HL 64: Focus Session: Semiconductor Heteroepitaxy on Nanopatterned Substrates

State-of-the-art electronic and optoelectronic devices are widely based on layered heteroepitaxial semiconductor systems. As the crystal quality of planar heteroepitaxial layers is often limited by lattice misfit relieving defects, the selective growth on small areas as well as on non-planar, nanopatterned substrates has attracted increasing interest. In these cases the three-dimensional elastic lattice relaxation largely extends the range of material combinations, for which defect-free heteroepitaxial growth is possible. In tandem with the nanopattern-induced modifications of the surface potential and growth characteristics this sets the fundament for the realization of unique architectures and new classes of self-assembled and site-controlled nanostructures, which are required for high-performance devices. Selective-area grown nanowires for example have been demonstrated to exhibit outstanding luminescence properties, and complex hierarchical heterostructures grown on nanowire templates have paved the way for new types of quantum structures and innovative device architectures. Worldwide, numerous research groups and institutes are involved in exploring the fabrication and properties of such nano-heteroepitaxial systems. Therefore, the proposed symposium focusses on experiments and simulations of the heteroepitaxial growth on nanopatterned substrates, structural and nanomorphological aspects as well as control of optical, electronic and transport properties, and device applications. The symposium aims at bundling the extensive research activitities in this area and at offering a forum for scientists from fields of epitaxial growth, nanopatterning, theory, surface science, characterization, and device fabrication.

Organizers: Thomas Riedl (U Paderborn), Gregor Koblmüller (WSI München), Martin Eickhoff (JLU Gießen)

Time: Wednesday 15:00–18:30 Location: H11

Topical Talk HL 64.1 Wed 15:00 H11

Single site-controlled InGaAs quantum dots grown on patterned GaAs nanoholes — •S. Höfling, S. Maier, S. Unsleber, M. Kamp, and C. Schneider — Technische Physik, Würzburg University

Single semiconductor quantum dots (QDs) are very attractive candidates to control charge and spin carriers at the quantum level. They are therefore very promising for applications in fields ranging from nanoelectronics over nanophotonics to spintronics. One of the major challenges regarding the scalable fabrication of single QD based devices is however the precise control of the QD position within device structures. In this presentation, we summarize our results obtained on the site-controlled growth using pre-patterned nanohole templates for the controlled integration of site-controlled QDs into nanoscale devices. By combining this growth technique with a process capable of accurately aligning QDs relatively to subsequently fabricated quantum device structures, several interesting devices like single photon sources and quantum dot memories have been realized.

Topical Talk HL 64.2 Wed 15:30 H11

Nanometer scale correlation of structural and optical properties of individual GaAs/AlGaAs nanorodsby Scanning Transmission Electron Microscope Cathodoluminescence — •Frank Bertram, Marcus Müller, Peter Veit, and Jürgen Christen — Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg

We will present a direct correlation of the luminescence with crystallographic realstructure of novel GaAs/AlGaAs coreshell nanowires using cathodoluminescence directly performed in transmission electron microscope at liquid helium temperature. The GaAs/AlGaAs coreshell NWs were produced by a unique twostep process enabling the growth of ultrathin GaAs cores. First, GaAs NWs were obtained by molecular beam epitaxy on a [111]-oriented Si. In a second step the GaAs core diameter was reduced by a reverse-reaction using in-situ thermal decomposition of the {110} side wall surfaces leading typically to a diameter down to 7 nm. Subsequently, the cores were overgrown by an AlGaAs passivation shell and a GaAs cap. TEM investigations reveal wurzite structure in the bottom part of the NW with a high density of extended defects whereas the upper part is dominated by the zincblende phase containing few twindefects. Highly spatially resolved CL measurements exhibit a blue shifted emission up to 1.66 eV as compared to bulk GaAs. In particular, we will present a detailed analysis of the impact of structural properties on the luminescence along the wire. Locally sharp emission lines originating from vicinity of twindefects within the ZB-structure indicate effective localization.

