. While the rings consist of nearly pure GaSb, strongly intermixed stoichiometries were obtained for the dots. Additionally, a shape unisotropy between the [110] and the [$\bar{1}$10] direction was observed for all structures.

This work was supported by the EU in the SANDiE Network of Excellence and by projects Da 408/8, and SFB 296 of the DFG.

[1] M. Geller et al., Appl. Phys. Lett. **82**, 2706 (2003)
[2] R. Timm et al., Appl. Phys. Lett. **85**, 5890 (2004)

HL 56.4 Fri 11:45 POT 51

Stacking of InGaAs/GaAs-based quantum dots for long-wavelength laser diodes — •Tim David Germann, André Strittmatter, Thorsten Kettler, Kristijan Posilovic, and Dieter Bimberg — Institute of Solid State Physics, Sekr. PN 5-2, Hardenbergstr. 36, Technical University of Berlin, D-10623 Berlin, Germany

Currently, only a few reports exist on quantum dot (QD) based laser diodes with emission wavelengths beyond 1240 nm grown by MOCVD on GaAs(100) substrates. Stacking of several QD planes is generally proposed in order to increase the gain at the target wavelength. However, the stacking of QD planes for long-wavelength emission around 1300 nm is not much investigated with respect to the chosen material combination. For example, an $In_{0.65}Ga_{0.35}As$ QD layer overgrown by an $In_{0.15}Ga_{0.85}As$ layer shows photoluminescence emission around 1310 nm with comparable intensity to a similar QD layer overgrown by an $In_{0.08}Ga_{0.92}As$ layer which peaks at 1250 nm. In contrast, upon stacking of the $In_{0.65}Ga_{0.35}As/In_{0.15}Ga_{0.85}As$ combination the photoluminescence intensity starts to deteriorate already when the third QD plane is deposited, while the latter combination could be stacked up to the fifth QD plane without degradation. Furthermore, using an $In_{0.65}Ga_{0.35}As$-QD/$In_{0.13}Ga_{0.85}As$-QW combination for 1290 nm emission only a triple stack could be grown without degradation. Presently, we realized QD laser diodes at a wavelength of 1246 nm with ultra-low threshold current densities of 66 A cm^{-2}, transparency current densities as low as 10 A cm^{-2} per QD plane, and high internal quantum efficiencies of 94 %.

HL 56.5 Fri 12:00 POT 51

Growth and characterization of self-assembled CdSe quantum dots in MgS barriers — •Arne Gust, Carsten Kruse, Henning Lohmeyer, Kathrin Sebald, and Jürgen Gutowski — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee, 28359 Bremen, Germany

Up to now it's only possible to achieve single quantum dot emission from CdSe QDs at low temperatures, which is bleached out for temperatures above 200 K due to the thermal emission of carriers [1]. By embedding the QDs in wide band gap materials such as MgS (5.5 eV) the stronger confinement should stabilize the emission up to room temperature (RT). Samples with additional 5 nm thick MgS barriers surrounding the QD region and a reference sample without barriers have been prepared.

Photoluminescence (PL) measurements were performed at RT in order to be close to the application. The PL spectrum of the reference sample shows a peak with a full-width at half-maximum around 110 meV at RT (emission at 2.38 eV). The emission of the sample including the MgS barriers is shifted by 240 meV to higher energies (2.62 eV) due to the increased confinement. Furthermore the activation energy raised by a factor of 2.5 compared to sample without MgS barriers. Micro-PL measurements on single QDs in dependence on the temperature will be presented in order to quantify the activation energy for different kinds of QD samples.

[1] K. Sebald *et al.*, Appl. Phys. Lett. **81**, 2920 (2002).

HL 56.6 Fri 12:15 POT 51

Influence of Indium-free sublayers on the formation of self-assembled quantum dots on InP (001) substrates — •Roland Enzmann, Susanne Dachs, Ralf Meyer, and Markus-Christian Amann — Walter Schottky Institut, Am Coulombwall 3, 85748 Garching

The deposition of InAs quantum dots on a lattice-matched AlGaInAs matrix material on (001) InP substrate leads to a prolate configuration known as "quantum dashes"oriented along the [1-10] direction. This effect is possibly caused by the indium atoms located in the uppermost layer of the matrix material of which the quantum dots are deposited.

