HL 81: Focus Session: Extended defects in semi- and nonpolar GaN II

Continuation of the morning session.
Afternoon session: Surfaces, adatomkinetics and indium incorporation in non- and semipolar surfaces / Defect associated luminescence in semipolar GaN / Semipolar InGaN quantum wells and doping of non-polar GaN

Time: Thursday 14:45–18:15 Location: H13

HL 81.1 Thu 14:45 H13

Energetics of step-edges and adatom kinetics on m-plane GaN surfaces: Implications for surface roughening and in-plane growth anisotropy. — •Andrew Duff[1], Liverios Lymperakis[2], and Jörg Neugebauer[2] — [1]Leibniz-Institut für Kristallzüchtung, Berlin — [2]Max-Planck-Institut für Eisenforschung, Düsseldorf

Growth of non-polar m-plane GaN surfaces have attracted considerable interest due to the absence of polarization fields associated with the growth of polar surfaces. Typical m-plane GaN grown by MBE is characterized by a strong in-plane anisotropy in the form of elongated stripes along the [11-20] direction. However, recent growth experiments have demonstrated that atomically smooth m-plane surfaces can be achieved for growth on inclined substrates even under N-rich conditions in contrast to c-plane growth [1]. Full control of the growth of non-polar GaN surfaces requires an atomic-scale understanding of the mechanisms underlying the growth. Hence in the present work, step-edge energetics and adatom kinetics (i.e. Ehrlich-Schwoebel barriers), both in the presence of step-edges as well as on flat terraces, are investigated using density functional theory. Step-edge formation energies are found to be prohibitively large under both N- and Ga-rich conditions, consistent with the achievable smooth growth observed in both N- and Ga-rich regimes. The effect of temperature and the interplay between surface and step-edge energetics and adatom kinetics are addressed with kinetic Monte Carlo simulations, providing physical insight into the anisotropic character of non-polar growth of GaN.

[1] M. Sawicka et al, Phys. Rev. B 83, 245434 (2011).

HL 81.2 Thu 15:00 H13

Electronic states at nonpolar GaN surfaces investigated by photoelectron spectroscopy and optical anisotropy spectroscopy — •Marcel Himmerlich[1], Anja Eisenhardt[1], Jochen Räthel[2], Eugen Speiser[2], Norbert Esser[2], and Stefan Krischok[1] — [1]Institut für Physik and Institut für Mikro- und Nanotechnologien, TU Ilmenau, PF 100565, 98684 Ilmenau, Germany — [2]Leibniz-Institut für Analytische Wissenschaften - ISAS - e.V., Albert-Einstein-Straße 9, 12489 Berlin, Germany

In-situ investigations were carried out on homoepitaxially grown nonpolar m-plane (1-100) and a-plane (11-20) GaN surfaces. Occupied surface states 3.1 and 3.2 eV below the Fermi energy are identified using photoelectron spectroscopy (PES). These states are involved in anisotropic optical transitions at photon energies of 3.2 and 3.3 eV for the m-plane and a-plane configurations, respectively, as confirmed by reflection anisotropy spectroscopy (RAS). Additionally, an optical transition at 4.7 eV was found in RAS. Excitonic and electronic surface band contributions in the RAS measurement were disentangled by comparing spectra of clean and oxidized surfaces. The experimental results are compared to calculated surface band structures from the literature. Furthermore, the influence of oxidation on the surface electronic properties and the correlated optical properties was also investigated. Besides degradation of the initial surface states, a reduction of the upward bend bending by 0.4 eV is found for both cases.

