HL 13: Quantum Dots and Wires: Preparation and Characterization I

Time: Monday 14:00–17:45 Location: H17

HL 13.1 Mon 14:00 H17

In-assisted growth of InAs nanowires by molecular beam epitaxy — •Thomas Grap, Christian Blömers, Mihail Ion Lepsa, Steffi Lenk, Thomas Schäpers, Hans Lüth, and Detlev Grützmacher — Institute of Bio- and Nanosystems (IBN-1) and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich GmbH, D-52425 Jülich

Semiconductor nanowires are expected to play a key role in future nanotechnology as well as for understanding the optical, electrical and spin-related properties in systems with reduced dimensionality and size. In particular, InAs nanowires are of special interest in connection with the material properties: low effective mass, narrow gap, high electron mobility and strong electron accumulation layer on its surface. As a better alternative to the growth of InAs nanowires using Au particles, we have successfully developed a method using In droplets as seeds. The nanowires have been grown on both GaAs and InP (111)B substrates covered with a very thin hydrogen silsesquioxan (HSQ) film. We show systematic results obtained for different growth conditions related to substrate temperature and beam fluxes of In and As. Information about the crystallographic structure of the nanowires got from transmission electron microscopy investigations is also presented.

HL 13.2 Mon 14:15 H17

Enhancement of Young's modulus in InAs nanowires — •Vadim Migunov[1], Zi-An Li[1], Marina Spasova[1], Michael Farle[1], Andrey Lysov[2], Werner Prost[2], Ingo Regolin[2], and Franz-Josef Tegude[2] — [1]Fakultät für Physik and CeNIDE — [2]Fakultät für Ingenieurwissenschaften and CeNIDE, Universität Duisburg-Essen, Duisburg, Deutschland

Semiconducting nanowires are of great interest due to their potential in electrical and electromechanical applications. In our study Young's modulus of InAs nanowires (NWs) with a diameter of approximately 50 nm was determined by electromechanical resonance measurements.

The NWs were grown by MOCVD on the (100) InAs substrate. Three types of NWs with different crystalline structures were identified by HR-TEM: Zinc-Blende (ZB) structure, Wurtzite (WZ) structure, mixed WZ and ZB structure. The electromechanical resonance was studied in-situ in TEM to correlate mechanical and structural properties of the NWs. The resonance frequency was determined by tuning the AC voltage frequency applied between STM tip and NW until the maximum amplitude of mechanical vibrations of the NW was achieved and directly observed in TEM. The measurements were performed on NWs with different lengths, diameters and structures. Young's modulus for two types of structures (pure WZ and mixed structure) was calculated using TEM tomography data for the NWs cross-section. An enhancement of about a factor of two of Young's modulus in comparison to the bulk value was observed for both NWs types.

The work is supported by SFB 445.

HL 13.3 Mon 14:30 H17

Improvement of the optical quality of site-controlled InAs quantum dots by a double stack growth technique in wet-chemically etched holes — •Tino Johannes Pfau[1], Aleksander Gushterov[1], Johann-Peter Reithmaier[1], Isabelle Cestier[2], Gadi Eisenstein[2], Evgany Linder[3], and David Gershoni[3] — [1]Technische Physik, INA, Universität Kassel, 34132 Kassel — [2]Electrical Engineering Dep., Technion, Haifa 32000, Israel — [3]Solid State Institute and Physics Dep., Technion, Haifa 32000, Israel

The optimization of the wet-chemically etching of holes and a special MBE growth stack technique allows enlarging the site-control of low density InAs QDs on GaAs substrates up to a buffer layer thickness of 55 nm [1]. The strain of InAs QDs, grown in the etched holes, reduces the hole closing, so that a pre-patterned surface is conserved for the second QD layer. The distance of 50 nm GaAs between the two QD layers exceeds drastically the maximum vertical alignment based on pure strain coupling (20 nm). Compared to stacks with several QD layers, this method avoids electronic coupling between the different QD layers and reduces the problems to distinguish the dots of different layers optically. Confocal microphotoluminecence reveals a significant diminution of the low temperature photoluminescence linewidth of the second InAs QD layer to an average value of 505 ± 53 μeV and a minimum width of 460 μeV compared to 2 to 4 meV for QDs grown on thin buffer layers. The increase of the buffer layer thickness decreases the influence of the surface defects caused by prepatterning.

