HL 66: GaN: Preparation and characterization of rods and wires

Time: Wednesday 17:00–19:30 Location: H15

HL 66.1 Wed 17:00 H15

Hybrid inorganic/organic GaN-based nanowire structures for Förster resonant energy transfer — •Johannes Zettler, Sergio Fernández-Garrido, Oliver Brandt, Lutz Geelhaar, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, D-10117 Berlin, Germany

The fabrication of hybrid GaN/organic semiconductor systems may facilitate combining the individual material's strength while compensating for their deficits. Förster resonant energy transfer (FRET) can be used to transfer energy from electrically injected carriers in GaN to an organic semiconductor overlayer, where light is generated more efficiently. Since FRET relies on dipole-dipole coupling, the separation between the GaN active region and the organic overlayer cannot be greater than a few nm. Thus, the use of GaN nanowires (NWs), where the side facets of the GaN active region can be covered with an organic semiconductor, may be an approach superior to planar structures as it permits both efficient electrical contacting and proximity of the GaN active region and the organic semiconductor. In this work, GaN and (Al,Ga)N/GaN NW heterostructures were grown by molecular beam epitaxy to study the FRET process in these hybrid systems. In a first stage, the growth and morphology of self-induced (Al,Ga)N NWs was optimized with respect to the FRET demands. Hence, thin, well separated NWs were grown with quantum disks extended over the whole diameter of the NWs. In a second stage, the spin-coating parameters for filling up the NWs with organic molecules were optimized to achieve a complete coverage of the GaN active region by organic molecules.

HL 66.2 Wed 17:15 H15

Investigation of the polarity of GaN nanowires grown by MBE on AlN/Si(111) with respect to substrate polarity — •Henning Hollermann, Joerg Malindretos, and Angela Rizzi — IV. Physikalisches Institut, Georg-August Universität Göttingen, Germany

III-V materials are most promising candidates for solid-state lighting devices. However, the problem of the green-gap, the drop of the external quantum efficiency at wavelengths around 550 nm, still remains unsolved. This could be overcome by InGaN/GaN quantum well structures grown in non-polar directions. But non-polar substrates are not available with sufficiently high quality at low prices, yet.

Here GaN-based nanowires could be an alternative. While self-organized GaN nanowires, grown on non-polar Si(111) substrates show N-polarity and flat c-plane top facets, we observed pyramidal semi-polar top facets in wires selectively grown on GaN/sapphire substrates with pre-structured molybdenum masks. Those facets could serve as a base for InGaN quantum well structures with strongly reduced quantum confined Stark effect.

Since simplification of the growth process is desirable for future applications we have investigated the influence of AlN buffer-layers on the morphology and polarity of GaN nanowires grown in a self-organized manner by plasma-assisted MBE on Si(111) substrates. The aim of this study is to produce wires with semi-polar top facets in a straightforward growth procedure. A detailed analysis of the structural properties is presented.

HL 66.3 Wed 17:30 H15

Nanometer scale correlation of optical and structural properties of individual InGaN/GaN nanorods by Scanning Transmission Electron Microscope Cathodoluminescence — •Marcus Müller[1], Gordon Schmidt[1], Peter Veit[1], Silke Petzold[1], Frank Bertram[1], Jürgen Christen[1], Steven Albert[2], Ana María Bengoechea-Encabo[2], Miguel Ángel Sánchez-Garcia[2], and Enrique Calleja[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany — [2]ISOM and Departamento de Ingeniería Electrónica, Universidad Politécnica de Madrid, Spain

A potential benefit of nanorods as light emitters, aside from their very high crystal quality, relies on better light extraction efficiency as compared to thin films, because of the high surface to volume ratio.
In this study we present a direct nano-scale correlation of the optical properties with the actual crystalline structure of ordered InGaN/GaN nanorods using low temperature cathodoluminescence spectroscopy in a scanning transmission electron microscope (STEM-CL). Direct comparison of the high-angle annular dark field image with the simultaneously recorded panchromatic CL mapping at 15 K reveals a weak luminescence from the bottom GaN layer. We observe the highest CL intensity in the middle of the InGaN region. The spectral position of the InGaN emission shifts continuously red from the GaN/InGaN interface (λ = 409 nm) to the NR top (λ = 446 nm) due to lattice pulling effects and InGaN partial decomposition. Additionally, optical active basal stacking faults in the GaN layer emitting at 366 nm can be found.

HL 66.4 Wed 17:45 H15

Optical and structural properties of InGaN/GaN multiple quantum wells grown on GaN nanorods by metal-organic vapor phase epitaxy — •Martin Heilmann[1], Christian Tessarek[1], Christel Dieker[2], Erdmann Spiecker[2], and Silke Christiansen[1] — [1]Max-Planck-Institute for the Science of Light, Günther-Scharowsky-Str. 1, 91058 Erlangen — [2]University Erlangen-Nuremberg, Center for Nanoanalysis and Electron Microscopy (CENEM), Cauerstraße 6, 91058 Erlangen

Hexagonally shaped GaN nanorods with varying aspect ratios were grown mask-free and uncatalyzed on c-sapphire substrates by metal-organic vapor phase epitaxy. The vertical nanorods consist of six non-polar sidewalls (m-plane) and one polar top facet (c-plane) which serve as growth surface for InGaN/GaN multiple quantum wells (MQWs). The influence of the growth temperature and growth time on the light emission characteristics of the core-shell structures will be quantified.

