HL 27: Nitrides: Preparation and characterization II

Time: Wednesday 9:30–13:00 Location: EW 203

HL 27.1 Wed 9:30 EW 203

Structural and optical characterisation of germanium doped cubic AlxGa1-xN grown by molecular beam epitaxy — •Michael Deppe[1], Fabian Tacken[1], Jürgen W. Gerlach[2], Dirk Reuter[1], and Donat J. As[1] — [1]Universität Paderborn, Department Physik, Warburger Straße 100, 33098 Paderborn — [2]Leibniz-Institut für Oberflächenmodifizierung e.V., Permoserstraße 15, 04318 Leipzig

In the recent past, much work has been done in investigating germanium as an alternative n-type dopant in both wurtzite and zinc blende GaN. To extend the emission of nitride-based structures further into the ultraviolet spectral region, the ternary alloy $Al_xGa_{1-x}N$ can be employed. The mostly used donor for wurtzite and zinc blende $Al_xGa_{1-x}N$ is silicon and only little work on germanium-doping of $Al_xGa_{1-x}N$ has been published. In this contribution we report on the growth and characterisation of germanium-doped cubic $Al_xGa_{1-x}N$ layers with aluminium mole fractions $0 \leq x \leq 0.6$. The aluminium mole fraction x is determined both by high resolution X-ray diffraction and energy dispersive X-ray spectroscopy. Time-of-flight secondary ion mass spectrometry (TOF-SIMS) is used to verify and quantify the incorporation of germanium into the layers. Furthermore with increasing x an increasing amount of oxygen is observed by TOF-SIMS which causes additional n-type doping. Photoluminescence (PL) spectroscopy is performed at 13 K. Up to $x = 0.25$ the Ge-related emission exactly follows the direct band gap of cubic $Al_xGa_{1-x}N$. For higher x the PL emission sticks to a deep defect level 0.9 eV below the indirect band gap, which seems not to be related to the germanium doping.

HL 27.2 Wed 9:45 EW 203

Photoelectrochemical response of GaN, InGaN and GaNP nanowire ensembles — •Jan M. Philipps[1], Rene Couturier[1], Sara Hölzel[2], Pascal Hille[2], Jörg Schörmann[1], Irina A. Buyanova[3], Sangam Chatterjee[1], Martin Eickhoff[2], and Detlev M. Hofmann[1] — [1]Institute of Experimental Physics I, Justus Liebig University Giessen, 35392 Giessen, Germany — [2]Institute of Solid State Physics, University of Bremen, 28359 Bremen, Germany — [3]Department of Physics, Chemistry and Biology, Linköping University, S-581 83 Linköping, Sweden

The photoelectrochemical responses of GaN, GaNP and InGaN nanowire ensembles are investigated by electrical bias dependent photoluminescence, photocurrent and spin trapping experiments. The results are explained in the frame of the surface band bending model. The model is sufficient for InGaN nanowires, but for GaN nanowires electrochemical etching processes in the anodic regime have to be considered additionally. These processes affect the nanowire shape and lead to oxygen rich surface (Ga_xO_y) conditions as evident from transmission electron microscopy and the analysis of energy dispersive X-ray fluorescence. For the GaNP nanowires a bias dependence of the carrier transfer to the electrolyte is not reflected in the photoluminescence response, which is tentatively ascribed to a different origin of radiative recombination in this material as compared with (In)GaN. The corresponding consequences for the applications of the materials for water splitting or pH-sensing will be discussed.

HL 27.3 Wed 10:00 EW 203

Impact of Growth Interruption on the Structure and Luminescence of two- and zero-dimensional GaN/AlN Heterostructures — •Hannes Schürmann, Gordon Schmidt, Sebastian Metzner, Peter Veit, Frank Bertram, Christoph Berger, Jürgen Bläsing, Armin Dadgar, André Strittmatter, and Jürgen Christen — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, 39106 Magdeburg, Germany

A systematic series of GaN/AlN quantum dot samples of different growth interruption (GRI) times after GaN deposition has been comprehensively investigated using scanning transmission electron microscopy (STEM) as well as cathodoluminescence (CL) spectroscopy directly performed in a STEM at LHe-temperatures. The sample set was grown by metal organic vapor phase epitaxy on an AlN/sapphire template. Few monolayers (ML) of GaN were grown on top of the smooth AlN surface with a dislocation density of $\sim 3\times10^{10}$ cm^{-2}. Before capping with 100 nm AlN the GaN surface was exposed only to hydrogen carrier gas for different durations (0 s to 60 s). STEM-CL images of the sample without GRI exhibit hexagonally-shaped GaN islands of 20 nm height and ~100 nm width located at dislocation bundles, which show no luminescence, and a continuous ~1.8 nm thin GaN film with an intense emission band between 250 nm and 360 nm wavelength. With increasing growth interruption time, split up, smaller islands indicate desorption processes during the GRI. This GaN island emission now dominates, emitting in the range of 260 to 330 nm and the CL of the 1-2 ML thin GaN film is blue shifted (210 nm).

