# HL 32: Quantum dots and wires: preparation and characterization I

Time: Wednesday 14:15–17:45 Location: ER 270

HL 32.1 Wed 14:15 ER 270

**Towards quantification of the In-distribution in embedded InGaAs quantum dots** — •Holger Blank[1], Dimitri Litvinov[1], Reinhard Schneider[1], Dagmar Gerthsen[1], Thorsten Passow[2], and Kurt Scheerschmidt[3] — [1]Laboratory for Electron Microscopy (LEM), University Karlsruhe (TH), 76128 Karlsruhe, Germany — [2]Institute for Applied Physics and Center for Functional Nanostructures (CFN), 76128 Karlsruhe, Germany — [3]Max Planck Institute for Microstructure Physics, 06120 Halle, Germany

The composition of InAs quantum dots (QDs) grown by molecular-beam epitaxy was studied by high-resolution transmission electron microscopy (TEM) using the composition evaluation by lattice fringe analysis (CELFA) technique [1]. Significant deviations between real and nominal QD composition occur frequently due to In-segregation during GaAs cap layer growth. To understand the opto-electronic properties of the QDs, the real composition needs to be determined. The application of TEM to three-dimensional structures is hampered by the averaging effects over the TEM specimen thickness. This lowers artificially the measured In-concentration in QDs which are embedded in a GaAs matrix. We solve the averaging problem by determining the QD shape and size as well as the TEM sample thickness. We show that QDs deposited at a very low InAs growth rate of 0.0056 ML/s contain a core of almost pure InAs.

[1] A. Rosenauer, D. Gerthsen, Ultramicroscopy 76 (1999), 49-60

HL 32.2 Wed 14:30 ER 270

**Nanoparticle size separation in a drying fluid droplet** — •Matthias Offer[1], Cedrik Meier[1], Stephan Lüttjohann[1], Axel Lorke[1], and Hartmut Wiggers[2] — [1]Experimental Physics, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [2]Institute of Combustion and Gas Dynamics, Universität Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany

We study the deposition of optically active nanoparticles with a broad size distribution in a drying fluid droplet on a solid surface. The nanoparticles are dispersed in a drying droplet and migrate to the edge of the droplet to form ring-like structures on the surface. After deposition we find a particle size separation, i.e., different particle diameters are deposited in different spatial locations. This leads to a position-dependent energy shift in the micro-photoluminescence signal. Furthermore, the observed photoluminescence peak of the deposited nanoparticles has a significantly lower full width at half maximum (FWHM) than the nanoparticle powder used for dispersion. The spatial size separation is caused by an outward flow within the droplet. The flow is driven by the loss of solvent during the evaporation phase. Nanoparticles with small masses are more stable in the dispersion than particles with large masses. There fore large particles are deposited first. We compare the deposition results for silicon nanoparticles, which are synthesized from the gas-phase, to results obtained using commercially available PbS nanoparticles with functionalized surfaces.

HL 32.3 Wed 14:45 ER 270

**Optical and structural properties of transition metal implanted ZnO nanowires** — •Sven Müller[1], Carsten Ronning[1], MinJie Zhou[2], and Quan Li[2] — [1]II. Physikalisches Institut, Georg-August Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Department of Physics, Chinese University of Hong Kong, Shatin, New Territory, Hong Kong

Room temperature ferromagnetism has been proposed for Transitions metal (TM) doped ZnO, and therefore ZnO:TM is of high potential for spintronic applications [1]. Additionally, TM-doped semiconductors show optical active and sharp intra-3d-transition with long life-times. Such intra-shell transitions are usually forbidden, but due to the incorporation into a suitable matrix the crystal field splitting leads to long-life partly allowed transitions [2,3]. Fe, Ni or Co-ions were implanted into VLS-grown ZnO nanowires [4] with a box like profile and different fluences to obtain TM concentrations of 1, 2 and 4 at.%. The nanowires were annealed at 700°C for 30min in air. The morphology was examined by SEM and HR-TEM, revealing an intense damage of the nanowires surface and the crystal lattice. EDX and EELS measurements showed effective incorporation of the TM elements with the desired concentrations. The optical properties were investigated using PL/CL and show sharp intra-3d transitions of the corresponding TM.

[1] K. Sato et al., Phys. Status Solidi B 229, 673 (2002)
[2] H.A. Weakliem, J. Chem. Phys. 36, 2117 (1962)
[3] R. Heitz et al., Phys. Rev. B 45, 8977 (1992)
[4] C. Borchers et al., J. Phys. Chem. B 110, 1656 (2006)

HL 32.4 Wed 15:00 ER 270

**Ion implanted GaAs nanowire pn junctions** — •Katharina Wegener[1], Daniel Stichtenoth[1], Carsten Ronning[1], Christoph Gutsche[2], Werner Prost[2], and Franz Josef Tegude[2] — [1]II. Institute of Physics, University of Göttingen, Germany — [2]Solid-State Electronics Department, University of Duisburg-Essen, Germany

Ion beam doping of materials offers advantages in comparison to doping during growth or by diffusion. First, the impurity concentration as well as the lateral and depth distributions of the dopants are precisely controllable, and secondly, almost all elements can be implanted isotope-selective even beyond any solubility limit.

