HL 56: Non- and Semi-polar Group-III-Nitrides

Time: Thursday 14:00–17:45 Location: H15

HL 56.1 Thu 14:00 H15

Optical anisotropy of *a*- and *m*-plane InN grown on free-standing GaN substrates — •Jochen Räthel[1], Pascal Schley[1], Egidius Sakalauskas[1], Gerhard Gobsch[1], René Müller[1], Thomas A. Klar[1], Jörg Pezoldt[1], Rüdiger Goldhahn[1], Gregor Koblmüller[2,3], James S. Speck[2], Matthias Wieneke[4], Jürgen Bläsing[4], and Alois Krost[4] — [1]Institut für Physik, Technische Universität Ilmenau — [2]Materials Department, University of California — [3]Walter Schottky Institut, Technische Universität München — [4]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg

The optical response of wurtzite nitride semiconductors at the band gap and in the spectral region of high-energy critical points differs appreciably for light polarization perpendicular (ordinary configuration) and parallel (extraordinary) to the *c*-axis. In order to demonstrate this effect, films (or bulk crystals) are required for which the optical axis lies in the surface plane (*a*- or *m*-plane). For InN, the only studies reported so far employed an *a*-plane layer deposited on *r*-plane sapphire with an *a*-plane GaN buffer. Considerable improvement of the film quality was recently achieved by growing *a*- and *m*-plane InN directly on free-standing *a*- and *m*-plane GaN by PAMBE. In this contribution, we present a comprehensive characterization of these higher-quality nonpolar InN materials by polarization-dependent Raman spectroscopy and ellipsometry. The influence of stress on the transition energies is discussed based on the lattice parameters obtained by high-resolution XRD.

HL 56.2 Thu 14:15 H15

Polarization-dependent photoluminescence studies of semipolar and nonpolar InGaN quantum wells — •Lukas Schade[1], Ulrich Schwarz[1], Tim Wernicke[2], Markus Weyers[2], and Michael Kneissl[2,3] — [1]IAF, Freiburg, Germany — [2]FBH Berlin, Germany — [3]Institute of Solid State Physics, TU Berlin, Germany

Light emitted from optical devices based on semi- and nonpolar GaN quantum well (QW) structures is partially or totally polarized, as a consequence of crystal symmetry and band structure. This can be an additional advantage over polar (0001) GaN in specific applications, e.g. in LED backlighting. Fundamentally, the polarized emission stems from breaking the isotropic symmetry of the hexagonal c-plane, resulting in two discrete semi- and nonpolar directions (parallel and normal to the projection of (0001)). We use the k.p method to simulate the crystal-direction dependent emission. The resulting transition matrix elements assign a specific (partial) polarization for each subband. The thermal occupation of the subbands results in a temperature dependent effective polarization of the light emission. We study MOVPE grown homoepitactical polar, semi- and nonpolar samples, measuring the polarization properties of the resonantly excited photoluminescence from the QW. With the complete polarization of the subbands for nonpolar devices it is possible to measure the energetic difference of the first two valence band levels. In contrast to our calculations we find a higher degree of polarization also in semipolar directions. A possible explanation could be a higher energetic subband difference than computed.

HL 56.3 Thu 14:30 H15

Heteroepitaxial growth of basal plane stacking fault free a-plane GaN — •Matthias Wieneke, Thomas Hempel, Martin Noltemeyer, Hartmut Witte, Armin Dadgar, Jürgen Bläsing, Jürgen Christen, and Alois Krost — Otto-von-Guericke Universitaet Magdeburg, FNW/IEP, Postfach 4120, 39016 Magdeburg