The optical properties of the MQWs were investigated by room temperature cathodoluminescence. The emission wavelength could be adjusted between 420 and 460 nm by changing the growth conditions. Scanning transmission electron microscopy was used to evaluate the structural properties of the MQWs. The optical and structural differences between MQWs grown on the c- and m-planes of the GaN nanorods will be presented.

HL 66.5 Wed 18:00 H15

Impact of Structural Properties on the Internal Quantum efficiency of InGaN - GaN Core-Shell Nanorods — •Tilman Schimpke[1,2], Martin Mandl[1], Fabian Schuster[2], Gregor Koblmüller[2], Martin Stutzmann[2], Stephan Furthmeier[3], Dominique Bougeard[3], Elisabeth Reiger[3], Tobias Korn[3], Christian Schüller[3], Hans-Jürgen Lugauer[1], and Martin Strassburg[1] — [1]Osram Opto Semiconductors GmbH, Regensburg — [2]Walter Schottky Institut, Technische Universität München — [3]Institut für Exp. und Angew. Physik, Universität Regensburg

Core-shell III-nitride nanorods (NRs) have been proposed to solve a major issue in solid-state lighting, the so-called efficiency droop, by significantly increasing the active layer area scaling with the aspect ratio. However, the reported internal quantum efficiencies (IQE) in such core-shell structures are behind best planar LEDs.

To study the processes limiting the IQE, position-controlled GaN/InGaN core-shell NRs were grown by MOVPE with diameters between 300nm and 1.5μm and aspect ratios of >5. The recombination processes in the InGaN quantum wells were investigated by temperature-dependent and time-resolved PL measurements. In addition, microscopic resolution was applied to correlate the structural properties obtained by SEM and Raman spectroscopy with optical properties. E.g., a double peak emission observed in micro-PL could be related to the semi-polar and non-polar facets of the InGaN quantum wells, respectively. The IQE values were deduced by temperature-dependent and time-resolved PL measurements.

HL 66.6 Wed 18:15 H15

MOVPE Growth of Position-Controlled InGaN / GaN Core-Shell Nanorods — •Martin Mandl[1,2], Tilman Schimpke[1], Michael Binder[1], Bastian Galler[1], Xue Wang[2], Johannes Ledig[2], Milena Ehrenburg[2], Hergo-Heinrich Wehmann[2], Andreas Waag[2], Xiang Kong[3], Achim Trampert[3], Hans-Jürgen Lugauer[1], and Martin Strassburg[1] — [1]Osram Opto Semiconductors GmbH, Regensburg — [2]Institut für Halbleitertechnik, TU Braunschweig — [3]Paul-Drude-Institut für Festkörperelektronik, Berlin

Core-shell group III-nitride nano- and microrods (NAMs) enable a significant increase of the active layer area by exploiting the non-polar side facets (m-planes) and thus can potentially contribute to mitigating the so-called efficiency droop in LEDs.

GaN NAMs exhibiting high aspect ratios were grown in a production-type MOVPE system. Low V/III ratio, hydrogen-rich carrier gas mixture and surfactants supported the 3D growth of the pencil-shape n-type GaN core. Desired narrow distributions of shape, diameter and height were achieved. The arrangement of the NAMs was controlled by patterns etched into SiO_2 masks deposited on GaN templates. The active layer (InGaN/GaN SQW and MQWs) and the layer for the p-side were deposited with 2D-like conditions wrapped around the core. The crystalline quality of the NAMs, shell growth rates and the Indium distribution were investigated by high resolution transmission electron microscopy. Furthermore, optical emission was studied using density-dependent photoluminescence spectroscopy.

HL 66.7 Wed 18:30 H15

Catalyst-free, self-organized growth of GaN nanorods on r-plane and c-plane sapphire with MBE and MOVPE — •Julian Stöver, Timo Aschenbrenner, Stephan Figge, Gerd Kunert, and Detlef Hommel — Institute of Solid State Physics, Epitaxy, University of Bremen, Otto-Hahn-Allee NW1, 28359 Bremen

High-quality GaN nanorods can be grown on r-plane sapphire by a combination of MOVPE and MBE. The r-plane sapphire was nitridated in a MOVPE reactor at 1050 °C, which leads to a change in surface morphology, e.g. small AlN islands are visible. The nanorod growth is carried out in MBE, in which the AlN islands act as nucleation centers. The nanorod density can be controlled by GaN overgrowth in MOVPE after the nitridation process. A sharp D_0X emission in μ-PL measurements indicates the high crystalline quality [Aschenbrenner et al., Nanotechnology **20**(7), 075604 (2009)]. Assigning the growth parameters on c-plane sapphire will not provide changes in the morphology. Due to the missing nucleation centers, nanorod growth did not take place. With a higher growth temperature of 1270 °C, changes in the surface morphology are achieved. AlN islands with a diameter of 35 nm and a density of 50 islands/μm^2 are provided. Similar to the growth on r-plane sapphire, GaN is deposited after the nitridation. The GaN provides a partial coverage with hexagonal structures. The structures itself and the space in between have diameters of $450 - 500$ nm.

