HL 50: Gallium Nitride: Fabrication and Characterization

Time: Wednesday 9:30–13:15 Location: H17

HL 50.1 Wed 9:30 H17

Molecular beam epitaxy and characterization of InGaN nanowires on Si (111) — •Saskia Weiszer, Andreas Zeidler, Maximilian Kolhep, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

Multi-junction solar cells have received wide attention as each cell can absorb different wavelengths of the solar spectrum which leads to an increased energy conversion efficiency. InGaN has a variable band gap from 0.7 to 3.4eV that covers nearly the whole solar spectrum. Combined with Si, theoretical considerations show that an InGaN/Si tandem solar cell could be an optimal implementation of a double-junction cell. Especially at an In content of 46%, it is expected that a resonant tunnel junction is formed between both cells. Furthermore, the cell efficiency could be increased by growing nanowires to enhance optical properties and to reduce structural defects, since the lattice mismatch strain can relax through the nanowire sidewalls. As first step towards such an InGaN/Si solar cell, the growth of high quality InN nanowires directly on Si(111) substrates by molecular beam epitaxy was studied. By varying the applied growth parameters, namely substrate temperature and III/V-ratio, different growth regimes were identified and the InN nanowire growth was optimized. As next step towards an InGaN/Si solar cell, the growth of InGaN nanowires with increasing Ga content was investigated. Recent results on the determination of the Ga content by energy dispersive X-ray spectroscopy, Raman spectroscopy and photoluminescence measurements will be presented.

HL 50.2 Wed 9:45 H17

RF sputter deposition of AlN layers on different substrates — •Florian Hörich, Marc Hoffmann, Jürgen Bläsing, Armin Dadgar, and Andre Stritmatter — Otto-von-Guericke-University Magdeburg

We investigated reactive sputtering of AlN by rf-plasma deposition using an Al-Target and varying plasma conditions. The influence of substrate temperature, gas mixture, plasma pressure and magnetron power is discussed for different substrates, like Silicon (111), sapphire, and epitaxially-grown AlN buffer layers on Silicon (111).

The growth of crystalline or amorphous layers depends mostly on the substrate type. Direct growth on Si(111) substrates results in crystalline layers if an Al nucleation layer is used similar to metalorganic vapour phase epitaxy of AlN/Si(111). Epitaxially grown AlN buffer layers can be overgrown without an Al interlayer.

Further analysis performed by high resolution x-ray diffraction (HRXRD) and atomic force microscopy (AFM) will be presented for qualification of the crystalline quality and surface morphology. In particular, the substrate-layer interface is investigated to understand the nucleation processes of the sputtered AlN layers in dependence of process parameters.

HL 50.3 Wed 10:00 H17

Growth of GaN nanowires on crystalline TiN films by molecular beam epitaxy — •David van Treeck, Gabriele Calabrese, Carsten Pfüller, Oliver Brandt, Lutz Geelhaar, and Sergio Fernández-Garrido — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany

The pronounced tendency of GaN to spontaneously form nanowires (NWs) on many different materials has recently been employed to fabricate GaN NW ensembles on a wide variety of substrates, ranging from amorphous dielectrics to crystalline metals. The use of metallic substrates is particularly appealing for applications because of their excellent electrical and thermal conductivity as well as their high optical reflectivity. We have recently demonstrated the growth of GaN NWs on crystalline TiN films by plasma-assisted molecular beam epitaxy [M. Wölz, et al. Nano Lett. 15, 3743 (2015)]. Here, we study the underlying growth mechanisms in detail. Our substrates consist of a Ti layer sputtered on Al2O3(0001). It is shown that the thickness of the Ti layer has a strong influence on the properties of the resulting NW ensembles. We have also investigated the formation of TiN under different conditions and the impact of the resulting TiN microstructure on the subsequent formation of GaN NWs. The combination of in situ and ex situ analytical tools allowed us to elucidate the nucleation and growth mechanisms resulting in the formation of long (>1 μm), uncoalesced, and single crystalline GaN NWs. We have found these NWs to be N-polar, and to exhibit a tilt and a comparatively small twist of 2.4° and 0.8°, respectively.

