TT 13: Focus Session: Functional Semiconductor Nanowires I (organized by HL)

The growth of nearly any kind of semiconductor in the form of nanowires as well as its properties have been intensely investigated in the past 15 years, because nanowires often offer superior properties compared to their bulk or thin-film counterparts. To fully exploit their unique properties, the challenging step is the integration of semiconductor nanowires into specific functional environments and devices. In this focus session, we present and offer a platform to discuss recent developments in exactly this area with applications in electronics, photonics and optoelectronics.

Organization: Carsten Ronning (FSU Jena), Martin Eickhoff (JLU Giessen), Tobias Voss (TU Braunschweig)

Time: Monday 9:30–13:15 Location: EW 201

Invited Talk TT 13.1 Mon 9:30 EW 201

Exploring the optical properties of 1D nanomaterials at sub-nanometer scale with a direct correlation to its structure at atomic scale — •Jordi Arbiol — Institució Catalana de Recerca i Estudis Avançats (ICREA), 08010 Barcelona, CAT, Spain — Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, E-08193 Bellaterra, CAT, Spain

Technology at the nanoscale has become one of the main challenges in science as new physical effects appear and can be modulated at will. New generations of functionalized materials are taking advantage of the low dimensionality, improving their properties and opening a new range of applications. As developments in materials science are pushing to the size limits of physics and chemistry, there is a critical need for understanding the origin of these unique physical properties (optical and electronic) and relate them to the changes originated at the atomic scale, e.g.: linked to changes in (electronic) structure of the material. Combining advanced electron microscopy imaging with electron spectroscopy, as well as cathodoluminescence in a STEM will allow us to probe the elemental composition and electronic structure simultaneously with the optical properties in unprecedented spatial detail. The seminar will focus on several examples in advanced nanomaterials for optical and plasmonic applications. In this way the latest results obtained by my group on direct correlation between optical properties at sub-nanometer scale and structure at atomic scale will be presented.

TT 13.2 Mon 10:00 EW 201

Selective Area Growth of GaN Nanowires and Nanotubes — •Martin Hetzl[1], Fabian Schuster[1], Saskia Weiszer[1], Jose A. Garrido[1], María de la Mata[2], Jordi Arbiol[2], and Martin Stutzmann[1] — [1]Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany — [2]Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Bellaterra, Spain

Selective area growth (SAG) of GaN nanowires (NWs) by molecular beam epitaxy has been investigated in a systematic way. A high uniformity of SAG NWs and a complete suppression of unintentional growth has been achieved. The nucleation sites were predefined by a titanium mask structured by e-beam lithography. The underlying growth kinetics will be addressed by varying the substrate temperature, the III/V-ratio, the growth time and the NW arrangement. For that, diamond (111) substrates have been used as a model material. However, successful transfer of SAG on Si (111), c-plane sapphire and other substrates confirms the general validity of the presented growth mechanism. Scanning transmission electron microscopy has been performed to investigate the structural quality of the NWs and to determine the polarity of the wurtzite lattice. At lower temperatures, so called "tripods" instead of NWs can occur, which result from large GaN zinc blende nuclei. The exact NW arrangement changes the local III/V-ratio. This has been used to force a transition from GaN NW to nanotube growth, leading to a much higher effective surface-to-volume ratio. The controllability of SAG GaN NWs represents an important step towards NW-based devices, e.g. for optoelectronics, sensing or catalysis.

TT 13.3 Mon 10:15 EW 201

Stability of heteroepitaxial coherent growth modes on nanowire radial surfaces — •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

Semiconductor nanowires (NWs) exhibit a large surface-to-volume ratio and are therefore interesting as a substrate for the growth of nanoscale heteroepitaxial islands as well as core-shell structures for use in optoelectronic applications. Compared to planar substrates the NW curvature leads to a modified thermodynamic stability of the coherent Frank-van-der-Merwe and Stranski-Krastanov (SK) heteroepitaxial growth modes. In the present contribution we investigate the stability of these growth modes on cylindrical NWs by means of continuum theory. In contrast to previous studies (i) the exact geometrical shape of pyramidal islands and (ii) the impact of the island contact angle on the elastic relaxation energy are considered. Maps of the growth mode stability are derived for the Si core / Ge shell structure, which display the favoured mode as a function of deposited volume, wetting layer thickness and NW radius. When using a Ge surface energy of 1.3 J/m^2 for both the shell and the pyramid surfaces the SK mode becomes stable only for large contact angles and NW radii larger than 40 nm. However, if the reduced surface energy of low-index Ge facets is taken into account, the transition between the two growth modes is shifted to smaller NW radii, as observed in experiments.