Differences in the growth on r-plane and c-plane sapphire will be presented as well as detailed analyses of the structures grown on c-plane sapphire.

HL 66.8 Wed 18:45 H15

Superradiant luminescence of GaN nanowires on diamond — •Fabian Schuster, Andrea Winnerl, Saskia Weiszer, Jose Garrido, and Martin Stutzmann — Walter Schottky Institut, Technische Universität München, 85748 Garching

GaN nanowires have attracted much interest in recent years due to their high crystalline quality and large surface area, desirable with respect to optoelectronics, (photo-) catalysis or sensing applications. However, these devices suffer from inefficient p-type doping, especially for AlxGa1-xN ternary alloys. In contrast, diamond with its indirect bandgap of 5.48 eV can be efficiently p-type doped, thus representing a perfect complement to the nitride material system as transparent electrode and efficient heat sink. We have recently demonstrated the growth of self-assembled GaN nanowires on (111) single-crystalline diamond substrates.[1]

In order to investigate waveguiding behaviour of the nanowires, the tips of the GaN nanowires were capped by 10 nm of AlGaN with 40% aluminum content. These capped nanowires exhibit strong superradiant photoluminescence for increasing excitation density at room temperature with a low gain threshold of 50 kW/cm2. A small variation of the emission energy with increasing excitation power indicates efficient heat dissipation by the diamond substrate.

[1] F. Schuster et al., Nano Letters 12, 2199 (2012)

HL 66.9 Wed 19:00 H15

Germanium doping of self assembled GaN nanowires grown by plasma assisted molecular beam epitaxy — •Pascal Hille[1], Paula Neuderth[1], Jörg Schörmann[1], Markus Schäfer[1], Jan Müssener[1], Pascal Becker[1], Matthias Kleine-Boyman[2], Marcus Rohnke[2], Maria de la Mata[3], Jordi Arbiol[3], Detlev M. Hofmann[1], Thomas Sander[1], Peter J. Klar[1], Jörg Teubert[1], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany — [2]Physikalisch-Chemisches Institut, Justus-Liebig-Universität Gießen, Germany — [3]ICREA and Institut de Ciencia de Materials de Barcelona,CSIC, Campus de la UAB, 08193 Bellaterra, CAT, Spain

For realization of nanowire (NW) based nano-optical or nano-electronic devices, doping is a crucial issue. Up to now the use of Si-donors prevented a systematic study of the NW electronic properties as a function of the doping-concentration due to changes in the NW morphology during growth and difficulties in quantifying the Si-doping concentration [Si]. Here, we investigate Ge as an alternative dopant. Self assembled GaN:Ge NWs were grown by PAMBE on Si(111) substrates. Time of flight secondary ion mass spectrometry revealed a homogenous Ge distribution along the NW growth direction and a linear dependence of [Ge] on the Ge-flux with a maximum [Ge] of $3 \cdot 10^{20}$ cm^{-3}. The influence of the Ge incorporation on the morphology was analyzed by SEM and TEM. Low temperature PL shows strong and sharp emission even at the highest [Ge]. A linear increase of conductivity with increasing [Ge] was obtained by single wire electrical measurements.

HL 66.10 Wed 19:15 H15

Electrical characterization of doped single GaN nanowires: A comparison of Si- and Ge-doping — •Markus Schäfer, Christian Länger, Marius Günther, Pascal Hille, Jörg Schörmann, Jörg Teubert, and Martin Eickhoff — I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany

We present a comparison of the impact of Si- and Ge-doping on the electrical properties of GaN nanowires (NWs). While Si is well established as a shallow donor in GaN thin films, a systematic study of its effect on the electrical properties of NWs has not been reported and no report on Ge-doping of GaN NWs exists. Here, GaN NWs doped with different concentrations of Si and Ge were grown by plasma assisted molecular beam epitaxy on Si(111) substrates. Single NW conductivity measurements were carried out in four point geometry realized by electron beam lithography processing. A linear increase of the conductivity with increasing Ge-flux was observed. The results are correlated to time-of-flight secondary ion mass spectrometry, revealing a constant doping profile and an estimate for the Ge-concentration. These results are compared to Si-doped NWs. Contact resistances and the effect of Si-doping of n.i.d. GaN NWs due to diffusion from the Si substrate are also discussed.