HL 50.4 Wed 10:15 H17

Germanium doping of cubic GaN — •Michael Deppe[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

Up to now the most commonly used n-type dopant for cubic GaN is silicon. We present a study of germanium as an alternative n-type dopant. The germanium doped cubic GaN films were grown on 3C-SiC/Si (001) substrates by plasma-assisted molecular beam epitaxy. The incorporation of germanium into the GaN films could be verified using secondary ion mass spectrometry (SIMS) and Hall effect measurements revealed the electrical properties of the samples. Films with doping densities above $3 \cdot 10^{18}$ cm^{-3} exhibit n-type conductivity whereas films with lower doping densities are p-type due to electrically active dislocations. A maximum electron concentration of $3.7 \cdot 10^{20}$ cm^{-3} was achieved. From a comparison of SIMS and Hall effect measurements we conclude that in the highest doped sample not all incorporated dopants are electrically active. For doping densities in the order of 10^{19} cm^{-3} and above, a degradation of the crystal quality was observed by high resolution x-ray diffraction (HRXRD). Furthermore, a comparison to silicon doped films reveals no significant differences.

HL 50.5 Wed 10:30 H17

Manipulation of indium incorporation by anisotropic strain in non- and semipolar GaInN/GaN multi quantum well structures — •P. Horenburg[1], U. Rossow[1], R. Buss[1], F. A. Ketzer[1], H. Bremers[1], F. Tendille[2], P. De Mierry[2], P. Vennéguès[2], J. Zuniga-Perez[2], and A. Hangleiter[1] — [1]Institute of Applied Physics, TU Braunschweig, Germany — [2]Centre de Recherche sur l'Hétéro-Epitaxie, Valbonne, France

We demonstrate the effect of anisotropic strain on the In incorporation efficiency in m-plane and (11$\bar{2}$2)-oriented GaInN/GaN multi quantum well (MQW) structures. Inserting a partially relaxed AlInN buffer layer enables manipulation of the strain state in the MQW grown on top. One-dimensional lattice-matching of this AlInN layer to the underlying GaN epilayer induces partial strain relaxation along the perpendicular in-plane direction of the growth surface. This leads to modified lattice constants of the template for the MQW grown subsequently. All samples are grown via low pressure metalorganic vapour phase epitaxy on (11$\bar{2}$2) GaN templates on patterned r-sapphire or commercial m-oriented pseudo-bulk substrates. From structural and optical characterization by X-ray diffraction and photoluminescence measurements, we deduce an impact on the In incorporation efficiency and In concentrations in the quantum wells (QW) up to $x = 40\%$ (semipolar) and $x = 38\%$ (nonpolar) without additional strain energy being accumulated in the QW region. Taking into consideration the reduced quantum-confined Stark effect in such structures, this approach is very encouraging in search for efficient green light-emitting devices.

HL 50.6 Wed 10:45 H17

Epitaxieentwicklung AlN/GaN HEMTs für die Leistungselektronik bei hohen Frequenzen — •Birte-Julia Godejohann, Stefan Müller, Lutz Kirste, Steffen Breuer, Rolf Aidam, Klaus Köhler und Oliver Ambacher — Fraunhofer IAF Tullastraße 72 79180 Freiburg

GaN-Leistungsverstärker ermöglichen im Vergleich zu konventionellen Materialsystemen (GaAs, Si) bei gleichen Betriebsfrequenzen deutlich höhere Leistungsdichten. Dies lässt sich auf die Materialeigenschaften wie hohe Durchbruchfestigkeit, Elektronengeschwindigkeit, Schichtladungsträgerdichten und große Bandlücken der Gruppe III Nitride zurückführen. Um High Electron Mobility Transistoren (HEMT) mit hohen Cut-off Frequenzen realisieren zu können, sind kleine Gatelänge, geringer Kanal-Gate-Abstand sowie eine ausreichend hohe Schichtladungsträgerdichte erforderlich. Hierfür bieten sich im III-Nitrid System grundsätzlich zwei Möglichkeiten an, das gitterangepasste und das verspannte Wachstum einer hoch Al-haltigen Barriere auf GaN; auf das verspannte Wachstum soll hier genauer eingegangen werden. AlN/GaN

HEMTs mit variierten Barriere- und Capdicken wurden simuliert und mittels Molekularstrahlepitaxie (MBE) hergestellt um die Schichtladungsträgerdichten beeinflussen zu können. Die elektrische Charakterisierung der Schichten hat Schichtladungsträgerdichten von 7E12 bis zu 3,3E13 cm-2 und Beweglichkeiten von 1040 bis 1580 cm2/Vs ergeben. Entsprechende Strukturen wurden mittels metallorganischer Gasphasenepitaxie (MOCVD) hergestellt und bezüglich ihrer Materialeigenschaften mit den MBE gezüchteten Proben verglichen.