TT 13.4 Mon 10:30 EW 201

Cd_3As_2 Nanowires by Chemical Vapour Deposition — •Piet Schönherr and Thorsten Hesjedal — Department of Physics, Clarendon Laboratory, University of Oxford, Oxford OX1 3PU, United Kingdom

Cd_3As_2 has been well known for its very high mobility. Recently, it was discovered that the material displays two Dirac points with linearly dispersing states that are stabilized by crystal symmetry (three-dimensional Dirac semimetal). The Dirac cones live in three-dimensional k-space unlike topological insulators that only have two-dimensional Dirac cones on their surface. This makes Cd_3As_2 a three-dimensional analogue of graphene.

We present the growth and characterisation of Cd_3As_2 nanowires including results from electric transport measurements. Nanowires with a diameter as small as 10 nm were grown in a self-catalysed vapour-liquid-solid process using chemical vapour deposition. We analyse the growth mechanism and compare the vibrational modes of Cd_3As_2 nanostructures with bulk samples.

TT 13.5 Mon 10:45 EW 201

MOCVD Growth and Characterization of InGaN/GaN Nanowire-based core/shell Heterostructures — Bartosz Foltynski, Christoph Giesen, and •Michael Heuken — AIXTRON SE, Dornkaulstr. 2, 52134 Herzogenrath, Germany

GaN based nanostructures have stimulated great interest in their applications for fabricating next-generation light emitting diodes (LEDs) for solid state lighting (SSL). Nanowires, benefiting from their geometry and offer a set of extraordinary properties like increase of light emission by utilizing the nanostructure side walls, limitation of negative effect of polarization fields and reduction of dislocation density. In our studies we present the optical and structural characterization of InGaN/GaN core/shell nanowires grown on Si(111) substrates by MOCVD. SEM,Photoluminescence and cathodoluminescence were used as characterization techniques. All growth experiments were performed in an AIXTRON CCS (Close Coupled Showerhead) reactor. The self-organized GaN nanowires were grown on Si(111) substrates using AlN buffer and in-situ SiNx masking layer. The growth conditions were optimized to achieve maximum density of vertical GaN microrods perpendicularly aligned to the substrate. Detailed results on growth optimization and structure characterization will be presented and discussed.

TT 13.6 Mon 11:00 EW 201

Modulation doped GaAs-AlGaAs core-shell nanowires — •Dominik Irber[1], Stefanie Morkötter[1], Jonathan Becker[1], Nari Jeon[2], Daniel Rudolph[1], Bernhard Loitsch[1], Markus Döblinger[3], Max Bichler[1], Jonathan J. Finley[1], Lincoln J. Lauhon[2], Gerhard Abstreiter[1,4], and Gregor Koblmüller[1] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, Garching, Germany — [2]Department of Materials Science and Engineering, Northwestern University, Evanston, U.S.A. — [3]Department of Chemistry, Ludwig-Maximilians-Universität München, Munich, Germany — [4]Institute for Advanced Study, Technische Universität München, Garching, Germany

In this work we will present electrical and structural properties of GaAs-AlGaAs core-shell nanowire (NW) MODFETs. The GaAs core was grown on Si (111) substrates via [111]-oriented self-catalyzed growth using MBE, followed by a Si δ-doped radial <110>-oriented AlGaAs shell. Using HRTEM and atom probe tomography (APT), the structure and elemental composition of the NWs were analyzed. The APT analysis revealed the position of the δ-doped layer and the Si dopant concentration, allowing to calculate the expected 2DEG carrier density. Electrical measurements using a top gate geometry verified the expected 2DEG density and further showed very steep switching behavior (SS=70mV/dec) with on/off-ratios $>10^4$ at 300K. The device geometry allowed to measure mobility at different sites of the NW. In combination with the APT data the influence of structural parameters on mobility can be studied.

