HL 62: Gallium Nitride: Optical and Electronic Properties

Time: Wednesday 14:45–18:30 Location: H17

HL 62.1 Wed 14:45 H17

Charge carrier localization in submonolayer InN/GaN superlattices — •Felix Feix, Timur Flissikowski, Caroline Chèze, Raffaella Calarco, Holger T. Grahn, and Oliver Brandt — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany

The inevitable compositional fluctuations in the random alloy (In,Ga)N lead to the localization of charge carriers with profound implications for their recombination dynamics. Digital alloys composed of an InN/GaN short-period superlattice (SPSL) are envisioned to eliminate alloy disorder and the resulting localization phenomena. However, a recent microscopic investigation of such structures demonstrated that the nominal InN monolayers (ML) in the SPSL have a coverage well below 100 %. Here, we use molecular beam epitaxy to fabricate sub-ML InN/m-ML-GaN superlattices with $m = 6 \dots 44$ MLs and investigate these structures by temperature-dependent photoluminescence (PL) spectroscopy under both continuous-wave and pulsed excitation. Both the peak energy and the linewidth of the emission band associated to the sub-ML InN wells exhibit an anomalous dependence on temperature indicative of carrier localization. Delocalization is accompanied by a thermally activated quenching of the emission. PL transients reveal a power law decay at low temperatures reflecting that recombining electrons and holes occupy spatially separate, individual potential minima reminescent of conventional (In,Ga)N quantum wells. These results suggest that essentially the sub-ML InN wells act electronically as two-dimensional random alloys.

HL 62.2 Wed 15:00 H17

Control of optical polarization properties by anisotropic strain in non- and semipolar GaInN/GaN quantum wells — •F. A. Ketzer[1], P. Horenburg[1], E. R. Buss[1], H. Bremers[1], U. Rossow[1], F. Tendille[2], P. De Mierry[2], P. Vennéguès[2], J. Zuniga-Perez[2], and A. Hangleiter[1] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig — [2]Centre de Recherche sur l'Hétéro-Epitaxie, Valbonne, France

In this contribution we show evidence of successful manipulation of anisotropic strain in non- and semipolar multi quantum well (MQW) GaInN/GaN structures. Using AlInN interlayers with different compositions and thicknesses prior to our QWs we are able to control the strain and therefore modify the properties of the emitted light significantly. The growth conditions for the active zone have been kept unchanged. Our samples are grown via low pressure MOVPE on m-oriented pseudo-bulk and $(11\bar{2}2)$ GaN templates grown on patterned r-sapphire substrates. We determine the composition and strain of our MQWs by high resolution X-ray diffraction. With polarization resolved photoluminescence (PL) spectroscopy at low and room temperature we analyze the influence of the unusual anisotropic strain on optical properties due to changes in the valence band structure. The manipulated QWs show good optical properties compared to regular structures. For m-plane we achieve polarization of more than 90% at 445nm and 25% at 525 nm, while the semipolar samples show polarizations of 7% and 18% at 550 nm and 580 nm, respectively. In order to understand the behaviour $\mathbf{k} \cdot \mathbf{p}$ calculations were compared to our measurements.

HL 62.3 Wed 15:15 H17

Optical properties of two dimensional photonic crystal membranes in cubic AlN — •Sarah Blumenthal[1], Matthias Bürger[1], Andre Hildebrandt[2], Jens Förstner[2], Nils Weber[1], Cedrik Meier[1], Dirk Reuter[1], and Donat J. As[1] — [1]University of Paderborn, Department of Physics, Germany — [2]University of Paderborn, Department of Theoretical Electrical Engineering, Germany

Group III-nitride quantum dots (QDs) attracted much attention for the development of optical and quantum optical devices, operating in the UV spectral range. Microresonators enable to control the spontaneous emission of light and to realize an efficient single photon emitter (SPE). Promising candidates for such devices are 2D photonic crystal (PhC) nanocavities. Recently, SPE employing hexagonal QDs in AlN have been realized. However h-GaN QDs exhibit a strong internal electrical field causing a reduced recombination probability of electrons and holes in confined states. This issue may be overcome by using cubic AlN/GaN. We implemented a process to fabricate freestanding c-AlN/GaN membranes with a 2D hexagonal array of holes. We have investigated the optical properties of the QD ensemble and different PhCs (including H1 and L3 cavities) using micro-photoluminescence measurements at room temperature. For both cavity types, fundamental modes with high quality factors were determined. To validate the experimental results, simulations, using the time domain solver from CST Microwave Studio, were done. The simulations fit very well to the experimental results.