[1] T. J. Pfau, *et al.,* Appl. Phys. Lett. 95 (2009)

HL 13.4 Mon 14:45 H17

Influence of arsenic species on InAs island formation on InAlGaAs/InP (100) surfaces — •Christian Gilfert[1], Emil-Mihai Pavelescu[2], and Johann Peter Reithmaier[1] — [1]Technische Physik, Institut für Nanostrukturtechnologie und Analytik, Universität Kassel, 34132 Kassel, Germany — [2]National Institute for Research and Development in Microtechnologies, 077190 Bucharest, Romania

The nucleation of $InAs$ on $InP\,(100)$ is far more complex than in the $In(Ga)As/GaAs$ system and a variety of different structures has been reported. However, optoelectronic devices such as semiconductor lasers and amplifiers for $1.3\mu m$ and $1.55\mu m$ require a well established electronic confinement of the charge carriers for improved device performance in terms of, e.g., threshold current and temperature stability. Therefore, homogenously grown round-shaped quantum dots are the structures of choice, since they present a zero-dimensional system for the carriers. Round-shaped quantum dots on InP were accomplished by several growth methods. To the best of the authors‘ knowledge a study of the influence of the arsenic species on the nucleation of $InAs$ has not been reported yet. We demonstrate that the arsenic species has quite a dramatic impact. When supplying As_2 the deposited $InAs$ preferentially forms round-shaped quantum dots, which exhibit an improved photoluminescence over the As_4 counterparts. FWHM values as low as 22meV at 10K were achieved. This linewidth is smaller than state-of-the-art linewidth reported yet for $InAs$ quantum dots grown on $InAlGaAs/InP\,(100)$ based compounds.

HL 13.5 Mon 15:00 H17

Herstellung und Charakterisierung von InAs/GaAs-Quantenpunktstrukturen mittels Droplet-Epitaxie — •Verena Zürbig, Aleksandar Gushterov und Johann Peter Reithmaier — Technische Physik, Institut für Nanostrukturtechnologie und Analytik, Universtät Kassel, 34132 Kassel, Germany

Die Droplet-Epitaxie bietet neben der konventionellen Stranski-Krastanov-Methode die Möglichkeit, Quantenpunkte durch selbstorganisiertes Wachstum herzustellen. Dabei werden zuerst In-Metalltropfen auf der GaAs-Oberfläche gebildet, bevor diese durch Zugabe von As-Molekülen zu InAs-Quantenpunkten auskristallisieren. Der Vorteil der Droplet-Epitaxie liegt in der Herstellung von dreidimensionalen Nanostrukturen aus gitterangepassten und gitterfehlangepassten Materialkombinationen und der Herstellung von Quantenpunktstrukturen ohne Benetzungsschicht. Auf einem nicht dotierten [100] GaAs-Substrat wurden InAs-Quantenpunkte mittels Droplet-Epitaxie bei hohen Substrattemperaturen (450 °C und 500 °C) realisiert. Die Proben wurden in einer Molekularstrahlepitaxie-Anlage hergestellt und topographisch mit dem Rasterkraftmikroskop und optisch mit der Photolumineszenzspektroskopie untersucht. Durch die Variation verschiedener Wachstumsparameter (Öffnungszeit der As-Zelle, Mengenzugabe von Indium, Wachstumsrate von Indium, As-Druck, Substrattemperatur) konnten optimierte Parameter für die Herstellung von InAs/GaAs-Quantenpunktstrukturen mit geringer Größe (Höhe: 5-7 nm), großer Homogenität und guten optischen Eigenschaften (FWHM: 65 meV, Messtemperatur: 10-300 K) ermittelt werden.

