HL 86: Quantum Dots: Growth and Characterization

Time: Friday 10:15–13:15 Location: FOE Anorg

HL 86.1 Fri 10:15 FOE Anorg

Effects of *in-situ* annealing on site-selective InAs quantum dots grown on pre-structured GaAs substrates — •Mathieu Helfrich[1,2], Daniel Rülke[1,2], Joshua Hendrickson[3], Michael Gehl[4], Dongzhi Hu[1,2], Michael Hetterich[1,2], Stefan Linden[5], Martin Wegener[1,2], Galina Khitrova[4], Hyatt M. Gibbs[4], Heinz Kalt[1,2], and Daniel M. Schaadt[1,2] — [1]DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede-Str. 1a, 76131 Karlsruhe, Germany — [2]Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany — [3]State Scientific Corp., 27-2 Wright Road, Hollis, NH 03049, U. S. A. — [4]College of Optical Sciences, University of Arizona, 1630 E. University Bld., Tucson, AZ 85721, U. S. A. — [5]Physikalisches Institut, University of Bonn, Nußallee 12, 53115 Bonn, Germany

Spatial localization of quantum dots has been achieved reproducibly within a certain range. The aim has shifted to improving the optical properties, decreasing the quantum dot density and controlling the occupation number of quantum dots per site. We report on our investigations of *in-situ* annealing of site-selective InAs quantum dots which aim at understanding the influence of this technique on the aforementioned parameters. We observed a morphological transition of double dots merging into single dots during annealing, accompanied by a reduction of quantum dot densities. The quantum dots are analyzed by atomic force microscopy and photoluminescence spectroscopy.

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Tuning the emission of GaAs and InGaAs quantum dots — •Eugenio Zallo, Paola Atkinson, Rinaldo Trotta, Armando Rastelli, and Oliver G. Schmidt — Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01059 Dresden, Germany

We report on a method to obtain unstrained GaAs/AlGaAs and InGaAs/AlGaAs quantum dots with low surface densities and widely tunable emission wavelength. We first prepare a template of self-assembled nanoholes on a GaAs(001) surface by a droplet etching step which consists of the alternate deposition of Ga and GaAs at a substrate temperature of 520 °C. The template is then overgrown with a 7-10 nm thick AlGaAs layer. The resulting nanoholes, with a depth of 6-10 nm are then filled with different amounts of GaAs or InGaAs, followed by deposition of the top AlGaAs barrier. By gradually increasing the amount of GaAs we can tune the emission wavelength in the spectral range 690-780 nm. By replacing the GaAs with InGaAs, long wavelength emission can be obtained with smaller dots. The high quality of the dots is demonstrated by single-dot photoluminescence spectra, which show excitonic emission linewidths down to 25 μeV (our resolution limit). Finally, we present preliminary results on the effect produced by external biaxial stress on the emission of single initially unstrained QDs.

HL 86.3 Fri 10:45 FOE Anorg

Atomic structure of submonolayer grown InAs/GaAs quantum dots — •Holger Eisele, Andrea Lenz, Jonas Becker, Lena Ivanova, Mario Dähne, Ernst Lenz, Franziska Luckert, Konstantin Pötschke, André Strittmatter, Udo W. Pohl, and Dieter Bimberg — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin

Submonolayer quantum dots are formed by a cycled deposition of the dot material with a thickness well below one monolayer and several monolayers of matrix material. Structural correlation, both vertically as in plane is coupled to strain originating from the dot material. Here, cross-sectional scanning tunneling microscopy (XSTM) is the most powerful tool to determine the spatial structure as well as the stoichiometry with atomic resolution. XSTM measurements demonstrate clearly that there is an island formation instead of a layer-like structure. The InAs is not assembled within a single atomic plane, but segregated along growth direction. The lateral separation between the islands is only about 2 nm, resulting in a very high dot density in the 10^12 cm-2 range. The height of the islands is about 4-5 ML, and the width is approximately 5 nm. The vertical segregation is determined in detail by the analysis of the lattice parameter. At each layer where 0.5 ML InAs was deposited, the measured InAs concentration jumps up to a lattice parameter corresponding to xIn = 15-20%, followed by an exponential decrease. For both structures with differently thick GaAs spacer layers a segregation coefficient of about 0.73 was determined.