We present studies on ion implanted gallium arsenide (GaAs) nanowire pn junctions. Nominal intrinsic GaAs nanowires were grown by the vapour-liquid-solid mechanism using gold nanoparticles on top of GaAs (100) substrates. Sulphur, being a donor in GaAs, was implanted into the nanowires using different ion energies resulting in a uniform concentration profile. The now n-type doped nanowires were then reinserted into the metal organic vapour phase epitaxy system. After an annealing procedure, the growth of the nanowires was continued under the addition of an acceptor. Finally, the fabricated nanowire pn junctions were shaved from the growth substrate and processed with contacts on top of insulating carrier substrates. First results on the electrical characterization of these structures will be shown.

HL 32.5 Wed 15:15 ER 270

**InAs/GaAs(001) quantum dots, investigation of dot shape and composition with synchrotron X-ray diffraction.** — •Andriy Zolotaryov, Andreas Schramm, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg

Quantum dot fabrication with molecular beam epitaxy (MBE) utilizes the three-dimensional self-organization of lattice-mismatched III-V heterostructures grown in Stranski-Krastanov mode. During MBE-growth of InAs QDs on GaAs a high amount of substrate material diffuses inside the QDs. This strongly modifies the QD strain status and thus, the process of QDs formation. The intermixing in the InAs/GaAs(001) QD systems is a complex function of growth parameters such as substrate temperature, InAs growth rate etc. and is still matter of scientific discussions. Our synchrotron X-ray studies of MBE grown InAs/GaAs(001) quantum dots reveal information about their composition and shape. The dot average chemical composition is quantitatively estimated by comparison to finite-element based calculations. A study of dots grown with varying amount of deposited InAs establishes that the composition remains constant within the whole probed InAs deposition region. Furthermore, the increase of deposited InAs amount entirely leads to a proportional increase of the surface dot density and does not significantly influence the dot size.

HL 32.6 Wed 15:30 ER 270

**Influence of the deposition rate on the InP quantum dot formation in $Al_{0.20}$GaInP barriers** — •Bjoern Jakobi — Universität Stuttgart, IHFG, Institut für Halbleiteroptik und funktionelle Grenzflächen, Allmandring 3, 70569 Stuttgart, Germany

The preconditions for high efficient quantum dot (QDs) devices and single photon emitters are high luminescence efficieny at elevated temperatures. We examine InP QDs capped $Al_{0.20}$GaInP barriers in order to achive these requirements for the red spectral range.

Major influence for the temperature stability can be attributed to band offsets between the barrier and the QDs, the confinement energy. This is mainly influenced by deposition parameters like the growth time and the growth rate of the InP QDs. In our experiment we hold the total amount of material of 2.1 monolayers (ML) constant and vary the growth rate between 2.1 ML/s and 0.525 ML/s. The samples in this series were grown at 650 °C to avoid Al incorporation into the dots. The dots were capped by 30 nm $Al_{0.20}$GaInP barriers.

The spectral analysis was done with photoluminescence (PL) measurements. Further we show the influence of the growth rate on the power and temperature dependent behavior of our structures by time-resolved and quasi continous PL-measurements with a pulsed Ti-Saphire laser. With these methods we deduced the confinement energy and differ the wetting layer from dots. The samples show a temperature stability to 80 K partly up to 90 K. Allthough a bimodal size distribution of the dots could have been expected, the presented series shows only small A-type QDs.

HL 32.7 Wed 15:45 ER 270

**Low strain AlGaInAs Quantum Dots for Cavity Quantum Electrodynamic Experiments** — •Christian Schneider, Andreas Loeffler, Stephan Reitzenstein, Sven Hoefling, and Alfred Forchel — Universitaet Wuerzburg, Germany

We present a novel kind of quantum dots (QDs) suitable for short-wavelength cavity QED (quantum electrodynamics) applications in the GaAs material system. Using the ability of the AlGaInAs material system to tailor the QD morphology and emission wavelength independently, we realized QDs with enlarged dimensions emitting below 900 nm by solid source MBE growth. Despite adding low amounts of aluminum into the QDs, the QD density could be reduced to $3*10^9 cm^{-2}$ by enhancing the surface diffusion length of the deposited atoms. The QDs showed elongations along the [0-11] direction of more than 100 nm, widths of 40 nm and heights of less than 5 nm. Low temperature photoluminescence measurements revealed that the QDs emit below 900 nm with an inhomogeneous broadening of 45 meV. Tuning low density QD arrays with enlarged dimension into the emission range below 900 nm, where highly sensible streak cameras and Si APDs have increased efficiencies, makes them promising candidates for cavity QED experiments. In a first approach we embedded a single QD layer in an AlAs/GaAs micropillar cavity with quality factors exceeding 50000 for a 4 $\mu$m pillar. By temperature tuning a single QD in resonance with the fundamental mode of the cavity we could measure a clear enhancement of the spontaneous emission rate in a micro PL study.