HL 27.4 Wed 10:15 EW 203

Charging of self-assembled GaN quantum dot ensembles by Capacitance-Voltage spectroscopy at room temperature — •Carlo A. Sgroi[1], Julien Brault[2], Jean Y. Duboz[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS * CRHEA, Rue Bernard Grégory, 06560 Valbonne, France

We present a capacitance voltage (CV) measurement of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an $Al_xGa_{1-x}N$ matrix at room temperature grown by MBE.

GaN and its alloys have excellent properties which makes them an ideal candidate for high power and high temperature microelectronic and QD storage devices, such as their thermal stability, high thermal conductivity and wide bandgap energies.

Due to polarization effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers the band structure is deformed. Band structure simulations were run to calculate a proper tunneling barrier and to estimate the quantum dot minimum to be close to the Fermi energy level with a sufficient lever arm to bring the QD energy levels in resonance with the Fermi energy.

Performing CV spectroscopy at room temperature we were able to evaluate a Coulomb blockade energy for electrons in the ground state of approximately 63 meV.

HL 27.5 Wed 10:30 EW 203

Pulsed reactive magnetron sputter deposition of AlN and GaN — •Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke University Magdeburg

Crystalline AlN and GaN buffer layers are essential to grow complex nitride semiconductor heterostructures by epitaxial methods. Using the most common growth technique, metalorganic vapor phase epitaxy, pure AlN buffers are difficult to grow due to GaN deposits in the reactor. We report on the growth of AlN and GaN layers on sapphire (0001) and silicon (111) by pulsed reactive magnetron sputtering. The crystalline quality of the layers is investigated in dependance of the nucleation layer thickness and plasma composition during growth. Atomic force microscopy and X-ray diffraction methods were used for structural analysis. Sputtered GaN layers were first grown on MOVPE-GaN templates to acquire best sputtering parameters. Sputtering of GaN is more difficult than AlN because metallic Ga melts at 29 °C and then tends to splash Ga clusters into the chamber and onto the sample.

HL 27.6 Wed 10:45 EW 203

Direct comparison of structural and optical properties of GaN fin LED microstructure with nonpolar sidewalls — •G. Schmidt[1], P. Veit[1], S. Petzold[1], A. Dempewolf[1], T. Hempel[1], F. Bertram[1], J. Hartmann[2], H. Zhou[2], F. Steib[2], J. Ledig[2], S. Fündling[2], H.-H. Wehmann[2], A. Waag[2], and J. Christen[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

We present structural and optical properties of an InGaN/GaN core-shell fin grown by metal organic vapor phase epitaxy (MOVPE) on GaN/sapphire template covered with a patterned SiO_x-mask. The MOVPE process results in selective area growth of Si-doped GaN walls out of the mask openings oriented in m-direction. Enveloping the n-GaN core, an InGaN layer as active region was grown with stepwise decreasing temperature. The fin was completed by a GaN:Mg cover.

Using highly spatially resolved cathodoluminescence (CL) microscopy, we give a direct insight into the optical properties of the individual core-shell layers. The GaN:Si core exhibits drastically low CL intensity above the mask opening. The epitaxially lateral overgrown region over the mask shows high intensity of the GaN near band edge emission. The InGaN region exhibits the highest CL intensity between 370 nm and 450 nm wavelengths. As expected, a redshift of the InGaN emission towards the fin side wall surface was resolved indicating the continuous increase of In-incorporation.

15 min. break.

HL 27.7 Wed 11:15 EW 203

MOVPE growth of large area InGaN LEDs with GaN-based tunnel junctions — •Silvio Neugebauer, Christoph Berger, Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Institut für Experimentelle Physik, Otto-von-Guericke-University Magdeburg, Germany

Improving current injection in nitride-based devices is an important task to further enhance the efficiencies of light emitting devices. One limiting factor is the low hole mobility in Mg-doped GaN which hampers lateral current spreading in conventional p/n-junction devices. In order to maintain high optical output power, non-epitaxial transparent and semi-transparent contact schemes are widely employed to inject holes into the p-side region. Still, the use of such current spreading layers is limited in terms of lateral conductivity and optical transparency. Epitaxial growth of GaN-based p/n tunnel junctions (TJs) structures is an attractive alternative to improve lateral current spreading in LEDs and VCSELs. However, the effectiveness of the MOVPE grown TJ is limited by the achievable donor and acceptor concentrations as well as the activation of the buried Mg-doped layer. In this study we have grown tunnel junction structures on top of conventional LEDs in a single growth process. The influence of thermal activation and individual parameter variations for the n- and p-type doping within the tunnel junction were analyzed in terms of current-voltage characteristics and light output of processed 1 mm^2 LED devices and compared to the performance of a reference LED with Ni/Au contacts.