HL 86.4 Fri 11:00 FOE Anorg

MBE growth of InAs quantum dots and dashes grown on (100) silicon substrates — •Tariq Al Zoubi, Muhammad Usman, Mohamed Benyoucef, and Johann Peter Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics, University of Kassel, D-34132 Kassel, Germany

Self assembled InAs quantum dots (QDs) are grown by solid source molecular beam epitaxy after deposition of a 50 nm silicon buffer layer on (100) Si substrates using Stranski-Krastanov (SK) growth mode. Reflection high energy electron diffraction (RHEED) streak patterns confirm that the combination of the atomic hydrogen at 500 °C followed by thermal desorption at 900 °C is an efficient surface cleaning method. The evolution of size, density and shape of the QDs are ex-situ characterized by atomic-force microscopy (AFM). Different growth parameters such as InAs coverage, growth temperature, In-growth rate and V/III ratio are examined on differently prepared silicon surfaces including ex- and in-situ cleaning procedures. Additional improvement for the cleaning and growth is achieved by exposing the Si surface with Ga at low fluxes. The Ga treatment at a temperature of 560 °C for two minutes results in a strong reduction of the lateral size of InAs QDs and a significant enhancement of the homogeneity of the dot size and distribution. The InAs QDs density is strongly increased from 10^8 to 10^11 cm^-2 for V/III ratios in the range of 15-35, respectively. InAs QD formations are not observed at temperatures as high as 500 °C. Moreover, InAs quantum dashes are observed at higher In-growth rate of 0.3 ML/s.

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Nanostructuring of silicon for the growth of site-controlled III/V quantum dots — •Muhammad Usman, Tariq Al Zoubi, Mohamed Benyoucef, and Johann Peter Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics, University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

In order to localize the nucleation of III/V quantum dots during MBE growth, the silicon (100) substrate has been patterned with sub 100 nm holes. The processes involved in the nano-patterning of silicon, including electron beam lithography (EBL) and dry etching process, have been optimized. An anisotropic dry etching recipe based on SF6+CHF3 plasma has been used with optimal parameters in order to insure the precise transfer of holes defined on e-beam resist to the underlying silicon substrate. The control over the diameter of the patterned holes has been achieved through optimal EBL parameters including beam acceleration voltage, aperture size and exposure dose for single pixel dot. Arrays of holes with different periods from 1 μm down to 200 nm have been fabricated on silicon substrates. The diameter of the holes has been found to be unchanged for holes with periods of 1 μm, 750 nm and 500 nm, while a slight increase in the diameter for holes with period of 200 nm has been observed due to proximity effect. Preliminary results for the MBE growth of III/V quantum dots on nano-patterned silicon substrate have shown highly selective formation of quantum dots in the patterned holes with 1μm period.

HL 86.6 Fri 11:30 FOE Anorg

Growth of small-period Si/Ge quantum dot crystals by MBE — •Svetlana Borisova[1], Julian C. Gerharz[1], Yasin Ekinci[2], Gregor Mussler[1], and Detlev Grützmacher[1] — [1]Institute of Bio- and Nanosystems 1, Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut, CH-5232 Villigen-PSI, Switzerland

We report on growth of arrays of Ge quantum dots (QDs) on Si substrates. The energy structure of small-period QDs arrays is predicted to be significantly modified by the artificial periodicity. High quality self-assembled Ge QDs can be grown by solid source molecular-beam epitaxy (MBE). The main drawbacks of self-assembled Ge QDs are arbitrary positions where the QDs nucleate as well as broad size dispersion. To solve this problem, prepatterned Si substrates were used to define the position and the size of the QDs. Check-patterns with different periods down to 35 nm and depth of 5-20 nm were realized by extreme ultraviolet interference lithography (XIL) and independently by electron beam lithography followed by reactive ion etching (RIE). Influence of both methods on MBE growth was studied from the point of view of final quality of the holes and simplicity of access, usage and precision of positioning on the substrate. The prepatterned Si substrates were overgrown by few single layers of Ge. The influence of substrate temperature and buffer layer thickness on homogeneity of Ge dots in order to optimize growth procedure was investigated by means of atomic force microscopy (AFM) and in-situ scanning tunnelling microscopy (STM).

15 min. break

HL 86.7 Fri 12:00 FOE Anorg

Ultraviolet photoluminescence of zinc oxide quantum dots sputtered at room-temperature — •Gillian Kiliani[1], Reinhard Schneider[2], Dimitri Litvinov[2], Dagmar Gerthsen[2], Mikhail Fonin[1], Ulrich Rüdiger[1], Alfred Leitenstorfer[1], and Rudolf Bratschitsch[1] — [1]Center for Applied Photonics, Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]Laboratorium für Elektronenmikroskopie, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany

Zinc oxide (ZnO) quantum dots showing room-temperature ultraviolet photoluminescence are prepared for the first time by radio-frequency magnetron sputtering without any annealing steps. The quantum dots are embedded in amorphous silicon dioxide and have a narrow size distribution of 3.5 ± 0.6 nm. Room-temperature photoluminescence shows emission in the ultraviolet. Optical transmittance and photoluminescence spectra both exhibit a blueshift of the quantum dot absorption and emission compared to bulk ZnO material which is attributed to quantum confinement. Carrying out the fabrication entirely at room-temperature prevents the degradation of nanooptical devices containing quantum dots which might occur during annealing steps.