This layer is in the following called sublayer. To avoid this direction-dependent growth we investigate the influence of indium-free sublayers to grow self-assembled quantum dots on InP (001) substrates. To this end, we first prepared InAs quantum dots on a GaAs sublayer with 0,55nm thickness. In this way a reduction of the asymmetry has already been obtained. Since indium is known to segregate, thicker indium free sublayers might be instrumental to avoid "quantum dashes". Because of the heavy strain, a GaAs sublayer has to be very thin. Thicker sublayers can be achieved by the substitution of GaAs by GaAsSb, which principally can be grown lattice matched to InP. Accordingly, a further reduction of the asymmetry can be expected for InAs-GaAsSb-AlGaInAs quantum dots.

HL 56.7 Fri 12:30 POT 51

Self-organization of InAs-quantum dots: kinetics, strain, and intermixing — •Christian Heyn — Institut für Angewandte Physik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg

The basic mechanisms of the self-assembly process which leads to the formation of InAs quantum dots will be addressed. Our goal is to develop a simple model of strain-induced quantum dot formation, that allows to directly determine correlations between structural features of the quantum dots and the growth parameters applied. In doing so, the major task is to identify and model the key processes controlling quantum dot formation such as the kinetics of rearrangement of material by surface diffusion, intermixing of the deposit with substrate material, and the influence of the strain energy. This presentation discusses results calculated with a rate equations based growth model and the related experimental behavior.

HL 56.8 Fri 12:45 POT 51

Growth-related structure of InAsN/GaAs quantum dots studied by cross-sectional scanning tunneling microscopy and spectroscopy — •L. Ivanova[1], H. Eisele[1], R. Timm[1], A. Lenz[1], M. Dähne[1], O. Schumann[2], L. Geelhaar[2], and H. Riechert[2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Infineon Technologies, Corporate Research Photonics, 81730 München, Germany

We investigated the influence of nitrogen on the growth of quantum dots (QD) in the $GaInN_{0.012}As_{0.988}$ system using cross-sectional scanning tunneling microscopy (XSTM). The incorporation of nitrogen into the InAs/GaAs QD leads to a dissolution of the dots and the formation of cluster-like structures of InAs intermixed with N at the anionic sublattice as well as Ga at the cationic sublattice. This observation is in very good agreement with photoluminescence spectra, showing a strong decrease of the dot signal with increasing nitrogen content within the InAs layer. The nitrogen-induced dissolution of the InAs QD occurs due to the highly localized perturbation caused by N atoms.

These InAs/GaAsN heterostructures we studied further by cross-sectional scanning tunneling spectroscopy, monitoring the local density of states. The nitrogen definitely changes the band structure of the matrix material with a reduction of the fundamental band gap by about 0.2 eV and the appearance of an additional state at 0.4 eV above the conduction band minimum, as compared to pure GaAs.

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HL 56.9 Fri 13:00 POT 51

Atomic structure of unstrained GaAs/AlGaAs quantum dots — •Andrea Lenz[1], Rainer Timm[1], Lena Ivanova[1], Dominik Martin[1], Vivien Vossebürger[1], Holger Eisele[1], Armando Rastelli[2], Oliver Schmidt[2], and Mario Dähne[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany

GaAs/AlGaAs quantum dots (QD), formed by a combination of self-assembled growth and atomic-layer etching technique, are a novel and promising structure [1]: The material is ideally unstrained and can be designed to emit light in the optical spectral range. For improving the epitaxial growth a detailed knowledge of the interfaces and the quantum dot structure after overgrowth is essential.
Cross-sectional scanning tunneling microscopy (XSTM) is a powerful method to investigate the shape and size of buried semiconductor nanostructures with atomically resolution. We present XSTM images of the GaAs/AlGaAs interface and of the inverted quantum dot structures, indicating that the unstrained QDs have a truncated cone shape and a relatively large base length of about 35 nm. Thereby the growth model [1] can be confirmed.
This work was supported by the EU in the SANDiE Network of Excellence and by SFB 296 of the DFG.
[1] A. Rastelli, S. Stufler, A. Schliwa, R. Songmuang, C. Manzano, G. Costantini, K. Kern, A. Zrenner, D. Bimberg, and O. G. Schmidt, Phys. Rev. Lett. **92**, 166104 (2004)