HL 24: Nitrides: Preparation and characterization I

Time: Wednesday 9:30–13:00 Location: H31

HL 24.1 Wed 9:30 H31

Band Offset at the Ga(N,As,P)/GaP Heterointerface — •Florian Dobener[1,3], Sebastian Gies[1], Jan O. Oelerich[1], Peter Ludewig[2], Kerstin Volz[1], Stephan W. Koch[1], Wolfgang Stolz[1,2], Wolfram Heimbrodt[1], and Sangam Chatterjee[3] — [1]Faculty of Physics and Material Sciences Center, Philipps-Universität Marburg, D-35032 Marburg — [2]NAsP III/V GmbH, Am Knechtsacker 19, D-35041 Marburg — [3]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, D-35392 Gießen

We investigate a series of Ga(N,As,P) multiple quantum well samples grown by MOVPE. The well thickness is varied, while the composition is kept quasi-constant. The samples are examined by PL excitation spectroscopy to reveal the absorptive states in the sample, which contribute to the actual PL intensity. Besides higher states, we find two clear peaks slightly above the band-gap energy, which we attribute to the highest-energy heavy-hole valence band to lowest-energy conduction band energy and highest-energy light-hole valence band to lowest-energy conduction band energy transitions of the samples. Consequently, we are able to model the band offset between the Ga(N,As,P) quantum well and the GaP barrier with a band anti-crossing model and the model solid theory to attribute for strain in the sample. Additionally, depth-scan X-ray and UV photoelectron spectroscopy reveals the valence band-offset at the GaP/Si and Ga(N,As,P)/GaP interface, too. Overall, a rather shallow valence band offset is found by comparing the outcomes to the optical studies and to DFT calculations.

HL 24.2 Wed 9:45 H31

Growth rate reduction of cubic III-nitrides at high doping levels in molecular beam epitaxy — •Michael Deppe[1], Jürgen W. Gerlach[2], Dirk Reuter[1], and Donat J. As[1] — [1]University of Paderborn, Department of Physics, Warburger Straße 100, 33098 Paderborn — [2]Leibniz Institute of Surface Engineering (IOM), Permoserstraße 15, 04318 Leipzig

The most common donor for n-type doping of cubic GaN (c-GaN) is silicon. Recently we have also investigated germanium as an n-type donor for c-GaN and found that it is a well-suited alternative to silicon. We present the growth of c-GaN layers doped by Si and Ge up to the order of 10^{20} cm^{-3}. Layers are grown by plasma-assisted molecular beam epitaxy on 3C-SiC (001) substrates. Thicknesses of the c-GaN layers are determined by reflectometric interference spectroscopy and time-of-flight secondary ion mass spectrometry. We find that the growth rate remains constant up to donor concentrations around 10^{19} cm^{-3} and decreases at higher doping levels both with Ge and Si dopants. The growth rate of the highest Ge-doped sample is reduced by 40% compared to undoped samples and it is reduced by 23% for the highest Si doping. Additionally, Ge-doped c-$Al_{0.25}Ga_{0.75}N$ layers are grown with donor concentrations comparable to the c-GaN layers. No reduction of the growth rate could be observed for c-$Al_{0.25}Ga_{0.75}N$. We suppose the growth rate reduction in c-GaN is among others due to higher bond dissociation energies of Ge-containing bonds compared to Ga-containing bonds. Dissociation energies of bonds involving Al however are higher, thus the effect is not observed in c-AlGaN.

HL 24.3 Wed 10:00 H31

Molecular beam epitaxial growth of GaZnON layers for photocatalytic applications — •Elise Sirotti, Max Kraut, Florian Pantle, Marvin Koch, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Am Coulomb-wall 4, 85748 Garching, Germany

GaN and ZnO have a favorable energy position of their band edges with respect to the redox levels of many electro-chemical reactions. Still, their large band gap limits the use for simultaneous solar light absorption and photocatalytic activity. One possibility to tune the bandgap into the visible regime are compounds of Ga, Zn, O, N, for which the valence band edge can be shifted to higher energies with respect to the vacuum level without affecting the conduction band energy.