Growth of light emitting quantum-wells based on a-plane GaN is a possibility to reduce or even to avoid polarization correlated luminescence red shift and reduction of radiative recombination efficiency. But until now heteroepitaxially grown a-plane GaN films are characterized by a poor crystalline quality expressed by a high density of basal plane stacking faults (BSF) and partial dislocations. We will present Si doped a-plane GaN films grown on r-plane sapphire substrates by metal organic vapor phase epitaxy using high temperature AlGaN nucleation layers. FE-SEM images revealed three dimensionally grown GaN crystallites sized up to tenth micrometer in the basal plane and a few tenth micrometers along the c-axes. Though, the full width at half maxima of the X-ray diffraction ω-scans of the in-plane GaN(1-100) and GaN(0002) Bragg reflections exhibited a very high crystal quality. Furthermore, luminescence spectra were dominated by near band gap emission, while there was no separated peak of the basal plane stacking fault. In summary we will present heteroepitaxially grown a-plane GaN without an evidence of basal plane stacking faults in X-ray diffraction measurements and luminescence spectra.

HL 56.4 Thu 14:45 H15

Surface morphology of homoepitaxial GaN grown on non- and semipolar GaN substrates — •Tim Wernicke[1], Simon Ploch[2], Veit Hoffmann[1], Jens Rass[2], Carsten Netzel[1], Lukas Schade[3], Ulrich Schwarz[3], Arne Knauer[1], Markus Weyers[1], and Michael Kneissl[1,2] — [1]FBH Berlin, Germany — [2]Institute of Solid State Physics, TU Berlin, Germany — [3]IAF, Freiburg, Germany

Recently a number of groups have reported laser diodes in the green spectral range on semi- and nonpolar GaN. Nevertheless the growth process on semipolar surfaces is not well understood. In this study $3.5\,\mu m$ thick MOVPE grown GaN layers on bulk m-plane, $(11\bar{2}2)$, $(10\bar{1}2)$, and $(10\bar{1}1)$ GaN substrates were investigated. XRD rocking curves exhibit a FWHM of less than 150", indicating excellent crystalline quality. But the surface morphology exhibits hillocks with a height of $1\,\mu m$ and lateral extension of $150\,\mu m$ in many cases. Depending on the substrate orientation and the growth temperature different hillock shapes were observed. Morphology and luminescence data point to threading dislocations as formation sources. In QWs the hillock structure is reproduced in the emission intensity and wavelength distribution on $(10\bar{1}1)$ but not on the m-plane surfaces. The hillocks could be eliminated for the semipolar planes (not for the m-plane) by increasing the reactor pressure and lowering the growth temperature. Hillock free separate confinement laser structures emitting at $405\,nm$ feature a very homgeneous luminescence in micro-PL and show amplified spontaneous emission under high power stripe excitation. Furthermore the In incorporation was found to be highest in QWs on $(10\bar{1}1)$.

HL 56.5 Thu 15:00 H15

Influence of stacking faults on the optical properties of m-plane GaInN quantum wells — •Holger Jönen[1], Uwe Rossow[1], Heiko Bremers[1], Torsten Langer[1], Daniel Dräger[1], Lars Hoffmann[1], Sebastian Metzner[2], Frank Bertram[2], Jürgen Christen[2], Lukas Schade[3], Ulrich T. Schwarz[3], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, TU Braunschweig — [2]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [3]Institut für Angewandte und Experimentelle Physik, Universität Regensburg

In the past few years GaN-based light emitting devices grown on non-polar planes have continuously attracted increasing attention due to their promising optical properties. While conventional structures grown on the polar c-plane suffer from the quantum-confined Stark effect (QCSE) non-polar structures are free from polarization fields in growth direction and thus might be more efficient. However, without defect reduction techniques heteroepitaxy of non- or semi-polar layers commonly results in high densities of threading dislocations and stacking faults. In this contribution we report on the optical properties of m-plane GaInN quantum wells grown on m-plane SiC. A reduced bandgap energy and the presence of two emission lines, which we attribute to basal and prismatic stacking faults, respectively, indicate that the optical properties are dominated by regions where stacking faults intersect the quantum wells. Quantum-wire-like states formed at these intersections may provide an effective carrier confinement resulting in high internal quantum efficiencies up to 45%.