HL 13.6 Mon 15:15 H17

Site Controlled InAs Quantum Dots with ultra low densities and improved spectral uniformity — •Carmen Drescher, Christian Schneider, Kousha Talebian, Martin Kamp, Sven Höfling, Stefan Reitzenstein, Lukas Worschech, and Alfred Forchel — Technische Physik,Physikalisches Institut, Universität Würzburg and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg,Am Hubland, 97074 Würzburg, Germany

In order to exploit InAs Quantum Dots (QDs) coupled to microcavities as single photon sources in a scalable manner one needs to know the exact position of the QD for device alignment. To improve the yield of spectrally resonant devices without adjusting the resonator geometry to the individual QD emission wavelength it is necessary to reduce spectral inhomgeneities in the ensemble emission of the QD array. The position control of our site controlled QDs (SCQDs) is maintained by directing the QD nucleation to shallow etched nanoholes on a (1,0,0) GaAs surface. To achieve a reasonably low single QD linewidth and ensemble broadening, growth parameters during the molecular beam epitaxy (MBE) deposition step of the QDs have been optimized and investigated. We have monitored the influence of the substrate temperature during SCQD growth as an important parameter for spectral homogeneity and achieved accurate QD nucleation of single SCQDs on pitches up to 4 μm on both uncapped and buried SCQDs.

HL 13.7 Mon 15:30 H17

High quality single-photon photoluminescence emission of MOVPE grown InGaAs quantum dots — •Daniel Richter, Robert Hafenbrak, Klaus Jöns, Wolfgang-Michael Schulz, Marcus Eichfelder, Robert Rossbach, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

In recent years, investigations on semiconductor quantum dots (QDs) have been motivated by their potential application in the field of quantum information processing. Therefore, optically or electrically addressable single quantum dots are needed on a mass production scale using metal-organic vapor-phase epitaxy (MOVPE). A narrow linewidth of QD emission makes them suitable for e.g. two photon interference and single-photon emitters at high repetition rates. By applying special annealing techniques the growth of low density (10^7 cm^{-2}), small sized quantum dots grown on misoriented GaAs substrates by MOVPE was realized. The influence of the growth conditions on the QD structural properties was investigated by atomic force microscopy measurements. To enhance the photoluminescence extraction efficiency a DBR structure is used. With a high resolution PL setup, using a Fabry-Perrot Etalon, QD PL emission linewidths of 12 μeV were found. Furthermore the fine structure splitting is investigated. We prove the zero-dimensionality of the QD structures by performing 2nd order intensity autocorrelation measurements.

15 Min. Coffee Break

HL 13.8 Mon 16:00 H17

Structural and optical characterization of high areal density $Ga_xIn_{1-x}P$ quantum dots on GaP — •Vasilij Baumann, Sven Gerhard, Sven Höfling, and Alfred Forchel — Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

We present a study of growth, morphology and optical properties of $Ga_xIn_{1-x}P$ quantum dots (QDs) for various Ga concentrations x.

All samples were grown on GaP substrates using a gas source molecular beam epitaxy system with thermally cracked PH_3 gas and Ga and In from solid source effusion cells.

QD areal densities up to 10^{11} cm^{-2} have been achieved showing strong dependence on the amount of gallium supplied. QD sizes and areal densities are evaluated using scanning electron microscopy and atomic force microscopy and are related to photoluminescence (PL) properties of the QDs.

Low temperature PL spectra are also presented showing emission in the visible red spectral range and emission intensities that are strongly dependent on Ga content.

Both structural and optical properties are promising for future applications of the herein reported QDs in visible wavelength optoelectronic devices.