30 min. Coffee Break

HL 50.7 Wed 11:30 H17

MOVPE growth and characterization of GaN based tunnel junctions employing highly Ge-doped GaN — •Silvio Neugebauer, Aqdas Fariza, Marc Hoffmann, Gordon Schmidt, Hartmut Witte, Jürgen Bläsing, Frank Bertram, Armin Dadgar, Jürgen Christen, and André Strittmatter — Institute of Experimental Physics, Otto-von- Guericke-University Magdeburg, Germany

GaN-based p-n tunnel junctions (TJs) are effective means to improve lateral current spreading in surface emitting light-emitting diodes and lasers. Owing to the large bandgap of GaN and the limited achievable acceptor and donor concentration by Mg and Si doping, respectively, the realization of effective TJs by metalorganic vapor phase epitaxy (MOVPE) is challenging. Ultra-high donor concentrations in MOVPE-grown GaN have been recently demonstrated by Ge doping. In this study, we have successfully used different growth sequences to prepare GaN-based TJs. In particular, the growth sequence at the transition from highly p-doped to highly n-doped material is critical for achieving a sufficient tunneling probability. Furthermore, the activation process for the Mg-doped GaN layer has to be optimized. We will compare thermal annealing schemes on mesa structures and unprocessed TJ structures as well as electron beam irradiation for its effective acceptor activation. First results on LED devices will also be presented and the mechanism responsible for the tunneling process will be discussed.

HL 50.8 Wed 11:45 H17

Evaluation and comparison of the intrinsic electric field of semipolar and polar InGaN/GaN QW structures — •Martina Dombrowski, Jan Wagner, Michael Jetter, and Peter Michael — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Centers SCoPE and IQST, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

One of the most promising material systems for green light emitting devices is InGaN/GaN. And still, one of the main issues to achieve high efficiency for light emitting devices is the appearance of piezoelectric fields in the active region. These lead to a tilt in the band structure and therefore to a reduced recombination efficiency. To overcome the effect of this so-called quantum confined Stark effect (QCSE), the active region can be grown on semipolar or nonpolar planes. In this work, we fabricated three-dimensional GaN pyramids by the selective area growth (SAG) method and used their side facets as semipolar GaN templates. To compare the effect of the reduced QCSE, semipolar and c-plane quantum wells (QW) were grown with different thicknesses emitting at the same spectral position. To evaluate the carrier dynamics, recombination efficiency and the strength of the electric field for both semipolar and polar QWs, optical characterizations by time-resolved photoluminescence were performed on these samples.

HL 50.9 Wed 12:00 H17

Capacitance Voltage Spectroscopy of GaN Quantum Dot Ensembles — •Carlo Alberto Sgroi[1], Julien Brault[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany — [2]CNRS CRHEA, 06560 Valbonne, France

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

GaN and its alloys have excellent properties regarding thermal stability at ambient conditions, high thermal conductivity and wide bandgap energies, thus making it an ideal candidate for high power and high temperature microelectronic and QD devices.

Due to polarization effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers induced intrinsically by inversion asymmetry and extrinsically by doping and strain, the band structure is deformed. Band structure simulations were run to calculate a decent tunneling barrier and estimate the quantum dot minimum to be close to the Fermi energy level with a sufficient lever arm to fill and deplete the QDs.

We used the known CV spectroscopy technique adapted to the GaN properties and measured the convoluted s- and p-states of the QDs at room temperature. The coulomb blockade energy is calculated to be 48.81 meV and the s- to p-energy difference is 126.26 meV.

HL 50.10 Wed 12:15 H17

Determination of polarization fields in InAlN/GaN heterostructures by capacitance-voltage-measurements — •Baran Avinc[1], Monir Rychetsky[1], Konrad Bellman[1], Ingrid Koslow[1], Tim Wernicke[1], Michael Narodovitch[1], Michael Lehmann[1], Silvio Neugebauer[2], Andre Strittmatter[2], Bernd Witzigmann[3], and Michael Kneissl[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany — [2]Otto von Guericke University Magdeburg, Institute of Experimental Physics, Magdeburg, Germany — [3]University of Kassel, Computational Electronics and Photonics Group and CINSat, Kassel, Germany

Lattice-matched InAlN/GaN heterostructures exhibit strong spontaneous polarization fields and sheet charges resulting in band bending. In the literature very few publications exist about the exact field strength values for this material system. In this contribution a new approach to determine polarization fields in nearly lattice-matched InAlN/GaN heterostructures based on capacitance-voltage measurements is used. The change of the polarization fields at the heterointerface influences the charge distribution in a PIN junction and consequently the capacitance. In order to enhance the accuracy of the method we compare the depletion width of two PIN junctions: one with an embedded InAlN layer and therefore influenced by the internal polarization fields, and one without it. The results show an internal field strength of 5.5 MV/cm +/- 1.1 MV/cm for a nearly lattice-matched (nearly 18 % In content) InAlN double heterostructure, in good agreement with theoretically predicted values.