HL 56.6 Thu 15:15 H15

Growth of *M*- and *A*-plane GaN on $LiGaO_2$ by plasma-assisted MBE — •Ralf Schuber[1], Mitch M.C. Chou[2], and Daniel M. Schaadt[1] — [1]Institut für Angewandte Physik/DFG-Center for Functional Nanostructures (CFN), Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe, Germany — [2]Department of Materials Science and Opto-electronic Engineering, National Sun Yat-Sen University, Kaohsiung 80424, Taiwan, ROC

Non-polar GaN presents a way to circumvent unwanted effects which arise due to its intrinsically built-in electric fields. Since GaN substrates are not readily available for homoepitaxy, various alternative substrates have been examined for growth of high quality *M*- or *A*-plane GaN crystals. $LiGaO_2$ (LGO) presents the closest lattice matched substrate that has been considered for GaN heteroepitaxy. However, so far only *C*-plane growth of GaN has been reported on (001)LGO.

Here we present the successful growth of *M*-plane GaN on (100)LGO and *A*-plane GaN on (010)LGO for the first time using plasma-assisted molecular beam epitaxy. Structural and morphological analysis was performed using x-ray and reflective high energy electron diffraction, scanning electron and atomic force microscopy. The phase purity of the grown films is shown to be very high. The surface morphology is in both cases flat and smooth.

HL 56.7 Thu 15:30 H15

Plasma supported cleaning of galliumnitride $(11\bar{2}0)$ surfaces — •Hendrik Geffers, Christian Schulz, Jan Ingo Flege, Thomas Schmidt, and Jens Falta — Institute of Solid State Physics, University of Bremen, 28359 Bremen, Germany

In this work we investigated the cleaning of non-polar galliumnitride $(11\bar{2}0)$ surfaces of metal organic chemical vapor phase epitaxy (*MOVPE*) grown samples by thermal annealing and sequential nitrogen plasma treatment. The chemical composition of the surface was analysed by x-ray photoelectron spectroscopy (*XPS*) before the treatment and after every cleaning step. The morphology and structure of the sample's surface was observed by scanning tunneling microscopy (*STM*) and low energy electron diffraction (*LEED*).

The XPS data of the untreated samples show large carbon and oxygen contaminations. The STM images exhibit a high roughness which is also reflected in the LEED patterns by a high background and diffuse diffraction spots. Most of the carbon contamination was found to be removed after the thermal annealing, while the amount of oxygen contamination could significantly be lowered with the plasma treatment. The STM images show a smoother surface after the cleaning process, this is also reflected in the LEED patterns by sharper diffraction spots and a lower background.

15 Min. Coffee Break

HL 56.8 Thu 16:00 H15

Atomic model of the Interface between m-plane sapphire and semi-polar GaN — •Martin Frentrup[1], Simon Ploch[1], Markus Pristovsek[1], and Michael Kneissl[1,2] — [1]TU Berlin, EW 6-1, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

InGaN based blue and green light emitting devices (LEDs) grown on c-plane GaN experience strong piezoelectric and spontaneous polarization fields. This results in a reduced radiative recombination efficiency due to the quantum confined Stark effect (QCSE). These effects are less pronounced for other surface orientation, like $\{11\bar{2}2\}$ or $\{10\bar{1}3\}$. Thus we investigate the MOVPE growth of semi-polar GaN on $\{10\bar{1}0\}$ (m-plane) sapphire substrates. Based on high resolution X-ray diffraction and AFM measurements, an atomic model of the interface and in-plane alignment between sapphire and GaN is proposed. The observed prefered $\{10\bar{1}3\}$ and $\{11\bar{2}2\}$ orientations show the best lattice match to m-plane sapphire of all regarded semipolar types. Furthermore our model gives an explanation for the often observed twinning effect of the $\{10\bar{1}3\}$ orientation, which lead to a very defective surface morphology.

