HL 55: Quantum dots and wires: Preparation and characterization

Time: Friday 9:30–12:45 Location: A 151

HL 55.1 Fri 9:30 A 151

MOVPE grown InGaAs Metamorphic Buffers for InAs Quantum Dots in the Telecom C-Band — •Robert Sittig, Matthias Paul, Fabian Olbrich, Susanne Schreier, Jonatan Höschele, Jan Kettler, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

For the application of semiconductor quantum dots (QDs) as nonclassical light sources in communication networks, single-photon emission at 1.55 μm, corresponding to the glass fiber and atmospheric transmission window known as the telecom C-band, is vital. While the desired QD emission is achievable in the InAs/InP-system, the InP substrate quality and cost as well as the absence of an efficient binary distributed Bragg reflector structure prevents an application in the industrial scale. The starting point is our success in showing single-photon emission at 1.55 μm with resolution-limited linewidths and low fine-structure splitting from InAs QDs grown on an InGaAs metamorphic buffer (MMB). Nevertheless, the MMB quality can still be improved for the integration of the QDs in photonic nanostructures. With the goal to decrease the layer thickness and increase the interface/surface quality, different MMB-designs are studied via AFM, photoluminescence spectroscopy and X-ray diffractometry. The influence of varied grading profiles, annealing steps and total thickness on the formation of dislocations, lattice relaxation and surface texture is discussed.

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Transport Measurements on Single CdSe Nanowires during Cation Exchange — •Maximilian Schwarz, Christian Strelow, August Dorn, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Cation Exchange proved to be a powerful tool for designing the composition of nanoparticles with a given shape. By using the anionic framework of a crystalline nanocrystal, cations can be exchanged topotaxial. Simple reaction routes can establish systems, which are unattainable by standard wet chemical synthesis. Here, we used CdSe Nanowires grown via the solution-liquid-solid (SLS) technique [1] directly on a substrate. The purpose was to get an insight into the reaction dynamics by monitoring the transport characteristics of single CdSe Nanowires during cation exchange to Ag2Se. Throughout the exchange reaction, the change in properties was traced non-invasive via spectroscopic and microscopic methods. We gratefully acknowledge financial support by the DFG via U-4-6-02-DFG-17-08.

[1] A. Dorn et al., Advanced Materials, 2009, 21 (34), pp 3479-3482

HL 55.3 Fri 10:00 A 151

Structural characterization of InGaAs/GaP quantum dots grown by MOVPE with varying growth interruptions — •Christopher Prohl[1], Andrea Lenz[1], Gernot Stracke[1], Udo W. Pohl[1], André Strittmatter[1,2], Dieter Bimberg[1], Mario Dähne[1], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, 10623 Berlin — [2]Otto-von-Guericke Universität Magdeburg, Institut für Exp. Physik, 39106 Magdeburg

The monolithic integration of III-V based nanostructures onto Si is enabled by using GaP, with its particularly low lattice mismatch to Si. InGaAs/GaP quantum dots (QDs) are very promising for novel nanoflash memories. Furthermore, a first light emitting diode grown on a monolithic GaP/Si substrate was already demonstrated.

In this contribution, cross-sectional scanning tunneling microscopy (XSTM) was used to structurally analyze InGaAs/GaP QD layers on the atomic scale, grown by metalorganic vapor-phase epitaxy (MOVPE). As shown previously, the introduction of a GaAs interlayer prior to the InGaAs deposition favors the local concentration of indium and thereby the formation of indium-rich QDs. The growth interruption (GRI) after the $In_{0.5}Ga_{0.5}As$ deposition was varied, influencing the photoluminescence intensity. The XSTM analysis shows that depending on the duration of the GRI a structural redistribution of the QD layer occurs. This is characterized by a strong intermixing of the locally concentrated indium within the layer and leads to the formation of a laterally more homogeneous quaternary InGaAsP layer.

This work was supported by the DFG, SFB 787, TP A2 and A4.