HL 50.11 Wed 12:30 H17

Modulation spectroscopy of semipolar InGaN/GaN light emitting diodes — •Stefan Freytag[1], Monir Rychetsky[2], Tim Wernicke[2], Ingrid Koslow[2], Duc V. Dinh[3], Brian Corbett[3], Peter J. Parbrook[3], Martin Feneberg[1], Rüdiger Goldhahn[1], and Michael Kneissl[2] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität, Magdeburg, Germany — [2]Institut für Festkörperphysik, Technische Universität, Berlin, Germany — [3]Tyndall National Institute, University College Cork, Cork, Ireland

Semipolar InGaN/GaN light emitting diodes containing three InGaN quantum well (QWs) were grown on $(20\bar{2}1)$ and $(20\bar{2}\bar{1})$ oriented bulk GaN substrates. The indium content of the QWs was varied between 0.13 and 0.24. Modulation spectroscopy measurements at variable temperatures are employed to investigate electro-optic properties of the devices. By photoreflection we observe free excitons in the GaN matrix and find a very prominent signal from the InGaN quantum wells. The energy position as a function of temperature is compared to photoluminescence data. In polarization dependend measurements we clearly observe a shift of the characteristic quantum well transition energy for different polarization angles attributed to the selection rules of the corresponding valence bands. Excitation density dependent photoluminescence and photoreflection measurements support this explanation. The studies contribute to the understanding of the valence band structure and the quantification of the polarization fields in semipolar InGaN/GaN multi quantum well structures.

HL 50.12 Wed 12:45 H17

Structural characterization and scanning surface potential microscopy (SSPM) of C-doped GaN layers on Sapphire — •Aqdas Fariza, Hartmut Witte, Andreas Lesnik, Jürgen Bläsing, Peter Veit, Armin Dadgar, and Andre Strittmatter — Institute of Experimental Physics, Otto von Guericke University Magdeburg, Magdeburg, Germany

We have compared undoped and C-doped GaN samples with a focus on electrical properties of the material in the vicinity of dislocations. Photoluminescence measurements showed an increase of blue and yellow band emission intensities with increasing carbon concentrations which points to an enhanced incorporation of deep defects. Dislocation densities are estimated from tilt and twist x-ray measurements using omega-scans for the (0002) reflection and grazing incidence in-plane geometry for the (10-10) reflection. Values of skew and edge type dislocation densities are obtained in the range of 10^8 cm^{-2} and 10^9 cm^{-2}, respectively, independent of the carbon content. The type of dislocations in the GaN layer is determined from TEM images. The

surface topography and electronic charge state of dislocations are explored by performing atomic force microscopy and scanning surface potential measurements in tapping mode. The charging state of dislocations in unintentionally doped samples is either neutral or negative whereas positively charged surface depressions are also found in highly carbon doped samples.

HL 50.13 Wed 13:00 H17

Investigation of AlInN/GaN heterostructures by scanning tunneling and transmission electron microscopy — •Verena Portz[1], Jean-François Carlin[2], Raphaël Butté[2], Nicolas Grandjean[2], Rafal Dunin-Borkowski[1], and Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institute of Condensed Matter Physics, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Ternary III-V semiconductors are of increasing interest for optoelectronic devices. One of the most promising alloys is $Al_{1-x}In_xN$, since it's band gap can be tuned from nearly 0.67 eV to 6.2 eV. Due to the high contrast of the refractive index, alternating layers of GaN and $Al_{1-x}In_xN$ are also commonly used in distributed Bragg reflectors (DBRs) for laser diodes. In these devices, the indium content is tuned to minimize lattice mismatch. Our investigations by scanning tunneling and transmission electron microscopy show that even in $Al_{1-x}In_xN$ layers, nominally lattice matched to GaN, compositional fluctuations can lead to stress and strain. The different strain and compositional effects are discussed.