HL 27.8 Wed 11:30 EW 203

X-ray diffraction studies of zincblende GaN — •Martin Frentrup[1], Lok Yi Lee[1], Suman-Lata Sahonta[1], Menno J. Kappers[1], Rachel A. Oliver[1], Colin J. Humphreys[1], and David J. Wallis[1,2] — [1]Department of Materials Science and Metallurgy, University of Cambridge, UK — [2]Centre for High Frequency Engineering, University of Cardiff, UK

A possible approach in solving the green gap problem is the growth of III-nitrides in the cubic zincblende phase (zb) with its non-polar nature and reduced bandgap compared to the common wurtzite (wz) GaN phase. However, the relative metastability of the zb phase and low stacking-fault energy, lead to phase mixing and incorporation of planar defects. XRD texture maps of our GaN thin films on 3C-SiC/Si reveal that under optimised MOVPE growth conditions the zb phase can be stabilized as the dominant phase. In non-optimised thin films distorted hexagonal-like reflection patterns were observed originating from a low concentration of wz phase inclusions. Our results also indicate that depending on the template miscut, the growth of wz-like inclusions may occur preferentially along certain directions. Following growth optimisation the hexagonal patterns were very weak with intensities only slightly above the noise level. Reciprocal space maps revealed that these signals are caused by diffuse scattering from stacking faults, while reflections from the wz phase could not be observed.

The presence of dominant cubic phase was also confirmed by TEM measurements, showing a periodic ... AaBbCc ... stacking of the atomic layers typical for the cubic zb structure.

HL 27.9 Wed 11:45 EW 203

Selective area growth of GaN-ZnO core-shell nanowires for photocatalytic CO2 reduction — •Florian Pantle, Max Kraut, Julia Winnerl, Marvin Koch, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany

GaN nanowires (NWs) have gained increasing interest as a promising system for photocatalytic water splitting and CO2 reduction due to their large surface-to-volume ratio and the favorable energy position of their bands with respect to many reduction or oxidation reactions. Compared to self-assembled growth, selective area epitaxy of NWs provides a better control over the electronic properties and the active surface area of such NWs due to the well-defined NW diameter and inter NW distance. We present the selective area growth of p-GaN core/n-ZnO shell NWs by plasma assisted molecular beam epitaxy with a shell thickness in the 10 nm range. We have performed photoluminescence and Raman spectroscopy measurements to investigate the optical and structural properties of the as-grown NW heterostructures and numerical simulations of their band structure. The internal field provided by the p-GaN/n-ZnO heterojunction improves the funneling of photo-excited conduction band electrons towards the surface, while the ZnO shell may act as a co-catalyst for CO2 reduction.

HL 27.10 Wed 12:00 EW 203

Parametric model for the anisotropic dielectric function of m-plane AlGaN up to 20eV — •Michael Winkler[1], Martin Feneberg[1], Shigefusa F. Chichibu[2], Ramón Collazo[3], Zlatko Sitar[3], Maciej D. Neumann[4], Norbert Esser[4], and Rüdiger Goldhahn[1] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Japan — [3]Department of Materials Science and Engineering, North Carolina State University, USA — [4]Leibniz-Institut für Analytische Wissenschaften - ISAS, Berlin, Germany

The linear optical response of nonpolar $(10\bar{1}0)$ (m-plane) $Al_xGa_{1-x}N$ epitaxial films was analyzed quantitatively for the full composition range. The samples were grown by metal-organic vapor phase epitaxy and molecular beam epitaxy on m-plane freestanding GaN and AlN substrates. Spectroscopic ellipsometry up to 20eV was measured at the synchrotron Metrology Light Source (MLS) of the PTB in Berlin for each sample. Using a point-by-point fit the ordinary and the extraordinary dielectric functions were obtained.

These data were used to fit the parameters for an ordinary and extraordinary model DF $\varepsilon_{\perp,\parallel}(x,\hbar\omega)$ in the spectral range from 0.7eV to 20eV, where the AlN-concentration x can be chosen arbitrarily. The model DF compares well with previous results for the ordinary DF and with the position of the high energy interband transitions.