Coffee break

Invited Talk TT 13.7 Mon 11:30 EW 201

Studying single semiconductor nanowires using a hard X-ray nanoprobe — •Gema Martinez-Criado — European Synchrotron Radiation Facility, Grenoble, France

Semiconductor nanowires present great advantages for optoelectronic and spintronic nanodevices. Their applications are basically controlled by multiple property-function relationships taking place at the nanoscale in the spatial and time regimes. Only a combination of high-resolution methods offer a comprehensive characterization of their complex nature. Here we present how a multimodal hard X-ray nanoprobe addresses fundamental questions in nanowire research. Selected topics ranging from cluster formation, dopant segregation, and phase separations to quantum confinement effects are examined with sub-100 nm spatial resolution and sub-50 ps temporal resolution. This scheme opens new opportunities for structural, composition and optical investigations with large potential in materials science.

TT 13.8 Mon 12:00 EW 201

Influence of surface depletion on electrical conductivity of freestnding GaAs nanowires investigated by a multi-tip STM — •Weihong Zhao[1], Matthias Steidl[1], Stefan Korte[2], Hubertus Junker[2], Werner Prost[3], Peter Kleinschmidt[1], and Thomas Hannapel[1] — [1]Photovoltaics Group, Institute for Physics, Technische Universität Ilmenau, D-98684 Ilmenau — [2]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, D-52425 — [3]CeNIDE and Center for Semiconductor Technology and Optoelectronics, University of Duisburg-Essen, D-47057 Duisburg

P-type Zn-doped GaAs-Nanowires were prepared by the Au-assisted vapor-liquid-solid growth mode in a metal-organic vapor phase apparatus. Electrical investigation was carried out by a multi-tip scanning tunneling microscope as nano-prober on free-standing p-GaAs nanowires. As an approach to understand the doping process through the growing process, Zn-doped GaAs nanowires with different diameter were prepared. The electrical measurements and analysis on the nanowires deliver the key-information about process related dopant incorporation along the nanowires, which is responsible for the varying charge carrier depletion thickness.

TT 13.9 Mon 12:15 EW 201

Antimony doped ZnO nanowires — •Thomas Kure[1], Alexander Franke[1], Sarah Schlichting[1], Emanuele Poliani[1], Felix Nippert[1], Markus R. Wagner[1], Marcus Müller[2], Peter Veit[2], Sebastian Metzner[2], Frank Bertram[2], Eswaran S. Kumar[3], Faezeh Mohammadbeigi[3], Jürgen Christen[2], Janina Maultzsch[1], Simon Watkins[3], and Axel Hoffmann[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany — [2]Otto-von-Guericke-University, Institut für Experimentalphysik, Germany — [3]Simon Fraser University, Department of Physics, Burnaby, Canada

We investigated the morphology of metalorganic vapor phase epitaxy (MOVPE) grown c-axis aligned Sb doped ZnO NWs as well as the doping distribution and structural defects of single NWs. Cathodoluminescence spectroscopy (CL) along several single NWs reveal that the luminescence stems predominately from the tip and decreases towards the bottom of the NW. Raman measurements on ensemble NWs show additional vibrational modes, where some appear exclusively in Sb doped ZnO. Tip-enhanced Raman spectroscopy (TERS) was performed to investigate the local doping concentration. The significant increase of Sb-related Raman modes towards the apex confirms the increase of Sb along the NW.