HL 62.4 Wed 15:30 H17

Role of coherency strain for optical properties of $In_xGa_{1-x}N$ active layers grown on GaN substrates — •Christoph Freysoldt[1], Siyuan Zhang[1,2], Ying Cui[1], and Jörg Neugebauer[1] — [1]Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany — [2]Department of Materials Science and Metallurgy, University of Cambridge, United Kingdom

$In_xGa_{1-x}N$ alloys are the material of choice for the optical recombination layers in GaN-based optoelectronic devices. When going from the violet-blue spectral range ($x \approx 15\%$) towards the green range $x > 30\%$), the growth of coherent $In_xGa_{1-x}N$ layers becomes increasingly difficult due to the lattice mismatch between InN and GaN. Yet, significant progress has been made experimentally to improve the quality of high-In films.

Theoretically, $In_xGa_{1-x}N$ alloys have been studied by a variety of methods ranging from multi-band k·p over tight-binding to density-functional theory. In our work, we explore the role of finite coherency strain on the electronic structure of $In_xGa_{1-x}N$ alloys for polar (c-plane) and non-polar (a-plane and m-plane) growth using state-of-the-art density-functional theory. Our calculations highlight that the high strains introduce non-linear effects in the elastic behavior and in the electronic structure that are missed by perturbative treatments of strain. We demonstrate that non-linear strain relaxation breaks the symmetry between a-plane and m-plane for the strain-induced valence band splitting that is relevant for inducing in-plane polarization of the emitted light.

HL 62.5 Wed 15:45 H17

Photoluminescence excitation measurements of molecular beam epitaxial grown cubic GaN/Al(Ga)N quantum well structures — •Tobias Wecker[1], Gordon Callsen[2], Axel Hoffmann[2], Dirk Reuter[1], and Donat J. As[1] — [1]Department of Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Institut für Festkörperphysik, TU Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

In recent years group III-nitrides and their compounds have been in the focus of interest for devices based on intersubband transitions in the 1.55 μm spectral region. For such devices the understanding of the complete energy level structure is crucial to manipulate the allowed transitions. Photoluminescence excitation (PLE) spectroscopy gives access to the excited energy levels. In hexagonal group III nitrides the adjustment of the quantum well (QW) energy levels is complicated by the quantum confined stark effect, resulting from spontaneous polarization fields. Due to the higher crystal symmetry this harmful effect is absent in the cubic phase along the (001) direction. We investigate an uncoupled asymmetric cubic GaN/$Al_{0.25}Ga_{0.75}N$ double quantum well and a single cubic GaN/AlN QW grown on 3C-SiC (001) substrate by radio-frequency plasma-assisted molecular beam epitaxy. PLE and photoluminescence spectra, taken at 7 K, show several emission bands. Comparing these emission bands with simulated transitions calculated by a Schrödinger-Poisson solver based on an effective mass model (nextnano^3) revealed a good agreement between theory and experiment.

HL 62.6 Wed 16:00 H17

Optical and electronic properties of InGaN/GaN core-shell microrod light emitting diodes — •Marcus Müller[1], Peter Veit[1], Frank Bertram[1], Christian Nenstiel[2], Gordon Callsen[2], Matin Mohajerani[3], Jana Hartmann[3], Hao Zhou[3], Hergo-H. Wehmann[3], Axel Hoffmann[2], Andreas Waag[3], and Jürgen Christen[1] — [1]Institut für Experimentelle Phssik, Otto-von-Guericke-Universität Magdeburg — [2]Institut für Festkörperphysik, Technische Universität Berlin — [3]Institut für Halbleitertechnik, Technische Universität Braunschweig

We present a comprehensive study of structural, optical, and electronic properties of three-dimensional, nitride-based, core-shell microrod LEDs. The InGaN/GaN microrod heterostructures were grown via the selective area growth technique by metal-organic vapor phase epitaxy. Using highly spatially resolved cathodoluminescence (CL) and Raman-spectroscopy directly performed on a thin TEM-lamella, we analyze free carrier concentrations of single Si-doped GaN core. Both, CL and Raman measurements reveal a high free carrier concentration of $6.9 \cdot 10^{19}$ cm^{-3} in the bottom part and a decreasing doping level towards the tip of the microrod. Structural investigations show that initial Si-doping of the core has a strong influence on the formation of extended defects in the overgrown shells. Highly spatially resolved CL mappings of the InGaN single quantum well luminescence exhibit a red shifted emission at these defects which most probably indicates indium clustering.