We present the growth of GaZnON layers by means of plasma-assisted molecular beam epitaxy (MBE) on c-plane sapphire. The quality and composition of the quaternary compound have been optimized by varying the temperature, metal fluxes and nitrogen-to-oxygen ratio during deposition. We performed photothermal deflection spectroscopy, transmission, and photoluminescence measurements to investigate the optical properties, as well as, AFM and Raman spectroscopy for insights into the structural properties of the as-grown layers. Furthermore, the MBE-growth of GaN\GaZnON nanowire (NW) core\shell structures is demonstrated. This geometry benefits from the efficient outcoupling of light from backside illumination through the GaN NWs and the promising catalytic properties of the GaZnON shells.

HL 24.4 Wed 10:15 H31

All-optical determination of free-carrier concentration and composition in cubic GaN and AlGaN — •Elias Baron[1], Michael Deppe[2], Fabian Tacken[2], Donat Josef As[2], Martin Feneberg[1], and Rüdiger Goldhahn[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Department Physik, Universität Paderborn, Germany

The doping by Ge is shown to be a very efficient way to achieve free electron concentrations n above $10^{20}cm^{-3}$ in wurtzite and zincblende GaN and AlGaN layers, while maintaining excellent structural properties. Here, thin films of zincblende III-N were deposited by plasma-assisted molecular beam epitaxy on 3C-SiC substrates. Utilizing Kane's model and the optical effective mass in semiconductors a consistent approach to determine the band structure near the Γ-point of the Brillouin zone is achieved, which is necessary to understand the optical properties. We present a characterization of GaN and AlGaN by spectroscopic ellipsometry from which the complex dielectric function (DF) is obtained. The analysis of the DFs in the mid-infrared yields the transverse-optical phonon frequencies as well as the plasma frequency for doped material. From the latter, the free-carrier concentration can be deduced. On the other hand, studies around the fundamental absorption edge indicate the superposition of n dependent Burstein-Moss effect, band gap renormalization and in case of AlGaN band gap bowing. A self-consistent description of plasma frequency and absorption onset yields both the free-carrier concentration and the composition in case of AlGaN.

HL 24.5 Wed 10:30 H31

Photo-induced selective etching of GaN nanowires in water — •Florian Pantle, Max Kraut, Julia Winnerl, Martin Hetzl, Felix Eckmann, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany

GaN nanowires (NWs) have gained much interest in current research as they are promising candidates for photo-catalytic water splitting devices. A key requirement is the stability of these nanostructures under operational conditions. Despite many reports regarding anodic oxidation and photo-electrochemical stability of bulk GaN, both including p- and n-type material and different crystallographic facets in aqueous environments, these properties have remained widely unexplored for GaN NWs.

We have investigated the stability of GaN NWs under illumination in water. While the non-polar m-plane side walls of the NWs are decomposed under the applied conditions, the polar c-plane top facet is stable. Photo-induced holes are found to be responsible for this effect. Further, the crystal quality is found to be a decisive parameter. All hexagonal NWs show a characteristic etching morphology, which is explained by means of numerical band structure simulations. Additionally, we present a chemical and a structural pathway to stabilize the GaN NWs against the applied environments.

HL 24.6 Wed 10:45 H31

Integrated GaN Light Emitting Diode - GaN Nanowire Devices for Photocatalysis — •Sabrina Artmeier, Julia Winnerl, and Martin Stutzmann — Walter Schottky Institut and Phyics Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

Gallium nitride (GaN) nanowires (NWs) have attracted much interest for device fabrication due to their large surface-to-volume ratio and their optical waveguide character. Moreover, the favorable energy position of their bands with respect to many redox potentials in liquid electrolytes make them promising candidates for photocatalytic applications, such as water splitting or CO2 conversion. GaN NWs in-

tegrated on a planar light emitting diode (LED), serving as a platform for photocatalytic reactions, enable the efficient coupling of the light from the LED to the waveguide modes supported within the NWs.

Using an LED as the light source for photocatalytic reactions enables the choice of a specific wavelength, which is matched to the photocatalytic reaction targeted, and pulsed operation, which is matched to the chemical reaction kinetics. Here, we present a systematic study of the time-resolved electroluminescence (EL) emitted from an LED operated in pulsed mode and coupled out through different GaN NW arrays. We have investigated the influence of the pulse length, the pulse form as well as the NW array geometry, namely the NW diameter and the period and compared the results to those of a bare LED. We found different behaviour of the turn-on delay time, the rise and the decay time for the different samples investigated.