**15 min. break**

HL 32.8 Wed 16:15 ER 270

**Formation, atomic structure, and electronic properties of GaSb/GaAs quantum rings** — •Rainer Timm[1], Andrea Lenz[1], Lena Ivanova[1], Holger Eisele[1], Ganesh Balakrishnan[2], Diana L. Huffaker[2], Ian Farrer[3], David A. Ritchie[3], and Mario Dähne[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Center for High Technology Materials, University of New Mexico, Albuquerque, USA — [3]Cavendish Laboratory, University of Cambridge, UK

The growth of semiconductor quantum dots (QDs) and their transition into quantum rings (QRs) upon overgrowth have attracted large interest during the last years. In the GaSb/GaAs material system, which is very promising for charge storage devices due to its type-II band alignment [1], a spontaneous transition of QDs into QRs during fast overgrowth has been observed.

Using cross-sectional scanning tunneling microscopy and spectroscopy [2], we were able to study the atomic structure, chemical composition, and electronic properties of GaSb/GaAs QRs grown by MBE using various growth conditions. Typical QR baselengths vary between 10 and 20 nm with inner diameters amounting to about 40% of the outer ones, at densities of up to $9 \times 10^{10}$ cm$^{-2}$.

A strong Sb segregation upon GaAs overgrowth is observed, which is assumed to be the driving force for ring formation together with the large strain within the nanostructures.

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

HL 32.9 Wed 16:30 ER 270

**X−ray investigations on $CoSi_2$ nano wires manufactured by focused ion beam synthesis** — •Jörg Grenzer[1], Lothar Bischoff[1], and Andreas Biermanns[2] — [1]Forschungszentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research 01314 Dresden, Germany — [2]FB7 - Physik, Universität Siegen, ENC - B012, 57068 Siegen, Germany

Nanowires and chains of nanoparticles are of emerging interest in nanoelectronics, nano-optics and plasmonics as well as for their monolithic integration into microelectronic devices; $CoSi_2$ is a promising material due to its CMOS-compatibility in micro-electronics technology. It shows metallic behaviour with low resistivity and high thermal stability. It is well known that cobalt disilicide films can be formed in silicon by implanting Co in stoichiometric concentration and a subsequent annealing procedure. Ion beam synthesis allows the fabrication of epitaxial buried or surface $CoSi_2$ layers on silicon. Sub-micron patterns with feature dimensions much smaller than $100nm$ can be directly produced by writing focused ion beam (FIB) cobalt implantation.

We have studied the strain of the Si host lattice in the surrounding area of a single nanostructures depending on their crystallographic orientation using high resolution x-ray diffraction in combination with a highly focused ($\approx 3\mu m$) x-ray beam at the beam line ID1 at the ESRF. The pattern measured directly on the wire shows a small peak indicating tensile strain (approx. $-1.4\%$). This feature can be only found if the beam focused on a nano wire whereas its intensity changes with the layer width.

HL 32.10 Wed 16:45 ER 270

**Limitations of In(Ga)As/GaAs quantum dot growth** — •Andrea Lenz[1], Rainer Timm[1], Holger Eisele[1], Lena Ivanova[1], Roman L. Sellin[1], Huiyun Liu[2], Mark Hopkinson[2], Udo W. Pohl[1], Dieter Bimberg[1], and Mario Dähne[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Germany — [2]University of Sheffield, Dept. of Electronic and Electrical Engineering, UK

Large In(Ga)As/GaAs quantum dots (QDs) with an emission wavelength of 1.3 $\mu$m are of widespread interest for devices in optoelectronics. Two different growth strategies to achieve those larger QDs are - among others - the overgrowth with a strain-reducing InGaAs layer [1] or the growth of InAs QDs within InGaAs quantum wells [2].

Using cross-sectional scanning tunneling microscopy (XSTM) we studied such In(Ga)As QD samples grown with MOCVD and MBE. In both cases the intended size increase of the QDs is confirmed, but it is accompanied by some QDs containing a material hole, and hence will not contribute to the luminescence. We will present atomically-resolved XSTM images of these defects and discuss the similarities and differences between the two samples. In addition, we developed growth models considering the strain and the limited growth kinetics during capping, demonstrating the limits of larger QD growth.

