HL 50: Nitrides: Preparation and Characterization

Time: Wednesday 9:30–13:00 Location: POT 251

Invited Talk HL 50.1 Wed 9:30 POT 251

Photoactivated chemical processes on group III-nitride nanostructures and nanohybrids — Paula Neuderth[1], Sara Hölzl[1,6], Pascal Hille[1,6], Jörg Schörmann[1], Christian Reitz[2], Mariona Coll[3], Jordi Arbiol[3,4], Roland Marschall[5], and •Martin Eickhoff[1,6] — [1]I. Physikalisches Institut, JLU Gießen, 35392 Gießen, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany — [3]ICMAB-CSIC, Bellaterra, CAT, Spain — [4]ICN2, Bellaterra, CAT, Spain — [5]Physikalisch-Chemisches Institut, JLU Gießen, 35392 Gießen, Germany — [6]Institut für Festkörperphysik, Universität Bremen,, 28359 Bremen, Germany

The photoluminescence (PL) emission properties of group III-nitride nanowires and nanowire heterostructures sensitively respond to changes in the chemical environment in gaseous and liquid atmospheres. At the same time, the presence of photogenerated charge carriers on their surfacecan trigger chemical processes by charge transfer into electronic levels/molecular orbitals of adsorbed gas molecules or surrounding electrolytes, as employed in photo-electrochemical water splitting. Hence, monitoring of the PL and controlling the photocurrent allows for analyzing and initiating photoactivated chemical surface processes as well as establishing new principles for opto-chemical nanosensors. We demonstrate these strategies by discussing different examples such as optical pH-sensing, detection of water adsorption or Performance enhancement of oxide-coated InGaN/GaN nanowire photoanodes. We show that part of these concepts can also be transferred to two dimensional semiconductor materials.

HL 50.2 Wed 10:00 POT 251

Effective electron mass in cubic GaN — •Elias Baron[1], Martin Feneberg[1], Rüdiger Goldhahn[1], Michael Deppe[2], and Donat J. As[2] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Department Physik, Universität Paderborn, Germany

Ge-doping has been proven a very efficient way to achive free electron concentrations n above $10^{20}\mathrm{cm}^{-3}$ in wurtzite GaN layers while maintaining excellent structural properties of the films. Recently, we demonstrated that similar high n values can also be obtained in cubic GaN layers by germanium doping. The films were deposited by plasma-assisted molecular beam epitaxy on 3C-SiC substrates. Here, we present a comprehensive characterization of those films covering a wide range of n values by spectroscopic ellipsometry from which the complex dielectric function (DF) is deduced. The analysis of the DFs in the mid-infrared yields the transverse-optical phonon frequency and the plasma frequencies. From the latter, the dependence of the effective electron mass on n is obtained indicating a strong non-parabolicity of the conduction band. Studies around the fundamental absorption edge indicate the superposition of carrier-density dependent Burstein-Moss effect and band gap shrinkage. Excellent agreement between theory and experiment is achieved for the energetic position of the absorption edge when applying the experimentally determined dependence electron mass dependence on n.

HL 50.3 Wed 10:15 POT 251

Hydrogen-induced modifications of N-polar InN surface properties — •Anja Himmerlich, Stefan Krischok, and Marcel Himmerlich — Institut für Physik and Institut für Mikro- und Nanotechnologien, TU Ilmenau, Germany

Indium nitride (InN) is a III-V semiconductor with controversially discussed surface electronic properties. Especially the normally observed high surface electron concentration is under debate. In contrast to In-polar InN, as-grown N-polar InN shows a reduced surface electron accumulation, that however significantly changes during storage in ambient conditions [1]. Here we present investigations on the interaction of atomic hydrogen, a dissociation product of different ambient molecules, with as-grown N-polar InN using in situ photoelectron spectroscopy. Within this study changes in the surface electronic properties, including band alignment and work function, as well as chemical bonding states of the substrate and adsorbates are characterized. We demonstrate that hydrogen preferentially bonds to the surface nitrogen atoms, resulting in the disappearance of nitrogen dangling-bond-related occupied surface state close to the valence band edge and the formation of new occupied electron states at the conduction band edge. The decrease in work function during adsorption and the increase in surface downward band bending confirm that hydrogen is acting as electron donor at N-polar InN surfaces and therefore has to be considered as one main reason for the increased electron accumulation observed for samples exposed to ambient conditions [2]. [1] Appl. Phys. Lett. 102, 231602 (2013); [2] Phys. Rev. B 91, 245305 (2015).

HL 50.4 Wed 10:30 POT 251

Improving lateral current spreading of InGaN LEDs by MOVPE grown GaN tunnel junctions — •Silvio Neugebauer, Andreas Lesnik, Florian Hörich, Hartmut Witte, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Institute of Experimental Physics, Otto-von- Guericke-University Magdeburg, Germany

Improving current injection into nitride-based p/n-junction devices is an important task for further enhancement of the efficiency of light-emitting diodes (LEDs) and vertical cavity surface emitting lasers. GaN-based homoepitaxial p/n tunnel junctions could be an effective means to improve lateral current spreading and still maintain high optical transparency. However, the effectiveness of the tunnel junction is limited due to the achievable maximum donor and acceptor concentrations as well as the activation of hydrogen passivated Mg acceptors buried beneath an n-type GaN layer. In this study, we have grown heavily doped GaN:Mg/GaN:Ge tunnel junctions on top of conventional LED structures using exclusively metal-organic vapor phase epitaxy (MOVPE). In particular, the activation process of the Mg-doped GaN layer is critical for device performance. We will compare post-growth thermal annealing schemes applied to LED mesa structures with thermal annealing of the p-type GaN:Mg layer during growth with regard to the efficiency of the activation. Furthermore, we currently investigate the potential of MOVPE regrowth of the GaN:Ge layer on top of an an ex-situ activated GaN:Mg layer.