TT 13.10 Mon 12:30 EW 201

Hard X-ray detection in a single 100 nm-diameter nanowire — •Jesper Wallentin[1], Markus Osterhoff[1], Robin Wilke[1], Karl-Magnus Persson[2], Lars-Erik Wernersson[2], Michael Sprung[3], and Tim Salditt[1] — [1]Institute for X-Ray Physics, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Department of Electrical and Information Technologies, Lund University, Lund S-221 00, Sweden — [3]DESY, Notkestrasse 85, 22607 Hamburg, Germany

While hard X-rays can now be focused below 10 nm, current semiconductor-based X-ray detectors have pixel sizes of tens of micron. It is desirable to shrink the detector pixel size in order to improve the resolution in imaging, spectroscopy and crystallography, but smaller detector volumes are expected to lead to a weak electrical signal. We investigated the electrical response of a 100 nm-diameter InP nanowire exposed to a hard X-ray nanofocus. A fixed bias voltage was used, and the current was measured with a picoammeter. The conductance increased about 4 orders of magnitude under full X-ray flux. Dynamic measurements revealed very slow processes, with lifetimes at the order of seconds. Such long lifetimes, possibly related to surface states, could explain the strong X-ray induced current. As a demonstration of the potential of nanowires as X-ray detectors, we imaged the X-ray nanofocus by making a 2D raster with the device. The spatial resolution was less than 1 micron, and could be improved by making devices with the nanowire oriented along the optical axis. These results show that nanostructures can have much stronger X-ray response than expected from a simple scaling of bulk parameters.

TT 13.11 Mon 12:45 EW 201

synchrotron X-ray photoelectron spectroscopy study of GaAs/InAs core/shell nanowires grown by MBE — •behnam khanbabaee[1], torsten rieger[2], nataliya demarina[2], detlev grützmacher[2], mihail Ion lepsa[2], rainer timm[3], and ullrich pietsch[1] — [1]Solid State Physics, Dept. of Physics, University of Siegen, Siegen, Germany — [2]Peter Grünberg Institute and JARA-FIT, Forschungszentrum Jülich GmbH, Jülich, Germany — [3]Synchrotron Radiation Research and The Nanometer Structure Consortium, Dept. of Physics, Lund University, Lund, Sweden

Semiconductor nanowire (NW) heterostructures are promising building blocks for future electronic devices. In particular, GaAs/InAs radial NWs heterostructures are candidates for nano-electronics, where a lower band gap semiconductor, e.g. InAs, is grown on a semiconductor with a higher band gap, e.g. GaAs, providing band bending at the interface. For effective band confinement it is necessary to control the radial thickness, and the local defect structure at the hetero-interface and its relation to the electronic properties. Here we report on X-ray photoelectron spectroscopy of GaAs/InAs core/shell NWs grown by molecular beam epitaxy. After cleaning under atomic hydrogen the As-oxides on top of the NWs were considerably reduced while the Ga- and In-oxides were slightly reduced. The binding energy of the As 3d core levels was shifted about 1 eV towards lower energies. These results show that the As component of the native oxide turns the NWs surface strongly n-type. Our findings show that the shelling of GaAs NWs with InAs may leads to band bending of 0.2 to 0.3 eV at hetero-interface.

TT 13.12 Mon 13:00 EW 201

Seebeck effect measurements on single InAs and GaAs nanowires — •Alexander Hirler[1], Vanessa Schaller[1], Jonathan Becker[1], Bernhard Loitsch[1], Stefanie Morkötter[1], Julian Treu[1], Gerhard Abstreiter[1,2], Jonathan Finley[1], and Gregor Koblmüller[1] — [1]Walter Schottky Institut and Physik Department, TU München, Garching, Germany — [2]TUM Institute of Advanced Study, Garching, Germany

We present recent results on measurements of the Seebeck coefficient of intrinsic n-type InAs and carbon doped p-type GaAs nanowires (NWs) grown on Si(111) substrates via catalyst free molecular beam epitaxy. To measure the Seebeck effect on single NWs, a temperature gradient is applied via lithographically fabricated heating coils and measured by two resistance thermometers each in a four-point measurement geometry, which also act as electric contacts to the NW. Equipped with another heating resistor the temperature dependent Seebeck-coefficient can be measured as well. Compared to field effect transistor (FET) measurements, the carrier density can be conducted independent of the gate geometry. In addition, the carrier type can be determined from the sign of the Seebeck voltage. Seebeck measurements presented here, demonstrate successful p-type doping of GaAs NWs via carbon. P-type doping and the quantitative measurement of the doping concentration via Seebeck measurements are important steps towards future heterojunction NW devices.