HL 81.3 Thu 15:15 H13

Comparative study on Si and Ge doping in a- and c-plane GaN — •Matthias Wieneke[1], Hartmut Witte[1], Stephanie Fritze[1,2], Armin Dadgar[1], Jürgen Bläsing[1], and Alois Krost[1] — [1]Otto-von-Guericke-Universität Magdeburg, FNW/IEP, Universitätsplatz 2, 39106 Magdeburg — [2]present address: LayTec AG, Seesener Str. 10-13, 10709 Berlin

The doping efficiencies of Si and Ge were studied by simultaneous growth of n-type doped a-plane and c-plane GaN. For this purpose undoped a-plane and c-plane GaN templates were grown by low pressure metal-organic vapor phase epitaxy (MOVPE) on 2 inch r-plane and c-plane sapphire substrates, respectively. After cleaving into half wafers one template of each orientation was re-loaded into the MOVPE system. Thus, in each case the Si- and Ge-doped GaN layers were grown at identical conditions on the a-plane and c-plane GaN templates using trimethylgallium (TMGa), ammonia (NH_3), silane (SiH_4) and germane (GeH_4) as precursors. The electrical properties of the undoped templates and the doped GaN layers were investigated by conductivity and Hall-effect measurements. By doping with germane the electron concentration in nonpolar a-plane GaN is typically about 50 times higher than in c-plane GaN, while it is nearly identical when using silane doping. Thus, the Ge incorporation is drastically enhanced in the case of a-plane GaN and is consequently strongly dependent on the crystal orientation of the GaN. In our contribution we will discuss possible origins of the different doping efficiencies.

HL 81.4 Thu 15:30 H13

Anisotropy of the optical response of nonpolar GaN in spectroscopic ellipsometry — •Karsten Lange, Christian Lidig, Martin Feneberg, Matthias Wieneke, Hartmut Witte, Armin Dadgar, Jürgen Bläsing, Alois Krost, and Rüdiger Goldhahn — Institut für Exp. Physik Otto-von-Guericke-Universität Magdeburg

A-plane Ge or Si doped GaN layers with electron concentrations between 7×10^{18} cm^{-3} and 2×10^{20} cm^{-3} were grown by metal-organic chemical vapour desposition. On these layers spectroscopic ellipsometry is carried out in order to determine both the ordinary and extraordinary dielectric tensor components. The infrared studies yield optical phonon frequencies influenced by plasmon-phonon coupling, opening a possibility to systematically determine the anisotropy of GaN. Thus, an experimental measure of the electron effective mass anisotropy is obtained. Furthermore, we will discuss first results of the related anisotropic shifts of the absorption edge around the fundamental band gap.

Coffee break

HL 81.5 Thu 16:00 H13

Defects of polar, semipolar and nonpolar (In)GaN - a comparison — •Lukas Schade[1,2], Tim Wernicke[3], Kamran Forghani[4,5], Jens Rass[3], Simon Ploch[3], Lutz Kirste[2], Markus Weyers[6], Michael Kneissl[3,6], Ferdinand Scholz[4], and Ulrich Schwarz[1,2] — [1]Department of Microsys tems Engeneering, IMTEK, University Freiburg — [2]Fraunhofer Institute for Applied Solid State Physics — [3]Institute of Solid State Physics, Technical University Berlin — [4]Institute for Optoelectronics, University Ulm — [5]University of Wisconsin, Madison, USA — [6]Ferdinand-Braun-Institute, Berlin

The GaN/InGaN material system is used to realize light emitting diodes from UV-A to the green-yellow spectral region. However, even on quasi bulk GaN substrates threading dislocations (TDs) are present with a density of 10^7 cm^{-2}. Here, we examine the influence of TDs on the luminescence intensity and transition energy. The impact caused by nonradiative recombination centers and strain fields is analyzed by micro photoluminescence and white light interferometry. We compare TDs in differently oriented GaN layers and InGaN QWs. Three types of burgers vectors are typically observed in GaN: a, c and a+c. When the surface orientation is changed from (0001) c-plane to $(10\bar{1}0)$ m-plane, their character changes from edge to screw type and vice versa. We studied TDs and V-defects associated to them in polar, semipolar and nonpolar GaN and InGaN QWs. Additionally, we will present the effect of Si doping onto the strain field in (0001) GaN edge dislocations. In undoped GaN, the strain around such a dislocation forms a symmetric dipole. With Si doping, the strain dipole becomes asymmetric.