HL 27.11 Wed 12:15 EW 203

Effects of well width on the recombination dynamics in m-plane GaInN/GaN quantum wells — •Philipp Henning, Fedor Alexej Ketzer, Philipp Horenburg, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

In this contribution we discuss the dependence of carrier recombination dynamics on quantum well width in nonpolar structures. For this purpose a set of m-plane GaInN/GaN quantum wells (QWs) with low indium content ($\leq$ 10 %) and varying QW width (1...6 nm) is grown by MOVPE on GaN pseudo bulk substrates and measured by time-resolved photoluminescence spectroscopy. We find a single-exponential PL decay and large radiative recombination rates at low temperatures. The corresponding lifetimes of about 500 ps stay constant for all QW widths, which is expected for nonpolar structures due to the absence of internal polarization fields that would reduce the wave function overlap for wider wells. Furthermore, we discuss the behavior of the radiative recombination at elevated temperatures, where the increase in radiative lifetime varies with changing QW width. Additionally, a sharp drop in the nonradiative lifetime can be observed in the measurements, which is unexpected due to the low indium content and the high-quality substrates. The lifetimes at room-temperature are of the order of 100 ps or below, clearly showing the dominance of nonradiative recombination. Dislocations originating from the substrate and penetrating through the QW are relatively rare, indicating that defects form during the QW growth.

HL 27.12 Wed 12:30 EW 203

Time-integrated and time-resolved luminescence studies of 3D InGaN/GaN microrod and fin heterostructures — Angelina Vogt[1], Jana Hartmann[1,2], Hao Zhou[1,2], Felix Blumenröther[1], Hergo-Heinrich Wehmann[1,2], Andreas Waag[1,2], and •Tobias Voss[1] — [1]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, TU Braunschweig, 38092 Braunschweig, Germany — [2]Epitaxy Competence Center, ec2, 38092 Braunschweig, Germany

Three-dimensional (3D) GaN-based structures allow for the integration of InGaN quantum wells (QWs) on their non-polar sidewalls while keeping the material free of extended defects. Thus, they represent a promising approach for next generation LEDs. In order to optimize the internal quantum efficiency (IQE) of the 3D heterostructures, a detailed knowledge of the radiative and non-radiative recombination channels and their rates is required. We compare the spectrally and temporally resolved photoluminescence (PL) and cathodoluminescence (CL) of InGaN QWs of 3D microrod and fin (microwalls) heterostructures. Both were grown by continuous selective area MOVPE. We analyse the homogeneity of the indium in the QWs along the height of the structures and the length of the fins with time-integrated PL and CL measurements. The dynamics are investigated by time-resolved PL measurements at different sample temperatures. The InGaN luminescence of the 3D structures show decay times in the order of 200 ps and just a weak influence of the quantum confined Stark effect due to the QW growth mainly on the non-polar sidewalls.

HL 27.13 Wed 12:45 EW 203

Fe-doped GaN a suitable material for antiferromagnetic spintronics? — •Andrea Navarro-Quezada[1,2], Thibaut Devillers[1], Tian Li[3], Andreas Grois[1], Maciej Sawicki[3], Tomasz Dietl[3], and Alberta Bonanni[1] — [1]Semiconductor and Solid State Physics, Johannes Kepler Universität, Linz, Austria — [2]Institute of Experimentalphysics, Johannes Kepler Universität, — [3]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

The control over the aggregation of magnetic ions in a non-magnetic semiconductor matrix constitutes a new way to realize semiconductor/ferromagnetic nanocomposites with yet unexplored but striking functionalities. In this work we show that it is possible to obtain a controlled and well-defined arrangement of single-phase magnetic GaxFe4-xN nanocrystals (NCs) embedded in a GaN matrix [1]. Depending on the fabrication conditions, a modification of the lattice parameter of the NCs is observed, pointing to the incorporation of Ga into the Fe4N structure and therefore, to the formation of GaFe3N. While Fe4N is a strong FM semi-metal with minority spin-polarization, GaFe3N is a weak AFM material. Our results open the perspectives of this magnetic semiconductor for the demonstration of interesting effects such as spin-pumping for spin current injectors/detectors, anisotropic magnetoresistance and the manipulation of the NCs magnetic moment via an electric field [2].

[1] A. Navarro-Quezada et al., Appl. Phys. Lett. 101, 081912 (2012)
[2] D. Sztenkiel et al., Nature Communications 7, 015034 (2017)