Topical Talk HL 64.3 Wed 16:00 H11

Local Heteroepitaxy for Large-Scale Integration — •Heinz Schmid, Mattias Borg, Davide Cutaia, Kirsten Moselund, Moritz Knoedler, Nicolas Bologna, and Heike Riel — IBM Research - Zurich , 8803 Rueschlikon, Switzerland

The cooperative use of unequal materials like silicon and III-Vs can lead to performance benefits and even enable novel devices and applications. Traditionally this has been achieved by clever joining of the individual Si and III-V components in a common package. Alternatively this could be achieved by building the devices directly from Si wafers with embedded III-V layers. However, such wafers are not readily available yet. Here we review our effort on local epitaxy of III-Vs on Si and introduce the concept of template-assisted selective epitaxy (TASE). Various III-V materials with nanowire or thin-film geometries were successfully grown with high yield on Si using TASE and further processed into field effect transistors (FETs) and tunnel-FETs that exhibited excellent performance.

15 min. break.

Topical Talk HL 64.4 Wed 16:45 H11

Fabrication and study of metal contacts on germanium nanowires using electrical biasing in a transmission electron microscope — •Martien den-Hertog[1], Khalil El-Hajroui[1], Clemens Zeiner[3], Alois Lugstein[3], Eric Robin[2], Miguel Lopez-Haro[2], and Jean-Luc Rouviere[2] — [1]Institut Neel, CNRS/UJF/UGA, Grenoble, France — [2]INAC, CEA-Grenoble/UGA, Grenoble, France — [3]Institute for solid state electronics, Vienna, Autriche

Semiconductor nanowires (NWs) are promising candidates for many device applications ranging from electronics and optoelectronics to energy conversion and spintronics. To allow successful device integration the contact quality between for example a NW and metal is of paramount importance. An interesting approach to create an atomically abrupt contact with low electrical resistance on NWs of group IV (silicon and germanium) is to create a metal-semiconductor phase in the extremities of the NW. To understand and control the metal diffusion into the NW that creates a metallic phase, detailed characterization at atomic length scales is necessary to understand how the metal atoms diffuse and incorporate into the formed phase at the reaction front and how these parameters relate to the electrical properties of the same interface. In this work we study two different kind of semiconducting NW devices fabricated on electron transparent Si3N4 membranes. We show in-situ phase propagation of a metal-semiconductor phase of Cu and Al in Ge NWs in the TEM while measuring the current through the device, and analyze the metal diffusion process.

Topical Talk HL 64.5 Wed 17:15 H11

Cubic GaN on pre-patterned 3C-SiC/Si (001) substrates —

•Donat Josef As, Ricarda Maria Kemper, Thomas Riedl, and Jörg K.N. Lindner — Department Physik, Universität Paderborn, Warburgerstrasse 100, 33098 Paderborn, Germany

The influence of growth area reduction towards length scales predicted to be effective for defect reduction by the theory of nano-hetero-epitaxy (NHE) is analyzed. This is studied in detail for the first time in the system of meta-stable cubic GaN (c-GaN) grown by plasma-assisted molecular beam epitaxy on pre-patterned 3C-SiC/Si (001) substrates. It is demonstrated that regardless of the pattern symmetry or size, the cubic phase of GaN nucleates on top of all investigated mesa structures. Electron beam lithography followed by a lift-off and a reactive ion etching process is used for tailoring post-shaped SiC structures. A successful reduction of the {111} stacking fault (SF) density is achieved by reducing the (001) top edge length of the posts from ~500 nm down to ~20 nm. Transmission electron microscopy reveals a nucleation of phase-pure and almost defect free c-GaN on top of the smallest SiC nanostructures as predicted by theoretical calculations.

HL 64.6 Wed 17:45 H11

GaAs-based nanowire integration on silicon via template-assisted selective epitaxy — •Moritz Knoedler, Nicolas Bologna, Mattias Borg, Heinz Schmid, Giorgio Signorello, Davide Cutaia, Kirsten Moselund, Marta Rossell, and Heike Riel — IBM Research Zurich, Säumerstrasse 4, 8803 Rüschlikon, Switzerland

As the scaling-down of conventional Si microelectronics is approaching fundamental physical limits, novel materials are heavily being investigated as alternative channel materials, with III-V semiconductor compounds being particularly promising candidates. Thus far, III-V integration into Si technologies has been limited due to poor epitaxial material quality. Our group has recently demonstrated a novel method to directly integrate III-V nanostructures on silicon called template-assisted selective epitaxy (TASE). Nanowires are grown inside lithographically pre-defined oxide templates, allowing for precise tuning of composition and crystal quality, independent from their shape and substrate orientation.