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Axial Ga(As,Bi) insertions in GaAs nanowires grown by molecular beam epitaxy — •Miriam Oliva, Ryan B. Lewis, Guanhui Gao, Esperanza Luna, Manfred Ramsteiner, Chiara Sinito, Oliver Brandt, Uwe Jahn, and Lutz Geelhaar — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin

The Ga(As,Bi) semiconductor alloy is promising for infrared optoelectronics, allowing all bandgaps below that of GaAs to be reached in principle. Growth of Ga(As,Bi) by molecular beam epitaxy requires very low growth temperatures (220–330°C) and Ga-rich environments [R. B. Lewis et al.; Appl. Phys. Lett. **101**, 082112 (2012)]. These requirements often result in Ga droplets on the Ga(As,Bi) surface, which are detrimental for optoelectronic applications. Here we show that the Ga droplets atop Ga-assisted GaAs nanowires provide an ideal environment for the growth of Ga(As,Bi), and we develop a novel growth procedure to realize axial Ga(As,Bi) insertions in GaAs nanowires. First, we enrich the Ga droplets with Bi, resulting in a Bi/Ga-volume ratio of around 8. We then expose these droplets to an As_2 flux, precipitating a Ga(As,Bi) segment from the liquid droplet. Finally, excess Bi that did not incorporate into Ga(As,Bi) can be desorbed. We explore the dependence of the Bi content on the substrate temperature during growth. Transmission electron microscopy reveals uniform Ga(As,Bi) segments, with a Bi content of about 17% for segments formed at 300°C. These results open the door to infrared optoelectronic devices based on GaAs/Ga(As,Bi) axial nanowire heterostructures.

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Self-catalysed MBE-grown III-V nanowire arrays on Si(111) substrates — •Pujitha Perla[1,3], Dinesh Arumugam[1,3], Lidia Kibkalo[1,3], Patrick Zellekens[1,3], Torsten Rieger[1,3], Thomas Schäpers[1,3], Detlev Grützmacher[1,2,3], and Mihail Ion Lepsa[2,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich GmbH, 52425 Jülich, — [2]Peter Grünberg Institute (PGI-10), Forschungszentrum Jülich GmbH, 52425 Jülich — [3]JARA - Fundamentals of Future Information Technology

III-V semiconductor nanowires (NWs) are interesting for studying new quantum transport phenomena. The selective growth in arrays on Silicon (Si) substrates offer the advantages of growth parameter optimization and easier integration of the processed NW devices. Here we report on the self-catalysed growth of InAs and GaAs NW arrays by molecular beam epitaxy (MBE) on Si(111) substrates.

For the growth of the NW arrays,hole patterns have been processed by e-beam lithography,dry and wet chemical etching on SiO2 on Si(111) substrates. We have observed that the substrate preparation is critical, especially for the growth GaAs NWs. For the growth of InAs and GaAs NW arrays, vapour-solid and vapour-liquid-solid growth modes have been used respectively. The influence of Te-doping on the morphology of InAs NWs was studied as well. The growth results have been analysed for the yield and morphology of vertical NWs using scanning electron microscopy. These results further increase the scope for evaluation of the Te-doping of the InAs NWs and the growth of advanced core-shell NW arrays with Sb based shell materials.

HL 55.6 Fri 10:45 A 151

Self-assembled low density In(Ga)As quantum dots — •Timo Langer, Nandlal Sharma, and Dirk Reuter — Universität Paderborn, Department Physik, Warburger Str. 100, 33098 Paderborn

Self-assembled InAs and $In_xGa_{1-x}As$ quantum dots (QDs) were grown on GaAs (100) substrates by molecular beam epitaxy (MBE). By modifying the growth conditions, it is possible to control the density. Furthermore, the transition energies can be tuned by using the In-flush-technique or by ex-situ annealing.