HL 13.9 Mon 16:15 H17

GaAs/GaMnAs core-shell nanowires grown by MBE — •Andreas Rudolph[1], Marcello Soda[1], Matthias Kiessling[1], Dieter Schuh[1], Christian Back[1], Josef Zweck[1], Tomasz Wojtowicz[2], Werner Wegscheider[3], and Elisabeth Reiger[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Universitätsstrasse 31, D-93053 Regensburg, Germany — [2]Institute of Physics, PAS, Al. Lotnikow 32/46, 02-668 Warsaw, Poland — [3]Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

Our research interest is focused on combining the diluted magnetic semiconductor GaMnAs with the growth of GaAs nanowires. We use a core shell nanowire approach were the core GaAs nanowire is grown at typical nanowire growth conditions using Au or Ga as catalysts [1,2]. The GaMnAs shell is deposited at low temperatures, known to be crucial for high quality GaMnAs. The nanowires are characterized by SEM, TEM, SQUID and transport measurements. Parameters like growth temperature, shell thickness and Mn content were varied to investigate their influence on Curie temperature and magnetic anisotropy [3]. Currently we work on improving the core nanowire growth to obtain more uniform nanowire samples with respect to size, shape and in particular side facets. With this samples the GaMnAs shell could be optimized on the specific crystal orientation of the side facets.

[1] M. Tchernycheva et al., Nanotechnology 17, (2006). [2] C. Colombo et al., PRB 77, (2008) [3] A. Rudolph et al., Nano Letters, (unpublished)

HL 13.10 Mon 16:30 H17

Single photon emission from positioned GaAs/AlGaAs axial heterostructure nanowires grown on pre-patterned substrate — •Jan Heinrich, Alexander Huggenberger, Tobias Heindel, Stephan Reitzenstein, Sven Höfling, Lukas Worschech, and Alfred Forchel — Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Nanowires (NWs) with axial heterostructure quantum dots (QDs) are predicted to be very efficient single photon sources (SPSs). In literature, besides the growth of positioned NW on pre-patterned substrates, also single photon emission from NW with embedded QD has been demonstrated. Here, the as-grown NWs are usually removed from the growth substrate for measurements, which has the drawback of a possible damage of the NW during the transfer. Moreover, there is an arbitrary orientation of the NW after the transfer. In contrast, we have grown AlGaAs NW with an embedded axial heterostructure GaAs QD, which allows us to probe single free standing and precisely positioned NW directly on the growth substrate. Single NW were examined by μPL and showed narrow PL emission around 740 nm with linewidths as small as 95 μeV. Morover, photon autocorrelation measurements were performed to examine the potential of the positioned NW to act as an SPS. The positioned NW with embedded QD showed clear photon anti-bunching, proving the non-classical light emission by emitting only one photon at a particular time.

HL 13.11 Mon 16:45 H17

Position control of self-catalyzed MBE-grown GaAs nanowires — •Benedikt Bauer[1], Andreas Rudolph[1], Anna Fontcuberta i Morral[2], Dieter Weiss[1], Dieter Schuh[1], Marcello Soda[1], Josef Zweck[1], and Elisabeth Reiger[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]Institut des Materiaux, EPFL Lausanne, Switzerland

Nanowires grown in bottom-up processes are regarded as possible building blocks of future electronic devices. For integrating them into conventional electronic circuits controlling the position and diameter of the nanowires is inevitable [1]. We report on position controlled GaAs nanowires grown via self-catalyzed growth using MBE [2]. Starting with a GaAs (111)B substrate covered by a thin SiO_2 layer we use E-beam lithography in combination with wet chemical etching to define arrays of holes with diameters of 100 nm and varying interhole distances between 200 and 2000 nm. These holes in the SiO_2 layer act as nucleation sites for nanowire growth. The nanowires are oriented in the [111] direction and are restricted to the patterned areas.

SEM/TEM characterizations show that the nanowires have a hexagonal shape with {110} side facets and zinc blende as dominant crystal structure.

[1] Thelander et al., Mater. Today **9** (2006) 28.
[2] Colombo et al., Phys. Rev. B **77** (2008) 15532.

HL 13.12 Mon 17:00 H17

Conversion of rare earth doped ZnS to ZnO nanowires — •Sebastian Geburt, Gabriele Bulgarini, Christian Borschel, and Carsten Ronning — Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena

The ideal properties for nanoscaled photonic devices (light emission, wave guiding and light amplification) are combined in semiconductor nanowires (NWs). Doping with optical active elements offers new possibilities, but doping during nanowire growth is still an unsolved problem. Ion implantation overcomes the limitations, but the ion induced lattice damage can not completely be avoided and leads to suboptimal optical properties.