HL 62.7 Wed 16:15 H17

Charge transfer across the GaN nanowire / electrolyte interface — •Jan Philipps, Sara Lippert, Pascal Hille, Jörg Schörmann, Detlev Hofmann, and Martin Eickhoff — 1. Physikalisches Institut, Justus-Liebig-Universität, Gießen, Deutschland

We have investigated the transfer processes of photogenerated charge carriers from GaN nanowires to an electrolyte environment by the means of photoluminescence, current measurements and electron paramagnetic resonance spin trap technique. We find that photogenerated holes can be transferred to the OH·/OH$^-$ redox couple or can be consumed by photoanodic oxidation of the GaN surface. The efficiencies of the two processes strongly depend on the applied bias between the nanowires and the electrolyte. The presented results will be discussed considering the redox potentials in the electrolyte as well as the electronic structure of the semiconductor material and the occupation of surface states in the frame of the surface band bending model.

30 min. Coffee Break

HL 62.8 Wed 17:00 H17

Defect analysis of $(11\bar{2}2)$ semipolar GaN materials and devices — •Matthias Hocker[1], Ingo Tischer[1], Marian Caliebe[2], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, University of Ulm, D-89081 Ulm, Germany — [2]Institute of Optoelectronics, University of Ulm, D-89081 Ulm, Germany

Semipolar GaN layers grown on foreign substrates typically suffer from a high density of extended defects like threading dislocations and stacking faults. We investigate such $(11\bar{2}2)$-oriented GaN layers grown by MOVPE on patterned sapphire substrates by spatially and spectrally resolved low-temperature cathodoluminescence. The emission below the excitonic bandgap region is mostly dominated by basal plane stacking faults of I_1 type, giving rise to a band at ≈ 3.41 eV, which shifts with the strain and doping level in the layers. We compare experimentally determined transition energies to model calculations based on a wurtzite/cubic/wurtzite GaN quantum well model. Also complete semipolar Ga(In)N based light emitting devices are investigated by spatially correlated cathodoluminescence and electron beam induced current measurements in order to visualize the impact of stacking faults and dislocations on the quality and homogeneity of the quantum wells and on the performance of the pn-junction.

HL 62.9 Wed 17:15 H17

Investigation of confined exciton luminescence of PAMBE-grown AlGaN/GaN nanowires for single photon applications — •Johannes Dühn[1], Pascal Hille[2], Jörg Schörmann[2], Martin Eickhoff[2], Jürgen Gutowski[1], and Kathrin Sebald[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]Institute of Experimental Physics I, Justus-Liebig University, Giessen, Germany

Efficient single photon sources are of pivotal importance for experimental quantum optics and cryptography. Currently available schemes of single photon sources and detectors are subject to low signal to noise ratios, which greatly inhibits their utilisation in quantum optical applications. A promising approach to this problem is the usage of confined excitons in wide band gap materials. Because of their huge oscillator strengths, confined excitons have extraordinarily short lifetimes, thus enabling for emitters with high count rates. Due to confinement, these excitons also possess large binding energies, even exceeding the thermal energy at room temperature, which makes them suitable emitters for high-temperature operation. In this work we investigate the micro-PL properties of individual plasma-assisted (PA)MBE-grown Mg-doped single GaN nanodiscs embedded in AlGaN barriers. We identify emissions centered at 3.55eV from the nanodisc, as well as sharp emission lines at 3.35eV most likely originating from excitons bound to stacking faults in the GaN nanowire base. The emission from single excitons bound to defects are investigated with respect to their single photon emission properties by using an HBT interferometer.

HL 62.10 Wed 17:30 H17

InGaN/GaN nanowire heterostructures for multifunctional optochemical sensor systems — •Sara Lippert[1], Marc Riedel[2], Christian Dern[1], Jens Wallys[1], Ervice Pouokam[3], Pascal Hille[1], Jörg Teubert[1], Fred Lisdat[2], Martin Diener[3], and Martin Eickhoff[1] — [1]I. Physical Institute, Justus-Liebig-University, Gießen, Germany — [2]Biosystems Technology, Institute of Applied Life Sciences, Technical University of Applied Sciences, Wildau, Germany — [3]Institute for Veterinary Physiology and Biochemistry, Justus-Liebig-University, Gießen, Germany

InGaN/GaN nanowire heterostructures as nanophotonic probes are presented for the detection and monitoring of biochemical processes in electrolytes. By incorporation of Indium the excitation wavelength was shifted to the visible part of the spectrum. These structures show a stable photoluminescence at room temperature which is sensitive to variations of the pH value and the applied bias voltage [1]. Biasing allows an adjustment of the working point to maximize the sensitivity. With each nanowire acting as an individual probe, dynamical imaging with biochemical contrast becomes feasible. The photoelectrode characteristics are dominated by radiative and non-radiative recombination of photo-generated electron-hole pairs that in turn are determined by the bias-dependent surface band bending in the nanowire electrodes. The photoelectrochemical properties of the InGaN/GaN nanowire are assessed by pH- and bias-dependent photocurrent and photoluminescence measurements.