HL 56.9 Thu 16:15 H15

Charakterisierung von AlGaInN mittels Röntgenbeugung und -fluoreszenz — •Lars Groh, Christoph Hums, Matthias Wieneke, Phannee Saengkaew, Jürgen Bläsing und Alois Krost — Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg

Quantum Well Strukturen für Nitrid-basierte Leuchtdioden werden derzeit zumeist c-Achsen orientiert gewachsen, wobei der Quantum Confined Stark-Effekt den Überlapp zwischen Elektron- und Lochwellenfunktion und somit die Effizienz der Bauelemente reduziert. Ursache dafür ist die unterschiedliche Polarisation der verschiedenen zum Einsatz kommenden Nitride, im Well und der Barriere. Zum Angleich dieser beiden Polarisationen wurden mittels MOVPE quaternäre Schichten aus AlGaInN gewachsen, die - zusätzlich zum Freiheitsgrad der Bandlücke der ternären Verbindungen - eine Anpassung der Polarisation erlauben. Die strukturelle Charakterisierung derartiger Schichten (Dicke, Verspannung, Twist, Tilt, Relaxationsgrad) ist mittels Röntgenbeugung nur begrenzt möglich, da die quaternäre Zusammensetzung keine eindeutige Bestimmung der Schichtkomposition mehr zulässt. Daher wurden verschiedene Röntgenfluoreszenzversuche (XRF, TXRF, GIXRF, GEXRF) unternommen, um die fehlende Information zur Bestimmung der Schichtkomposition zu ergänzen.

HL 56.10 Thu 16:30 H15

Detailed investigation of the defect-related emissions around 3.3 eV in GaN ELOG structures — •Ingo Tischer[1], Hady Yacoub[1], Martin Schirra[1], Martin Feneberg[1], Thomas Wunderer[2], Ferdinand Scholz[2], Levin Dieterle[3], Erich Müller[3], Dagmar Gerthsen[3], and Klaus Thonke[1] — [1]Institut für Halbleiterphysik, Universität Ulm, 89069 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89069 Ulm — [3]Laboratorium für Elekronenmikroskopie, Universität Karlsruhe, 76128 Karlsruhe

We investigate the origin of defect-related emission lines in a sample with triangular shaped GaN stripes forming semipolar $\{1\bar{1}01\}$ facets. The emission lines between 3.0 eV and 3.41 eV are characterized by high resolution transmission electron microscopy (HRTEM) and scanning electron microscope cathodolumence (SEM-CL). We are able to distinguish between different types of basal plane stacking faults which correspond to different emission energies. The assignment of the optical features to the different types of basal plane stacking faults and other defects are discussed using a one-to-one correlation between HRTEM and SEM-CL results.

HL 56.11 Thu 16:45 H15

Spectrally resolved cathodoluminescence microscopy of an InGaN SQW on hexagonally inverted GaN pyramids — •Christopher Karbaum[1], Frank Bertram[1], Sebastian Metzner[1], Juergen Christen[1], Thomas Wunderer[2], and Ferdinand Scholz[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Optoelectronics, University of Ulm, Germany

Three-dimensional self organized hexagonally shaped inverted GaN pyramids with semipolar $\{11\bar{2}2\}$ facets were grown using MOVPE by applying selective area epitaxy on a two-dimensional pattern of hexagonally shaped SiO_2-masks on an optimized c-GaN buffer layer. Subsequently, an InGaN SQW suited for green emission was deposited on the semipolar facets to make use of the reduced QCSE. The spatially-integral spectrum exhibits the near band edge (D^0,X) emission of GaN at about 357 nm and an intense broad InGaN luminescence at about 500 nm having a FWHM = 320 meV. The evolution of the (D^0,X) luminescence of GaN will be discussed in detail. The InGaN luminescence at the top of the facets is centered at about 535 nm and shifts about 960 meV to shorter wavelengths indicating a strong gradient of the In-concentration. Finally, the InGaN luminescence reaches up to 378 nm close to the (D^0,X) luminescence of GaN. Simultaneously the InGaN emission band narrows from FWHM = 235 meV at the top to FWHM = 104 meV above the masks. Furthermore, the temperature-dependence of the InGaN emission energy and the influence of enduring excitation on the InGaN luminescence will be discussed.