In a new approach, ZnS nanowires were implanted with rare earth elements (RE = Nd, Sm; 0.02 - 2 at%) and annealed in vacuum. Spatial resolved cathodoluminescence (CL) shows the optical activation of the RE in the ZnS matrix. Upon further annealing at higher temperatures, the ZnS nanowires were converted to ZnO by oxidation. The conversion process eliminates lattice defects and enhances the integration of the optical active dopants into their surrounding. SEM, TEM and EDX give insights to the conversion process from ZnS to ZnO. Highly enhanced luminescence from the impurities can be detected by CL. The influence of annealing conditions, dopant concentration and temperature are subject of investigation. The results are compared with RE implanted ZnO nanowires yielding into much lower intensities.

HL 13.13 Mon 17:15 H17

Epitaxial silicon nanowire growth catalyzed by gold dot arrays from electron beam lithography patterning using silane precursors — •Björn Hoffmann, Gerald Brönstrup, Uwe Hübner, and Silke Christiansen — Institut für Photonische Technologien e.V., Abt. Halbleiter Nanostrukturen, 07745 Jena

Ordered arrays of silicon nanowires (SiNWs) are promising building blocks for a variety of photonic, photovoltaic and sensor applications. In our approach to create SiNWs we use electron beam lithography (EBL) and thermal metal evaporation to create nano-patterned arrays of gold nanodots on a Si(111) wafer. These Au dots are subsequently used to catalyze the bottom-up growth of SiNWs that follow the vapor-liquid-solid (VLS) growth mechanism using silane in a CVD reactor.

The grown nanowires are characterized structurally using SEM, TEM and electron backscatter diffraction (EBSD).

We observe epitaxial growth of the SiNWs on the Si(111) wafer and we are able to control the growth direction to be either dominated by <111> or <112> directions by just changing the silane partial pressure. The lengths as well as the diameters of the wires are precisely controlled by the EBL Au dot patterning and CVD parameters. To predict wire diameters modelling is carried out that takes into account the EBL- and CVD-parameters and describes the observed experimental results very well.

Furthermore we were able to create single crystalline Au-dot arrays which are very promising structures for surface enhanced raman spectroscopy (SERS) substrates.

HL 13.14 Mon 17:30 H17

Scaled nanowire field effect transistors and dopant free logic — •Andre Heinzig[1], Walter M. Weber[1], Daniel Grimm[2], Thorsten Roessler[3], Monika Emmerling[4], Martin Kamp[4], and Thomas Mikolajick[1] — [1]Namlab gGmbH, D-01187 Dresden — [2]IFW-Dresden — [3]IHM, TU-Dresden — [4]Universität Würzburg

Most digital electronic applications are based on complementary logic where symmetric pairs of p- and n-type transistors are combined to significantly reduce the power consumption. As downscaling proceeds the accurate and reproducible adjustment of doping profiles has proven to be a difficult task. Intrinsic silicon nanowire (NW) FETs were fabricated with intruded, abrupt Schottky junctions. The carrier injection over the metal ($NiSi_2$) to Si NW-hetero-junctions can be controlled accurately by locally adjusting the electric field. Successful gate control and saturation of the devices has been achieved for gate lengths down to 32 nm for a NW diameter of 17 nm. The integration of high-k dielectrics (HfO_2, Al_2O_3) was implemented to improve the gate coupling. A novel approach with a double top gate architecture was used to independently control the carrier injection through each junction. By blocking the undesired type of carriers at one junction, the intrinsic ambipolar behavior of the NW-FET can be tuned to p- or n-type without the use of doping. The first dopant free complementary inverter has been fabricated by combining two NW-FETs with inverse programmed polarity. The transfer characteristics show a clear inversion behavior with stable states over several periods. These results imply that all types of digital functions can be realized with undoped Si-NWs.