HL 86.8 Fri 12:15 FOE Anorg

InGaN quantum dots growth by metalorganic vapour phase epitaxy for green light emitters — •Tilman Schwaner, Abdul Kadir, Christian Meissner, Markus Pristovsek, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

High efficiency green InGaN light emitting diodes and projection displays are one of the most important challenges in solid state lighting technology. To improve the device performance, we studied InGaN/GaN quantum dots as active region. Self-organized InGaN quantum dots were grown on GaN (0001) in the Stranski-Krastanov growth mode in a horizontal metalorganic vapour phase epitaxy reactor. We varied the growth temperature between 600°C - 725°C and the growth times between 20 s and 300 s. The resulting indium content was between 10% and 32% as determined by X-ray diffraction measurements. We could clearly see a transition from 2D to 3D growth mode by atomic force microscopy. The wetting layer thicknesses were 4 nm at 675°C and 3 nm at 625°C, which implies that the wetting layer thickness decreases with increasing indium content. Capping and stacking of multi-InGaN layers are still under investigation. Preliminary photoluminescence and electroluminescence showed strong green emission around 530 nm for a three InGaN quantum dot layer stack.

HL 86.9 Fri 12:30 FOE Anorg

Correlating different characterization methods on individual Carbon Nanotubes — •Robert Frielinghaus[1,2], Karin Goss[1,2], Christian Spudat[1,2], Lothar Houben[2,3], Matthias Müller[4], Christian Thomsen[4], Stefan Trellenkamp[2,5], Carola Meyer[1,2], and Claus M. Schneider[1,2] — [1]Peter-Grünberg-Institut (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA Fundamentals of Future Information Technologies, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Peter-Grünberg-Institut (PGI-5) und Ernst-Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany — [4]Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [5]Peter-Grünberg-Institut (PGI-8-PT), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

Carbon nanotubes (CNTs) can serve as model systems for molecular interactions in (quantum) transport experiments. Their properties are greatly affected by their chemical modification as, e.g., filling with fullerenes. Yet standard samples do not allow for a direct structural observation. Here we present an approach to perform transport, transmission electron microscopy (TEM) as well as optical Raman measurements all on a single CNT. Windows are etched in a Si_3N_4 TEM membrane on which CNTs are grown by means of chemical vapour deposition. They can then be contacted via standard electron beam lithography. The TEM measurements provide the structural information that is needed for the interpretation of the transport data. This process may readily be applied to other material systems such as nanowires.

HL 86.10 Fri 12:45 FOE Anorg

Cell-internal structure of hexagonal polytypes in III-V semiconductors — •Christian Panse[1], Dominik Kriegner[2], and Friedhelm Bechstedt[1] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Germany — [2]Institute for Semiconductor and Solid State Physics, Johannes Kepler University Linz, Austria

Semiconductor nanowires (NW) play a key role in future nanotechnology. Despite of the zinc-blende (3C) bulk structure III-V nanowires exhibit a mixture of wurtzite (2H) and zinc-blende (3C) layers. With better control over the crystal structure it became possible to grow not only pure 3C or 2H layers but also small segments of the hexagonal 4H polytype. This offers a new degree of freedom for NW device design, like polytypic superlattices. Therefore, we investigate the structural properties of the different polytypes (3C, 2H, 4H, 6H). We perform *ab-initio* calculations within the density functional theory for different III-V compounds (GaAs, InAs, InP, InSb). The structural properties are calculated versus the hexagonality of the polytypes using the LDA exchange-correlation functional. Experiment (XRD) and theory show that hexagonal bilayers tends to increase the layer thickness along the c-axis, while simultaneously reduce the in-plane distances. Thereby, the change of the lattice parameters scales linearly with the hexagonality of the polytype. Overall an increase in the relative aspect ratio of the 2H structure by 0.6% compared to the ideal structure is observed. It turns out that only a careful treatment of the cell-internal parameters could guarantee a correct description of the structural properties.

HL 86.11 Fri 13:00 FOE Anorg

Model and applications of local droplet etching — •Christian Heyn — Institut für Angewandte Physik, Jungiusstr 11, 20355 Hamburg

The self-organized in situ drilling of nanoholes into semiconductor surfaces by using liquid metallic droplets as local etchant represents a new degree of freedom for the design of heterostructure devices.[1,2] The process is fully compatible with conventional molecular beam epitaxy (MBE) technology and does not require additional equipment. A model of this local droplet etching (LDE) is presented that is based on a core-shell structure of the droplets. With the model, the evolution of the droplet and substrate surface morphology is calculated. We demonstrate quantitative agreement between model results and measured surface morphologies. Furthermore, also the influence of the process temperature is correctly reproduced by the model. A brief overview on recent applications of the LDE method will be given, including the self-assembly of GaAs quantum rings and dots as well as the fabrication of air-gap heterostructures.

[1] Zh. M. Wang, B. L. Liang, K. A. Sablon, and G. J. Salamo, Appl. Phys. Lett. 90, 113120 (2007).

[2] Ch. Heyn, A. Stemmann, and W. Hansen, Appl. Phys. Lett. 95, 173110 (2009)