HL 56.12 Thu 17:00 H15

Microscopic correlation of real structure and recombination kinetics in semipolar InGaN SQW using spatio-time-resolved cathodoluminescence — •Sebastian Metzner[1], Frank Bertram[1], Jürgen Christen[1], Thomas Wunderer[2], Frank Lipski[2], Stephan Schwaiger[2], and Ferdinand Scholz[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg — [2]Institute of Optoelectronics, University of Ulm

Highly spatially, spectrally and time-resolved cathodoluminescence microscopy of an InGaN SQW grown on semipolar facets of 3D inverse pyramids formed by MOVPE on hexagonally masked c-plane GaN is presented. The spectra mapping of the SQW exhibits an emission at $\lambda = 400$ nm at the center of the inverted pyramids and $\lambda = 530$ nm at the hexagonal ridge. For a correlation with the recombination kinetics the same sample area was investigated by time-resolved CL using an electrostatic beam-blanking that switches "on" the electron beam, keeps it "on" for a selected time and turns it "off" extremely fast allowing a transient mapping in single-photon-counting mode. This gives the opportunity to evaluate time-delayed intensity images in order to generate an initial lifetime map by a digital box-car method. So, the high energy emission at the center exhibits initial lifetimes of $\tau = 200$ ps whereas the low energy emission at the ridge developes nearly two orders of magnitude more slowly in time ($\tau > 13$ ns). For different positions along a facet time-delayed spectra were recorded to study the spectral *and* temporal characteristics of the InGaN SQW observing the impact of localization and polarization fields.

HL 56.13 Thu 17:15 H15

Towards green electroluminescence of semipolar InGaN-MQWs on GaN pyramids — •Alexander Meyer, Clemens Wächter, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

InGaN-structures have attracted much interest due to their properties which allow the development of optoelectronic devices such as light emitting diodes (LEDs) and laser diodes. Recently, blue and green InGaN-LEDs are available, but the so-called quantum-confined Stark effect (QCSE) reduces the emission efficiency of these devices by bowing of the band structure.

To lower the QCSE, hexagonal Si-doped GaN-pyramids were deposited, providing semipolar sidewalls tilted 62° with respect to the GaN c-plane. These planes are used for the deposition of InGaN-multiple quantum wells (MQWs). The whole structure is fabricated by low-pressure metal-organic vapor-phase epitaxy (MOVPE). Next to the structural characterization of the samples by scanning electron microscopy, photoluminescence techniques are used to reveal the optical properties.

Besides these optical investigation of the Indium distribution on the pyramidal structures, p-i-n junctions are formed by placing a hole injection coating on top of the pyramids. Contact structures were developed to allow electrical injection and the examination of electroluminescence.

HL 56.14 Thu 17:30 H15

Growth of planar semipolar GaN via epitaxial lateral overgrowth on pre-patterned sapphire substrate — •Stephan Schwaiger, Ilona Argut, Thomas Wunderer, Frank Lipski, Rudolf Rösch, and Ferdinand Scholz — Institute of Optoelectronics, University of Ulm

We report on the growth of planar semipolar GaN on pre-patterned sapphire substrates via metalorganic vapor phase epitaxy. The sapphire templates were structured with grooves perpendicular to the c-direction of the crystal. Using appropriate growth parameters semipolar GaN can be grown from the c-plane like sidewall of the patterned sapphire, resulting in a flat and planar semipolar surface. Hence, this method allows the growth of semipolar GaN on large areas. Scanning electron, transmission electron and atomic force microscopy measurements show an atomically flat surface. Photoluminescence spectroscopy spectra show the high quality of the material since the spectra are dominated by the near band edge emission but still exhibit some defect related contributions. Furthermore high resolution x-ray diffraction rocking curve measurements result in small full widths at half maximum of less than 400arcsec for both, the symmetrical reflection and the asymmetrical (0002) reflection.