[1] Wallys, J. et al., Nano Lett., 12, 6180-6186 (2012)

HL 62.11 Wed 17:45 H17

Analysis of in-situ reflectance measurements during growth of AlInN/GaN Bragg reflectors — •Christoph Berger, Armin Dadgar, Jürgen Bläsing, and André Strittmatter — Otto-von-Guericke-Universität Magdeburg

We present in-situ analysis of lattice-matched AlInN/GaN distributed Bragg reflectors. For a comprehensive analysis of the in-situ reflectance monitored at three different wavelengths (405 nm, 633 nm, 950 nm), we first determined the optical constants of AlInN at high (growth) temperature. Therefore, we have grown single AlInN layers on a thick GaN-on-sapphire buffer structure. Fitting the resulting in-situ transients, allowed us to extract the refractive index and extinction coefficient at growth temperature. In combination with the optical properties of AlInN determined at room temperature, we were able to interpolate a temperature dependent dispersion for lattice-matched AlInN. With these data, the complex reflectance transients were simulated with very good agreement. From these simulations, growth rates and the resulting layer thickness were determined and even small growth rate fluctuations could be detected. In addition, the optical characteristic of the final DBR structure has been predicted already from the in-situ measurement. Simulations from high-resolution X-ray diffraction scans agree very well with the results from in-situ analysis.

HL 62.12 Wed 18:00 H17

Nanoscale (in)homogeneities of a thick $In_{0.2}Ga_{0.8}N$ layer grown on high quality bulk GaN substrate — •Max Trippel[1], Gordon Schmidt[1], Peter Veit[1], Sebastian Metzner[1], Thomas Hempel[1], Silke Petzold[1], Frank Bertram[1], Marlene Glauser[2], Lise Lahourcade[2], Raphaël Butté[2], Jean-François Carlin[2], Nicolas Grandjean[2], and Jürgen Christen[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Condensed Matter Physics, École Polytechnique Fédérale de Lausanne, Switzerland

InGaN alloys have received much attention for their successful use as active layers for optoelectronic applications. Despite considerable progress in the understanding of this material system the growth of high quality thick InGaN layers is still a challenge due to relaxation and compositional inhomogeneities.

We report on the inhomogeneities of a thick $In_{0.2}Ga_{0.8}N$ layer on nanometerscale using transmission electron microscopy combined with cathodoluminescence spectroscopy (STEM-CL) at 15 K.

A nominally 100 nm thick InGaN layer on top of a 1 μm GaN buffer was grown by metal-organic chemical vapor phase epitaxy (MOVPE) on a high quality free standing GaN pseudo substrate. (S)TEM images show two different regions on the surface: planar areas as well as regions of three dimensional growth. Highly spatially resolved STEM-CL mappings performed at 15 K reveal dominant luminescence at about 465 nm within planar regions and strong inhomogeneities of the InGaN emission in the regions of three dimensional growth.

HL 62.13 Wed 18:15 H17

AlN growth transition between step flow growth and step bunching — •Konrad Bellmann, Alexander Sabelfeld, Christian Kuhn, Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany

Opto-electronic devices operating in the UV range rely on smooth AlN layers with step flow morphology. This work will present a systematic study by metal organic vapor phase epitaxy of AlN layers grown on sapphire substrates to tailor the surface morphology by changing the V/III ratio and the substrate offcut angle between 0.1° and 0.3°. At a growth temperature of 1200°C the transition between step bunching and step flow growth occurs at a V/III ratio of about 5 to 20. This behavior can be explained by a change of the Ehrlich-Schwöbel(ES) barrier, due to the influence of the V/III ratio on the surface energy. However, the transition additionally depends on the offcut of the sapphire substrates which has no influence on the ES barrier. Therefore, a Monte Carlo simulation is presented which is based on the surface adatom diffusion combined with a variable sticking probability at the edges. The ES barrier is implemented by differentiating between an incorporation probability at the step edge from the top or the bottom terrace.