15 min. break

HL 24.7 Wed 11:15 H31

Optical properties of homoepitaxial AlGaN/GaN MQWs — •Markus Schleuning[1], Markus Wagner[1], Benjamin Damilano[2], and Axel Hoffmann[1] — [1]Technische Universität Berlin, Berlin, — [2]CRHEA-CNRS, Valbonne, France

AlGaN/GaN MQWs with varying well thickness, Al barrier content and number of stacks were grown by homoepitaxial MBE on c-plane GaN substrates and investigated using PL, TRPL and CL spectroscopy. The quantum well structures exhibit a low surface roughness of $R_{RMS} \approx 0.3\,\mathrm{nm}$. The MQW emission energies could be adjusted between 3.3 eV and 3.5 eV as function of well width and Al composition of the barrier. TRPL measurements reveal radiative lifetimes between 0.5 ns and 0.5 μs. The luminescence shift to lower energies and increase of lifetimes are interpreted as consequence of the quantum confined Stark effect (QCSE) that has its origin in piezoelectric and spontaneous polarization fields. Furthermore localization energies at 10 K of up to 30 meV are found using temperature resolved PL. Especially the 3 nm thick MQWs show efficient free exciton luminescence with a FWHM of only 40 meV at 300 K caused by large exciton binding energies in the confined structure.

HL 24.8 Wed 11:30 H31

Effect of optimized GaN underlayers on the radiative efficiency of GaInN/GaN quantum wells — •Philipp Horenburg[1], Philipp Henning[1], Savutjan Sidik[1], Uwe Rossow[1], Heiko Bremers[1,2], and Andreas Hangleiter[1,2] — [1]Institute of Applied Physics, Technische Universität Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany

We present the influence of optimized low temperature GaN underlayers on the efficiency of GaInN/GaN quantum well (QW) structures prepared by metal-organic vapor phase epitaxy (MOVPE).
As light emission from group-III nitride QW structures is governed by radiative and nonradiative processes, the active region is highly susceptible to structural defects, acting as nonradiative recombination centers and therefore diminishing the radiative efficiency. Insertion of a low indium content GaInN underlayer prior to the QW structure has become a widely used strategy to bury crystallographic defects outside the active region. In this context, the In atoms have been ascribed to play a special role in the defect trap mechanism.
We have grown a series of c-plane single and multiple QW structures by low-pressure MOVPE on sapphire and GaN substrates. By introducing a GaN pre-barrier prior to the GaInN/GaN QWs and optimizing the growth conditions of the former, we find improved efficiency as observed by photoluminescence measurements. Thus, we argue that not merely the material composition of the underlayer, but particularly the growth parameters, such as the temperature and the precursor fluxes, crucially affect the efficiency of GaInN/GaN QW structures.

HL 24.9 Wed 11:45 H31

Reactive pulsed sputtering of AlN and GaN — •Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke University, Universitätsplatz 2, 39106 Magdeburg, Germany

GaN based devices require high quality buffer layers difficult to achieve on Si(111) substrates. There are several limitations in common growth techniques as MOVPE growth struggles with residual Ga in the AlN nucleation layer and a high thermal mismatch between substrate and grown layer. MBE growth suffers from low lateral growth rates and a sophisticated vacuum system. Here we present a cost-effective growth technique using high purity metal targets and gases in a reactive pulsed sputter process. Plasma generation is carried out by a bipolar pulsed voltage. At negative voltages the targets are sputtered by Ar-ions whereas the positive pulse leads to a stabilisation of the target preventing the increase of an insulating nitride layer on the target. Growth of AlN and GaN on MOVPE grown AlN and GaN templates is investigated to study the process parameters. Growth pressure and gas composition impact surface morphologies of the layers as observed by AFM measurements. Below 750 °C surfaces show grainy appearance with grain sizes between 10 and 50 nm. Substrate temperatures of 750 °C lead to smoother surfaces with grain sizes up to 250 nm and improved crystal quality determined by XRD measurements. FWHM values in (002) and (103) direction reveal the same values for the grown layer and the MOVPE grown templates.

HL 24.10 Wed 12:00 H31

Influence of Electron Beam Irradiation on the Emission Spectra of InGaN/GaN MQWs — •Hendrik Spende[1], Johannes Ledig[2], Christoph Margenfeld[1], Hergo-Heinrich Wehmann[1], and Andreas Waag[1] — [1]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, Braunschweig University of Technology, 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

A scanning electron microscope equipped with a cathodoluminescence (CL) detection system is a powerful tool for investigating the optical properties of semiconductor microstructures with high spatial resolution. Due to the high kinetic energy of the probe, electrons are scattered and many electron-hole-pairs are generated in the material. As a result, the excitation and recombination rate inside the material are spatially inhomogeneous.