Here we present a comprehensive investigation of GaAs-based epitaxy directly on Si wafers via TASE, by correlating growth parameters with crystal morphology. To this end, nanowires were grown with metal-organic chemical vapour deposition (MOCVD) under different conditions by varying template width, growth duration, temperature, group III molar flows and V/III precursor ratio. Crystal quality was then analyzed at atomic resolution by state-of-the-art double-aberration-corrected (scanning) transmission electron microscopy (STEM/TEM). Zinc blende/wurtzite polytypism and twin defect formation were investigated in detail.

Low-temperature and temperature-dependent micro photoluminescence (PL) spectroscopy was used to further characterize their optical properties. Significant photoemission of the nanostructures even at room temperature was observed. When the GaAs is surrounded by the oxide template or an AlGaAs shell luminescence is much enhanced, indicating reduced surface recombination velocity.

HL 64.7 Wed 18:00 H11

Theoretical analysis of strain and misfit dislocation stability in axial-heteroepitaxial GaAs/InAs nanopillars — •Thomas Riedl[1,2] and Jörg Lindner[1,2] — [1]University of Paderborn, Department of Physics, Warburger Straße 100, 33098 Paderborn, Germany — [2]Center for Optoelectronics and Photonics Paderborn (CeOPP), Warburger Straße 100, 33098 Paderborn, Germany

Heteroepitaxial nanopillars and -wires represent a promising building block for advanced optoeletronic devices like dot-in-wire LEDs or lasers. Such structures offer a large surface-to-volume ratio and the possibility to accommodate considerable lattice mismatch in a pure elastic manner without formation of misfit relieving defects. As misfit dislocations are reported to occur in heterostructure nanowires in case of larger misfit and diameter, it is important to determine the critical wire dimensions for dislocation stability. In the present contribution we analyze this for the case of [111] orientied axial-heteroepitaxial GaAs/InAs nanopillars with zinc blende structure. Because of its applicability to various dislocation configurations and the availability of suitable parametrizations we use atomistic molecular statics simulation based on the Tersoff potential. We find that the defect-free elastically strained state is stable for small wire diameters ($<$ 10 nm for a single 60° dislocation), whereas the dislocated state becomes favorable for larger diameters. In this presentation the influence of dislocation type, wire morphology and chemical width of the heterointerface on the coherent-semicoherent transition is analyzed and discussed. The results are compared with the literature.

HL 64.8 Wed 18:15 H11

Selective nano-heteroepitaxial growth of GeSn islands on nano-patterned Si(001) — Viktoria Schlykow[1], Noriyuki Taoka[1], Marvin Zöllner[1], Oliver Skibitzki[1], Peter Zaumseil[1], •Giovanni Capellini[1,2], Yuji Yamamoto[1], Thomas Schröder[1,3], and Gang Niu[1] — [1]IHP, Frankfurt (Oder) — [2]Dipartimento di Scienze, Italy — [3]BTU Cottbus-Senftenberg

Ge is a promising candidate for optical devices due to its band gap, resulting in high absorption at the telecommunication wavelength. The introduction of Sn into Ge forming GeSn alloys enables further flexibility to engineer the optical properties like the semiconductor band gap. However, crystalline defects induced by lattice mismatch between GeSn and Si are a crucial challenge to realize high performance optical devices. Recently, we demonstrated fully coherent, dislocation free Ge islands on nano-pillar patterned Si (NPP-Si) substrates using nano heteroepitaxy approach. In this study, we demonstrate the selective MBE growth of GeSn islands on NPP-Si at high temperatures. In order to establish selective MBE growth of GeSn on NPP-Si surrounded by SiO2, the impact of growth temperature (500-750 °C) on the selectivity and the Sn incorporation was investigated. XRD, TEM and micro-PL studies confirmed that the growth at 600 °C results in good selectivity and homogeneous distribution of Sn in Ge nano-islands and good optical properties. Growth below 600 °C results in non-selectivity whereas growth above 600 °C leads to better selectivity but an enhanced Sn migration to {111} facets thus reduced Sn incorporation.