This work was supported by the DFG by projects Da 408/12, Da 408/13, and Sfb 296, TP A4 and A7, as well as the SANDiE Network of Excellence of the EC.

[1] A. Lenz et al., Appl. Phys. Lett. **85**, 3848 (2004)
[2] H. Y. Liu et al., Appl. Phys. Lett. **89**, 073113 (2006)

HL 32.11 Wed 17:00 ER 270

**Electroluminescence of InP-quantum dots in $Al_{0.20}$GaInP-barriers** — •Wolfgang-Michael Schulz, Robert Rossbach, Björn Jakobi, Michael Wiesner, Michael Jetter, and Peter Michler — Universität Stuttgart, Institut für Halbleiteroptik und Funktionelle Grenzflächen, Allmandring 3, 70569 Stuttgart, Germany

The use of electrically pumped single-photon emitters (SPE) in the red spectral range is of high interest for future quantum information technologies, as modern APDs have their maximum sensitivity in the visible red. With InP-quantum dots (QDs) in AlGaInP-barriers, these wavelengths are quite easily reachable.

On the way to the rather complex structure of such an SPE, one has to carefully adjust the electrooptical properties of the active region.

Within this contribution we present the continuously driven ensemble electroluminescence characteristics of InP-quantum dots embedded in an $Al_{0.20}$GaInP-barrier with $Al_{0.50}$GaInP-cladding in a pin-LED-structure. With a total confinement energy of around 300 meV for the Quantum dots, it was possible to achieve bright electroluminescence from 5 K up to 320 K. The growth process of the QDs on the Al-containing barriers implies usually a bimodal distribution, which just can be observed in the low temperature electroluminescence-spectra. At higher temperatures the emission of the lower energetic QDs is suppressed.

HL 32.12 Wed 17:15 ER 270

**Self-assembled quantum dots grown by Molecular Beam Epitaxy on InP-substrate for single photon application at 1.55 $\mu$m** — •Daniela Baierl, Roland Enzmann, Christian Jendrysik, Christian Seidel, Susanne Dachs, Gerhard Böhm, Ralf Meyer, Jonathan Finley, and Markus-Christian Amann — Walter Schottky Institut

Quantum key distribution requires practical sources of single photons with the standard telecommunication wavelength 1.55 $\mu$m, thus they can be efficiently transmitted through fiber optics. Self-assembled

InAs-quantum dots allow the observation of single photons as long as their surface density is small enough (approximately 1 dot/$\mu$m$^2$). To achieve emission at 1.55 $\mu$m it is necessary to use InP(001) as substrate material instead of GaAs - dots on GaAs can not provide higher wavelength than 1.3 $\mu$m. But instead of dot formation the deposition of InAs on InP or lattice-matched AlInAs and GaInAs matrix-materials leads to elongated structures, so called "'quantum dashes"'. The mechanism which drives this asymmetric growth is not fully understand, but Indium on the surface, where dot-formation starts, plays an important role. By avoiding Indium in the uppermost layers we show the formation of quantum dots, even with low density. We present several realizations of In-free materials, e. g. a thin sublayer GaSb which suppresses In-segregation from the subjacent Indium-containing matrix-material. We also discuss the photoluminescence characteristics which are different to dots on GaAs, because combining Antimony-containing materials with InAs often results in a type-II band-alignment.

HL 32.13 Wed 17:30 ER 270

**Growth of Sub-Monolayer Quantum Dots by MOCVD** —
•Franziska Luckert, Konstantin Pötschke, Till Warming, and Dieter Bimberg — Technical University of Berlin, Institute of Solid State Physics, Sekr. EW 5-2, Hardenbergstr. 36, D-10623 Berlin, Germany

Sub-monolayer (SML) deposition is an alternative approach for the self-organised formation of quantum dots (QDs) different from the Stranski-Krastanow growth mode. The deposition of a SML InAs on GaAs (001) surface results in the formation of distinct monolayer (ML) high InAs islands which influence, after overgrowth with GaAs, the deposition of the next SML by non-uniform lateral strain.

In this study the growth of the SML QDs was done by metal-organic chemical vapour deposition. Several samples with varying: -thickness of the GaAs spacer, -amount of InAs ($<$ 1 ML) and -number of repetitions of InAs/GaAs cycles were grown and examined with Photoluminescence (PL) at 10K. The emission wavelength was observed to be tuneable from 900 to 1000 nm, depending on the growth parameters. The peaks observed in the PL spectra are characterised by a very small full width at half maximum of 4-12 meV. The detailed mathematical analysis of the line shape of these peaks yields that the SML heterostructures can be described as a quantum-dot in a quantum-well structure. This implies that there are regions with a high In concentration in a lower In-content quantum well which show a Gaussian PL shape.