Experiments using a gradient approach resulted in densities from 10^8 to $10^{10}\,cm^{-2}$. The ground state transition energy at 4.2 K can be increased from 1.0 to 1.3 eV by using the In-flush-technique. Also by growing $In_xGa_{1-x}As$ QDs we were able to achieve emission energies around 1.3 eV. The QDs have been analyzed by photoluminescence spectroscopy, atomic force microscopy and capacitance-voltage-spectroscopy. We will also discuss an alternative approach to realize low QD densities employing a subcritical InAs deposition and subsequent annealing.

15 min. break.

HL 55.7 Fri 11:15 A 151

Wet chemical etching of optical microstructures in gallium arsenide to enhance the extraction efficiency of InAs quantum dots — •Lena Engel, Marc Sartison, Sascha Kolatschek, Stefan Hepp, Simone Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Semiconductor quantum dots (QDs) have proven to be well-defined, pure and efficient single-photon sources. They have shown to be promising candidates for various applications such as quantum communication or quantum computing. One prerequisite for these applications in free-space or fiber-based quantum information is high brightness. As the emitters are embedded in a semiconductor environment, the extraction efficiency is strongly limited. In contrast to narrow band cavity quantum electrodynamic systems like micro pillars or photonic crystal cavities, we investigate a broadband approach, introducing wet chemically etched hemispheric and Gaussian micro lenses precisely aligned on a single emitter. The QDs are optically pre-selected, marked via in-situ lithography and formed by a following wet chemical etching step. This wet chemical approach results in a superior surface quality, which enables us to perform quantum optical experiments on optically resonant excited QDs with enhanced extraction efficiency. According to FDTD simulations, hemispheric and Gaussian micro lens geometries also show promising enhancement factors.

HL 55.8 Fri 11:30 A 151

Epitaxial Growth and Characterization of low-density InGaAs Quantum Dots for Single-Photon Emission at 1300 nm — •Jan Grosse, Nicole Srocka, Tobias Heindel, and Stephan Reitzenstein — Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

Quantum dots are widely known as promising sources for single photons, which in turn enables a large variety of photonic applications from quantum cryptography to quantum computing. In(Ga)As/GaAs quantum dots grown by metal organic chemical vapour deposition (MOCVD) have been proven to emit single photons over a widely tuneable spectral range. Moreover they allow for a relatively easy monolithic integration in photonic cavities using lattice matched AlGaAs/GaAs DBR mirrors. Here we tackle the challenge to grow InGaAs quantum dots for single-photon emission at the telecom O-Band around 1300 nm. The spectral shift of the quantum dot emission wavelength is achieved by introducing a strain reducing InGaAs layer [1] with an indium content of approximately 25 % immediately after the growth of the quantum dot layer, tailored to yield a dot density of about 5×10^7 cm^{-2}. We present micro-photoluminescence and atomic force measurements for the characterization of the quantum dots. Moreover, we show deterministic device integration and discuss preliminary results of optical characterization measurements.

[1] Bloch, J. et al. Appl. Phys. Lett. 75, 2199 (1999).

HL 55.9 Fri 11:45 A 151

Investigation of Bi induced three-dimensional InAs nanostructures on GaAs(110) by cross-sectional scanning tunnelling microscopy. — •Wjatscheslav Martyanov[1], Ryan B. Lewis[2], Hendrik Janssen[1], Celina S. Schulze[1], Pascal Farin[1], Andrea Lenz[1], Mario Dähne[1], Lutz Geelhaar[2], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

While on GaAs(100) three-dimensional (3D) growth is preferred, on other low-index GaAs surfaces such as (110) and (111) the deposition always results in a two-dimensional growth. On the other hand, the growth of 3D nanostructures like quantum dots on these surfaces is of interest for high efficiency single photon sources. Latest investigations show that the presence of Bi as a surfactant induces the 3D growth on GaAs(110) by modifying the surface energy. In this contribution the Bi induced InAs-3D-island within InAs monolayers grown on GaAs(110) are investigated by cross-sectional scanning tunnelling microscopy (XSTM). The XSTM images allow the characterisation of these structures in terms of size, density, and atomic structure depending on Bi exposure time. In order to explore the influence of Bi, we compare XSTM images of monolayers deposited without Bi, monolayers grown with simultaneous Bi flux and monolayers exposed Bi flux for different times after deposition. This work was supported by the CRC 787, Project A4.

