HL 33: Quantum wires: preparation and characterization

Time: Wednesday 14:00–17:15 Location: BEY 81

HL 33.1 Wed 14:00 BEY 81

Electrical characterization of InAs/GaAs (110) nanostructures by Conductive Atomic Force Microscopy — •Igor Beinik[1], Christian Teichert[1], Laura Díez-Merino[2], and Paloma Tejedor[2] — [1]Institute of Physics, Montanuniversität Leoben, Franz Josef Straße 18, 8700 Leoben, Austria — [2]Instituto de Ciencia de Materiales de Madrid, CSIC, C/Sor Juana Inés de la Cruz 3, 28049-Madrid, Spain

Self-assembled InAs quantum dots and wires have been studied over many years and still they are of great interest for application in nanoelectronics, high-speed spintronic devices, etc. Samples for our investigation were grown by molecular beam epitaxy on misoriented (110) GaAs substrates. Conductive Atomic Force Microscopy (C-AFM) technique was used to study the surface topography and conductivity simultaneously. Comparison of the corresponding cross-section profiles indicated that InAs nucleation takes place on the [1-10]-oriented step bunches, forming 3 nm-high and up to 70 nm-wide wires of variable length. On the other hand, [1-12]-type steps very rarely appeared to be decorated by InAs, also in agreement with previous TEM studies[1]. The presented results prove that C-AFM technique might be successfully applied as a tool for investigation of electrical properties in III-V quantum dots and wires on the nanometer scale. This work is supported by FWF Project # P19636, ÖAD project # ES 17/2007, TEC2007-66955 and HU2006-0022. [1] X.M. Zhang, D.W. Pashley, I. Kamiya, J.H. Neave, B.A. Joyce, J. Cryst. Growth 147 (1995) 234.

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Nucleation of Au-induced GaAs Nanowires on Si(111) and GaAs(111)B — •Steffen Breuer, Maria Wagler, Lutz Geelhaar, Achim Trampert, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin

Vertical nanowires (NWs) offer a novel path towards monolithic integration of III-V semiconductors such as GaAs on Si. We studied nucleation and growth of GaAs NWs by the Au-induced vapor-liquid-solid (VLS) mechanism in a molecular beam epitaxy (MBE) chamber on Si(111) and compared it to the homoepitaxial case on GaAs(111)B. NWs grown for 30 min on each substrate are straight and have very similar shapes, lengths and densities, as found by scanning electron microscopy (SEM). We conclude from reflection high-energy electron diffraction (RHEED) patterns that on both substrates the NWs have Wurtzite (WZ) crystal structure and are epitaxially aligned to the respective substrate. A series of experiments with growth times between 5 s and 300 s was performed on each substrate. At this early stage, there are significantly more NWs on GaAs(111)B than on Si(111). Apparently, on Si(111) NW formation is delayed. Instead, the early surface is predominantly covered by three-dimensional GaAs islands that have Zincblende (ZB) crystal structure and a high density of twinning defects, as found by RHEED. We conclude that on Si(111) most Au droplets are inactive initially until the whole surface is covered by coalesced GaAs islands. We speculatively explain this by a model that assumes different interface energies for liquid Au on the two types of substrate.

HL 33.3 Wed 14:30 BEY 81

Ga-assisted growth of GaAs nanowires by molecular beam epitaxy — •Sonja Heiderich[1,2], Mihail Ion Lepsa[1], and Detlev Grützmnacher[1] — [1]Institute of Bio- and Nanosystems (IBN-1) and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich GmbH, D-52425 Jülich — [2]Universität Hamburg, Institut für Angewandte Physik, Jungiusstr. 11, D-20355 Hamburg

An important aim of many research activities is the integration of III-V semiconductor nanowires in the established and cheaper silicon technology to get novel electronic and optoelectronic devices. Until now, III-V semiconductor nanowires have been typically synthesized using Au nanoparticles (catalyst) as a seed and the vapor-liquid-solid (VLS) or vapor-solid-solid (VSS) mechanisms. However, the Au can diffuse into the wire during the growth and affect the electronic transport properties. Therefore the growth of nanowires using the group III element as a seed represent the ideal option. In this report, we present data about the Ga-assisted growth of GaAs nanowires by molecular beam epitaxy (MBE). The nanowires have been grown on (100) or (111) GaAs substrates covered with a thin hydrogen silsesquioxan (HSQ) film. A study varying the growth conditions has been realized. From the analysis of the nanowire diameter and length (growth rate) in different growth conditions, we propose a phenomenological growth model. The model take into account that the growth proceeds via VLS mechanism from Ga droplets which develop at the beginning and are situated over preexisting pinholes in HSQ.