Here we analyze CL spectra of InGaN/AlGaN/GaN samples, each containing MQWs emitting at different wavelengths. By varying the electron beam energy, the electron penetration depth changes and thus the obtained CL signal gives insight into the excitation ratios and relative efficiencies of the different MQWs. We also observe an unexpected and persistent change in the room temperature CL emission of the samples, indicating electron beam induced changes in carrier dynamics within the active area. Electrochemical capacitance-voltage measurement profiles show changes in the active carrier concentration in irradiated regions. Both can be reset by thermal annealing, indicating that the irradiation changes crystal bonds or the charge of trap states.

HL 24.11 Wed 12:15 H31

Thermal activation of non-radiative recombination processes in III-nitride quantum wells — •Philipp Henning, Torsten Langer, Fedor Alexej Ketzer, Silvia Müllner, Philipp Horenburg, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38106 Braunschweig, Germany

In order to understand the origins of defect-related non-radiative charge carrier losses in III-nitride quantum wells, the thermal activation of non-radiative charge carrier recombination is analyzed. Therefore, time-resolved photoluminescence measurements are performed in a wide temperature range between 3.5 and 500 K, which allows a more accurate determination of activation energies compared to an analysis limited to room temperature. Among the possible non-radiative mechanisms are thermal activation over potential barriers, exciton dissociation and multi-phonon capture, which may also be present at low temperatures via tunneling-assisted processes. We compare quantum well samples with different crystal orientations and substrate qualities, as well as the impact of intentionally introduced defects by ion implantation, in order to distinguish the thermal activation of different non-radiative recombination mechanisms. The measurements show activation energies of 5 to 50 meV, reaching up to hundreds of meV. At room temperature, a broad range of non-radiative lifetimes between $<$100 ps and several 10 ns is found, depending on the crystal orientation and the defect density controlled by the implantation dose.

HL 24.12 Wed 12:30 H31

Dislocation bending in GaN/step-graded (Al,Ga)N/AlN buffer layers on Si(111) investigated by STM and STEM — •Yuhan Wang[1], Lei Zhang[2], Verena Portz[1], Michael Schnedler[1], Lei Jin[3], Xiaopeng Hao[2], Holger Eisele[4], Rafal E. Dunin-Borkowski[1,3], and Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Jülich, 52425, Germany —

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The distribution and bending of dislocations in GaN/step-graded (Al,Ga)N/AlN buffer layers grown on Si(111) are investigated by cross-sectional scanning tunneling microscopy (STM) and scanning transmission electron microscopy (STEM). We observe dislocations with {a/3}<11-20>-type Burgers vector intersecting the m-plane cleavage surface and having line directions bent off the [0001] growth direction toward non-polar directions. The spatial distribution of dislocations intersecting the m-plane cleavage surface indicates consecutive bending of dislocations due to strain at interfaces between subsequent lattice mismatched buffer layers and at doping junctions, reducing the density of threading dislocations at the (0001) growth front. No interface misfit dislocations, v-shaped defects, or loss of crystalline quality are observed, demonstrating the high performance of the step-graded (Al,Ga)N/AlN buffer layers on Si for relaxing the lattice constant without creating large defect concentrations.

HL 24.13 Wed 12:45 H31

Electron affinity and surface states of GaN m-plane facets: Implication for electronic self-passivation — Verena Portz[1], Michael Schnedler[1], Holger Eisele[2], Rafal E. Dunin-Borkowski[1], and •Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Jülich, 52425, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Germany

The electron affinity and surface states are of utmost importance for designing the potential landscape within (heterojunction) nanowires and hence for tuning conductivity and carrier lifetimes. Therefore, we determined for stoichiometric nonpolar GaN($10\bar{1}0$) m-plane facets, i.e., the dominating sidewalls of GaN nanowires, the electron affinity to 4.06±0.07 eV and the energy of the empty Ga-derived surface state in the band gap to 0.99±0.08 eV below the conduction band minimum using scanning tunneling spectroscopy. These values imply that the potential landscape within GaN nanowires is defined by a surface state-induced Fermi-level pinning, creating an upward band bending at the sidewall facets, which provides an electronic passivation.