HL 55.10 Fri 12:00 A 151

Quantum dot-microlenses for single-photon sources operating at telecom wavelength — •Nicole Srocka[1], Pawel Mrowinski[2], Lukasz Duanowski[2], Anna Musial[2], Grzegorz Sek[2], David Quandt[1], Andrei Strittmatter[1,3], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universiät Berlin, D-10623 Berlin, Germany — [2]Laboratory for Optical Spectroscopy of nanostructures, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland — [3]Present address: Institute of Experimental Physics, Otto von Guericke University Magdeburg, D-39106 Magdeburg, Germany

Advanced quantum communication applications require single photon sources featuring i) high photon-extraction efficiency, ii) high flux rate, iii) high suppression of multi-photon emission and iv) high degree of photon indistinguishability. The concept of monolithic microlenses aligned to self-assembled semiconductor-quantum-dots has been proven to be an efficient approach to satisfy all of these four requirements in a single device operating at $900 - 950$ nm [1]. We report on applying this approach to In(Ga)As/GaAs quantum dots emitting in the telecom O-band. We will sketch a full circuit from theory based design optimization to fabrication utilizing in situ three-dimensional electron-beam lithography and results of a final spectroscopic evaluation [2].

References:

[1] M. Gschrey, A.Thoma *et al*, Nat. Commun., 6, 7662 (2015).
[2] L. Dusanowski, *et al*, Opt. Express., 25(25), 31122-31129 (2017).

HL 55.11 Fri 12:15 A 151

Macro-mechanics Controls Quantum Mechanics: Mechanically Controllable Quantum Conductance Switching of an Electrochemically Fabricated Atomic-scale Transistor — •Torben Staiger[1,2], Florian Wertz[1], Fangqing Xie[1], Marcel Heinze[1], Philipp Schmieder[1], Christian Lutzweiler[1], and Thomas Schimmel[1,2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany

We present a silver atomic-scale device fabricated and operated by a combined technique of electrochemical control (EC) and mechanically controllable break junction (MCBJ). With this EC-MCBJ technique, we can perform mechanically controllable bistable quantum conductance switching of a silver quantum point contact (QPC) in an electrochemical environment at room temperature. In this way, the silver QPC of the atomic quantum transistor can be controlled both mechanically and electrochemically, and the operating modes can be changed from electrochemical to mechanical, which expands the possibilities for controlling QPCs.

HL 55.12 Fri 12:30 A 151

Investigation of Bi induced three-dimensional InAs nanostructures on GaAs(110) by cross-sectional scanning tunnelling microscopy. — •Wjatscheslav Martyanov[1], Ryan B. Lewis[2], Hendrik Janssen[1], Celina S. Schulze[1], Pascal Farin[1], Andrea Lenz[1], Mario Dähne[1], Lutz Geelhaar[2], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

While on GaAs(100) three-dimensional (3D) growth of InAs is preferred, on other low-index GaAs surfaces such as (110) and (111) the deposition always results in a two-dimensional growth. On the other hand, the growth of 3D nanostructures like quantum dots on these surfaces is of interest for high efficiency single photon sources. Recent investigations show that the presence of Bi as a surfactant induces 3D growth on GaAs(110) by modifying the surface energy. In this contribution Bi induced InAs 3D islands formed within InAs monolayers on GaAs(110) are investigated by cross-sectional scanning tunneling microscopy (XSTM). The XSTM images allow the characterization of these structures in terms of size, density, and atomic structure depending on Bi exposure time. In order to explore the influence of Bi, we compare XSTM images of InAs monolayers deposited both with and without the presence of a Bi flux, and InAs monolayers subsequently exposed to Bi for different durations. This work was supported by the DFG, SFB 787, Project A4.