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Fabrication of longitudinal silicon nanowire heterostructures for implementation in field effect transistors — •Andre Heinzig and Walter M. Weber — Namlab GmbH, D-01187 Dresden

Continuous down scaling of field effect transistors will eventually lead to fabrication and performance related difficulties. In this respect, Schottky contact nanowire FETs are an interesting alternative for post-CMOS applications. Longitudinal metal-semiconductor-metal heterostructures are particularly interesting, since homogeneous and well defined Schottky junctions can be created. These are necessary to ensure a reliable device performance. A process for synthesizing such heterostructures has been developed by the silicidation of silicon nanowires with nickel. In particular, radial and longitudinal silicidation schemes have been established by applying self-aligned techniques. Both methods will be assessed to provide a customized metallic segment length with sharp interfaces in the nanometer scale. Finally, the fabrication of nanowire FETs based on nanowire heterostructures will be shown.

15 min. break

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Local droplet etching of nanoholes and semiconductor quantum rings — •Christian Heyn, Andrea Stemmann, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg

Local droplet etching (LDE) is a very interesting technique which allows the patterning of semiconductor surfaces without any lithographic steps. In particular, the fabrication of deep nanoholes [1,2] and the generation of semiconductor quantum rings [2] has been demonstrated. The LDE technique is related to the droplet epitaxy, where at first liquid Ga droplets are formed on crystalline surfaces in a Volmer-Weber-like growth mode which in a subsequent step are crystallized under As pressure. As a main difference, during LDE, significantly higher temperatures are used at which nanoholes at the interface between the liquid droplets and the surface are formed by local etching. Furthermore, distinct walls surrounding the nanohole openings are crystallized from droplet material [2] and act as semiconductor quantum rings with tunable size and composition. This presentation gives an overview on the LDE technique and the influence of the process parameters on nanohole and wall structural properties.

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

[2] A. Stemmann, Ch. Heyn, T. Köppen, T. Kipp, and W. Hansen, Appl. Phys. Lett. 93, 123108 (2008).

HL 33.6 Wed 15:30 BEY 81

In-situ study of catalyst-induced GaN nanowire nucleation — •Caroline Chèze[1,2], Lutz Geelhaar[1,2], Achim Trampert[1], Oliver Brandt[1], and Henning Riechert[1,2] — [1]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin — [2]Formerly at Qimonda, 81730 Munich, Germany

We investigated in situ the nucleation of Ni-seeded GaN nanowires (NWs) grown on C-plane sapphire by molecular beam epitaxy (MBE). The crystal structure was probed by reflection high-energy electron diffraction (RHEED), and simultaneously the incorporated amount of Ga was monitored by line-of-sight quadrupole mass spectrometry (QMS). Additionally, some samples were investigated by transmission electron microscopy (TEM). During growth three different RHEED patterns appear subsequently, and each of them is accompanied by a change in the Ga incorporation behavior. We explained these three different nucleation phases as follows: first an accumulation of Ga into Ni seeds, then a drastic change in the orientation of the seed structure probably corresponding to a phase change induced by Ga incorporation, and finally growth of GaN below the seeds. The comparison of the QMS profiles for the first phase with and without Ni showed that Ga incorporation into the Ni seeds is not the growth limiting step. Moreover the tilt of the seed crystal structure in the second phase suggests a bulk diffusion process of Ga into the Ni seeds. Last the observation of a clear RHEED pattern during the whole nucleation is a strong evidence for the vapor-solid-solid mechanism (VSS).

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Catalyst free selective area MBE growth of InN nanocolumns on Si — •Boris Landgraf, Christian Denker, Joerg Malindretos, and Angela Rizzi — IV. Physikalisches Institut, Georg-August Universität Göttingen, 37077 Göttingen, Germany

Nowadays InN nanocolumns (NCs) are studied for many possible applications, e.g. as single devices - nanowire transistors - as well as ensembles in solar cells. A size and position controlled growth of nanocolumns is highly desirable. It allows a detailed study and optimization of the growth mechanism and is mandatory for the growth of axial and radial heterostructures. To maintain the high purity of MBE grown nanocolumns a catalyst free approach is preferable.

The selective area MBE growth of InN NCs has been investigated by using various masking materials. Electron beam lithography is applied to pattern the material masks with different layouts in order to determine the diffusion length of the indium on the respective materials. Subsequently nanocolumns were grown on the patterned substrates. It will be shown that the size and position of the InN nanocolumns can be controlled by the use of appropriate mask patterns and materials.

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GaN and InN nanowires: Si and Mg doping — Toma Stoica[1], Eli Sutter[2], Ralph Meijers[1], Ratan Debnath[1], Kulandaivel Jeganathan[1,3], Thomas Richter[1], Michel Marso[1,4], Hans Lüth[1], and •Raffaella Calarco[1] — [1]Institute of Semiconductor Nanoelectronics (IBN-1), Research Centre Jülich GmbH, D-52425 Jülich, Germany, and JARA- Fundamentals of Future Information Technology — [2]Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, New York 11973 — [3]Department of Physics, Bharathidasan University, Trichirappalli - 620 025, India — [4]University of Luxembourg, Faculty of Sciences, Technology and Communication - 6, rue Richard Coudenhove-Kalergi, L-1359 Luxembourg

Doping is essential for the realization of optoelectronic devices and represents a complex task if related to nanowires. We have studied GaN and InN nanowires (NWs) doped by Si and Mg obtained by catalyst-free MBE on Si(111) in N-rich conditions. Increasing the Si amount the morphology as well as the density of the wires changes. Successful n-doping of GaN nanowires has been shown by electrical and optoelectrical measurements. Due to the sensitivity of the electrical transport to the wire diameter (size dependent surface barrier), it was possible to determine the doping level of single nanowire. A small amount of Mg increases the tendency of the wires to coalesce. For InN nanowires doped with Si a reduced NWs density is observed as compared to the undoped counterpart. The Mg doping does not change the morphology of the NWs as compared to the undoped however some staking faults at the tip could be observed.