HL 81.6 Thu 16:15 H13

Investigation of defect related luminescence features in semipolar AlGaN layers on GaN — •Ingo Tischer[1], Matthias Hocker[1], Manuel Frey[1], Robert A.R. Leute[2], Ferdinand Scholz[2], Willem van Mierlo[3], Johannes Biskupek[3], Ute Kaiser[3], and Klaus Thonke[1] — [1]Institut für Quantenmaterie, Gruppe Halbleiterphysik, Universität Ulm, 89081 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89081 Ulm —

[3]Materialwissenschaftliche Elektronenmikroskopie, Universität Ulm, 89081 Ulm

For nitride-based laser diodes and LEDs high quality AlGaN electron blocking layers are required. With increasing Al content the lattice mismatch between GaN and AlGaN leads to a modified strain situation and to the introduction of structural defects. In this study, we investigate the luminescence features of such AlGaN on GaN layers. Spatially resolved cathodolumenescence (CL) recorded at temperatures below 10K using a scanning electron microscope (SEM) performed on cross sections allows to determine the spatial and spectral distribution of luminescence features contributing to the global emission spectra. Micrographs and energy dispersive X-ray spectroscopy (EDX) maps recorded in a transmission electron microscope (TEM) at the same sample area allow the direct assignment of optical bands to structural features like defects and regions with different Al content.

HL 81.7 Thu 16:30 H13

Correlation of microscopic optical properties and defect structures of semipolar GaN on pre-patterned sapphire substrates by cathodoluminescence — •Sebastian Metzner[1], Frank Bertram[1], Thomas Hempel[1], Tobias Meisch[2], Stephan Schwaiger[2,3], Ferdinand Scholz[2], and Jürgen Christen[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg — [2]Institute of Optoelectronics, University of Ulm — [3]now with OSRAM Herbrechtingen

Spatially and spectrally resolved cathodoluminescence(CL) microscopy has been used to analyze the local luminescence characteristics of semipolar (11-22)GaN stripes grown out of trenches exhibiting c-plane-like sapphire sidewalls. The micro structure has been etched into a (10-12)sapphire substrate yielding an inclination angle of 58° towards (0001)sapphire which enables a planar semipolar (11-22) surface for the coalesced triangularly shaped GaN stripes. Local CL spectra reveal a distinct contribution of structural defects like basal plane stacking faults(BSF), prismatic stacking faults(PSF), and partial dislocations(PD) to the CL emission at the region where the GaN is grown into -c direction after leaving the trench. In complete contrast, the main part grown into +c exhibits pure donor-bound exciton emission interrupted by bundled and bended threading dislocations. Due to a delayed coalescence process the defect structures run into a void and, thus are prevented from propagating further through the coalesced layer. The optical properties of InGaN QW structures grown on top of this SF-free semipolar GaN surfaces are going to be discussed.

HL 81.8 Thu 16:45 H13

Structural and luminescence properties of defects in silicon doped a-plane GaN — •Gordon Schmidt, Peter Veit, Frank Bertram, Sebastian Metzner, Silke Petzold, Matthias Wieneke, Armin Dadgar, Alois Krost, and Jürgen Christen — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany

We present a correlation of the optical properties with the crystalline real structure of a silicon doped nonpolar GaN layer by means of highly spatially resolved cathodoluminescence spectroscopy (CL) performed in a scanning transmission electron microscope (STEM).

Using metal-organic vapor-phase epitaxy the structure was grown under a silane flow rate of 3.5 sccm on an r-plane sapphire substrate with an AlGaN seeding layer resulting in an a-plane GaN layer with a typically high basal plane stacking fault (BSF) as well as partial dislocation (PD) density.

The STEM-CL plan view images clearly resolve the BSF and their terminating PD at the surface of the nonpolar GaN layer. The comparison of the annular dark field images in STEM mode with the simultaneously recorded monochromatic CL intensity mappings directly identifies the BSF I_1 as the dominating emission. Furthermore, we observe a luminescence within 363 - 372 nm in the vicinity of the PD/BSF.