15 min. break

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In-situ RHEED study on the morphology of MBE-grown GaN nanowires — •Matthias Knelangen, Achim Trampert, Lutz Geelhaar, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

GaN nanowires are defect-free, quasi 1-dimensional nanocrystals. Although the fabrication of nanowires is well established, there is still a lack of understanding of the initial nucleation and the catalyst-free self-organized growth mechanism. In this work, we will present an in-situ RHEED study of the nucleation process of GaN nanowires growth on Si (111) substrates.

If GaN growth is initiated directly on Si, the RHEED pattern turns faint and blurry, characteristic for the formation of an amorphous Si_xN_y layer. After GaN nucleation, the RHEED spots are broadened, indicating a tilt of the wires with respect to the substrate. The superposition of two different azimuthal RHEED patterns and the independence to substrate rotation demonstrate the loss of in-plane orientation.

When growing on a smooth AlN buffer, the RHEED shows a clear transition from the AlN reflection pattern to a GaN transmission pattern. The two characteristic azimuths do correspond, showing the epitaxial alignment between AlN and GaN. HRTEM images show that the AlN layer relaxes by formation of misfit dislocations. The GaN/AlN interface is defect-free, so there is no plastic relaxation in the nanowires. Additional ex-situ TEM and XRD experiments will complement this RHEED study to investigate the overall strain of GaN and AlN.

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Local electrical analysis of a single semiconductor nanowire by Kelvin probe force microscopy — •Sasa Vinaji[1], André Lochthofen[1], Wolfgang Mertin[1], Ingo Regolin[2], Christoph Gutsche[2], Kai Blekker[2], Werner Prost[2], Franz Josef Tegude[2], and Gerd Bacher[1] — [1]Werkstoffe der Elektrotechnik & CeNIDE, Universität Duisburg-Essen, Bismarckstr. 81, 47057 Duisburg, Germany — [2]Halbleitertechnologie & CeNIDE, Universität Duisburg-Essen, Lotharstr. 55, 47048 Duisburg, Germany

Semiconductor nanowires open a wide range of innovative electronic and optoelectronic applications. For future device design a detailed knowledge of the local electrical potential is essential. This can be easily accessed by non-contact Kelvin Probe Force Microscopy (KPFM) without damaging the fragile nanowire.

Single GaAs nanowires grown by metal-organic vapour phase epitaxy have been investigated with KPFM. In order to prove the efficiency of p-type doping by ion implantation of Zn [1], the local voltage drop across a biased nanowire was measured quantitatively. From the resistance of the nanowire found, an effective carrier concentration of 6*10^17 cm^-3 could be estimated. Alternatively, a GaAs nanowire was doped during growth with Si and C for n- and p-type doping, respectively. We could localize the doping transition inside the nanowire via KPFM measurements and found a depletion zone of about 350 nm.

[1] D. Stichtenoth, K. Wegener, C. Gutsche, I. Regolin, F. J. Tegude, W. Prost, M. Seibt and C. Ronning, Appl. Phys. Lett. 92, 163107 (2008)

HL 33.11 Wed 17:00 BEY 81

Ion Beam Induced Alignment of Semiconductor Nanowires — •Christian Borschel[1], Raphael Niepelt[1], Sebastian Geburt[1], Christoph Gutsche[2], Ingo Regolin[2], Werner Prost[2], Franz-Josef Tegude[2], Daniel Stichtenoth[3], Daniel Schwen[4], and Carsten Ronning[1] — [1]Institute for Solid State Physics, University of Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Institute for Semiconductor Technology, University of Duisburg-Essen, Lotharstraße 55, 47057-Duisburg, Germany — [3]II. Institute of Physics, University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [4]Department of Materials Science and Engineering, University of Illinois @ Urbana-Champaign, 1304 W. Green St., Urbana, IL 61801, USA

GaAs nanowires were grown on top of <100> GaAs substrates, mainly adopting the epitaxial relation and thus growing with an angle of about 35° off the substrate surface. These perfectly straight nanowires were irradiated with different kinds of energetic ions. Depending on ion species, energy, and fluence, we observed that the nanowires bended down towards the surface or up. The intensity of the bending increased with ion fluence. In the case of upwards bending, alignment of the nanowires along the incident ion beam direction could be achieved. The experiments have been simulated to obtain vacancy and interstitial distributions using a special version of TRIM, which accounts for the geometry of the nanowires. The simulated distributions indicate vacancy and interstitial formation within the implantation cascade as the key mechanism for bending.