Coffee break

HL 81.9 Thu 17:15 H13

Determination of In mole fraction and strain state in semi- and nonpolar InGaN layers by XRD — •Martin Frentrup, Simon Ploch, Tim Wernicke, and Michael Kneissl — TU Berlin, EW 6-1, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

In wurtzite semiconductor heterostructures with semi- and nonpolar orientation the anisotropic lattice mismatch leads to a triclinic distortion. The distortion can be described by introduction of two new lattice parameters δ_1 and δ_2 describing the deviation of the basis angles α (β) and γ from 90° and 120° respectively. This must be taken into account for the determination of ternary alloy composition by XRD.
In this paper, we will compare different XRD algorithms to determine the composition. With the method of Young et al.[1] the position of the symmetric reflection is used to estimate the strain state and composition, assuming a relaxation mechanism by layer tilt.
Alternatively one can determine all parameters of the triclinic lattice (a, c, δ_1, δ_2) by measurement of several X-ray reflexes in ω-2θ-scans. This method is more accurate, since the exact strain state can be determined without making assumptions on the specific mechanism.
We will discuss the advantages and disadvantages of both methods regarding the determination of stoichiometry for $(20\bar{2}1)$ oriented InGaN. These results will be used for comparison of the In incorporation efficiencies and relaxation in $(11\bar{2}2)$ and (0001) orientated InGaN layers.
[1] E. Young, A. Romanov, J. Speck; APEX, 4 (2011), 061001

HL 81.10 Thu 17:30 H13

Growth Studies on Submicrometer-sized GaN Stripes with Semipolar QWs — •Robert Anton Richard Leute, Junjun Wang, Tobias Meisch, and Ferdinand Scholz — Institute of Optoelectronics, Ulm University, 89081 Ulm, Germany

Nanoimprint technology is used to pattern dielectric masks on c-oriented GaN templates grown on two-inch sapphire substrates. Selective epitaxy of GaN and InGaN results in submicrometer-sized GaN stripes with semipolar side facets. The stripes have triangular cross-section and form a 1D grating with a 260 nm periodicity. Stripes aligned $\parallel m$ and $\parallel a$ resulting in $\{11\bar{2}2\}$ and $\{10\bar{1}1\}$ facets respectively are studied. Growth is optimized to create sharp ridges (below 10 nm wide). Quantum wells emitting in the blue to cyan spectral range are deposited on the side surfaces. The effect of embedding as well as the inclusion of InGaN pre-wells and AlGaN claddings is investigated.

HL 81.11 Thu 17:45 H13

Influence of the semipolar GaN template on the charge carrier dynamics in an active InGaN layer — •Jan Wagner, Sarah Schröder, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

The growth on semipolar GaN is in the focus of many research studies for several years now since the influence of the Quantum Confined Stark Effect (QCSE) on an active region grown on these planes is significantly reduced. This leads to superior charge carrier dynamics, enhanced emission efficiency and increased indium incorporation with respect to an active region grown on c-plane GaN. As the production of native semipolar substrates with adequate crystalline quality is still difficult and expensive other growth techniques have to be considered. In this work we use the facets of three-dimensional grown GaN pyramids as semipolar templates for active InGaN quantum wells. The pyramids are grown by epitaxial lateral overgrowth (ELO). Since the pyramid facets serve as growth template for the active region, their crystalline quality directly affects the emission efficiency and carrier dynamics of the InGaN layer. Therefore, GaN pyramids of different sizes grown on the same sample were examined by time dependent photoluminescence measurements.

HL 81.12 Thu 18:00 H13

Microphotoluminescence studies on the effect of V-pits and the surface orientation on the indium incorporation within InGaN quantum wells on free standing polar GaN — •Sebastian Bauer[1], Benjamin Neuschl[1], Ingo Tischer[1], Manuel Frey[1], Matthias Hocker[1], Robert A.R. Leute[2], SK. Shaid-Ur Rahman[2], Martin Klein[2], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, 89081 Ulm, Germany — [2]Institute of Optoelectronics, Ulm University, 89081 Ulm, Germany

During the growth of *c*-plane GaN by hydride vapor phase epitaxy, occasionally large "V-pits" and different surface facets are formed. When such bulk-like thick free standing layers are overgrown by metal organic vapor phase epitaxy with a GaN layer containing multiple InGaN quantum wells, different indium content and quantum well thicknesses result on different facets and facet transition regions.

We investigate such samples in detail by spatially resolved microphotoluminescence and cathodoluminescence at different temperatures. An effect of the surface orientation on the incorporation of indium can be clearly observed.