HL 50.5 Wed 10:45 POT 251

Capacitance-voltage spectroscopy of charge-tunable GaN quantum dot ensembles at room temperature — •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, Rue Bernard Grégory, 06560 Valbonne, France

We present capacitance voltage (CV) measurement at room temperature of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an AlxGa1-xN matrix 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 devices, such as their thermal stability, high thermal conductivity and wide bandgap energies.

Due to polarization effects in wurtzite GaN/AlxGa1-xN heterostructure layers the band structure is deformed. Band structure simulations were run to calculate a decent 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. The length of the blocking barrier influences the position of the QDs in the energy level. Therefore, the thickness of this layer is crucial for QD position on the energy scale.

We used the known CV spectroscopy technique adapted to the GaN properties and measured the s-states of the QDs at room temperature. The Coulomb blockade energy for the electrons was calculated to be as huge as 142 meV.

Coffee Break

HL 50.6 Wed 11:30 POT 251

Impact of strain and valence band structure on radiative and non-radiative recombination in m-plane GaInN/GaN quantum wells — •Philipp Henning, Torsten Langer, Manuela Klisch, Fedor Alexej Ketzer, Philipp Horenburg, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

Even for thin c-plane quantum wells (QWs), where the polarization field is negligible, we observe longer room-temperature radiative lifetimes compared to m-plane structures. We use time-resolved photo-

luminescence spectroscopy to measure the radiative and non-radiative carrier lifetimes in GaInN/GaN QW structures grown by MOVPE, where we find room-temperature radiative lifetimes between 1ns and 200ps for m-plane QWs and minimum values around 2ns for c-plane structures. The difference amounts up to one order of magnitude and can partly be explained by an increased exciton binding energy for non-polar QWs. As confirmed by simulations, another major contribution to the shorter radiative lifetimes stems from a modified valence band structure, which results in reduced effective hole masses for non-polar QWs. A change of the strain state in the QW, as it is present for higher indium contents, has further impact on the valence band structure. By introducing a metamorphic AlInN buffer layer we aim to reduce the strain in the QW, which allows for a more detailed study of the impact of the valence band structure on the radiative lifetimes. Moreover, we find increasing non-radiative lifetimes as a consequence of the reduced strain state and lower defect formation in the QW.

HL 50.7 Wed 11:45 POT 251

Strain and compositional fluctuations in AlInN/GaN heterostructures — •Verena Portz[1], Michael Schnedler[1], Martial Duchamp[1,2], Fei-Man Hsiao[1,3], Holger Eisele[4], Jean-François Carlin[5], Raphael Butté[5], Nicolas Grandjean[5], Rafal E. Dunin-Borkowski[1,2], and Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Ernst Ruska-Centrum, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [3]Department of Physics, National Sun Yat-sen University, Kaohsinung 80424, Taiwan — [4]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [5]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

The strain and compositional fluctuations of nearly lattice-matched AlInN/GaN heterostructures are investigated by cross-sectional scanning tunneling microscopy and selected area electron diffraction measurements in scanning electron transmission microscopy. The presence of strain induces height modulations governed by different roughness components at the cleavage surfaces. The surface height modulations are compatible with a relaxation of alternatingly compressive and tensile strained domains, indicating compositional fluctuations. Changes of the a lattice constant are traced to interface misfit edge dislocations. The dislocations induce steps increasing the roughness within the AlInN layers.

HL 50.8 Wed 12:00 POT 251

Surface properties of p-type, n-type, and semi-insulating GaN layers on sapphire — •Aqdas Fariza, Andreas Lesnik, Silvio Neugebauer, Matthias Wieneke, Jürgen Bläsing, Hartmut Witte, Armin Dadgar, and André Strittmatter — Otto-von-Guericke University Magdeburg, Magdeburg, Germany

GaN and related heterostructures have been the subject of intensive research in recent years for optoelectronics and high power as well as high frequency devices. However, the large lattice constant mismatch between heterosubstrate and GaN epitaxial film leads to the generation of a high threading dislocation (TD) density which degrades device performance. Understanding the electrical activity of these dislocations and their surface potentials is very important to enhance the reliability of power electronics devices. Therefore, we have investigated defects in Mg-, Si-, C- and Fe-doped GaN samples with a focus on the local electronic properties of the material in the vicinity of dislocations. Dislocation densities are estimated from tilt and twist x-ray measurements using omega-scans of the (0002) reflection and in grazing incidence in-plane geometry of the (10-10) reflection. The surface topography, contact potentials and electronic charge states of dislocations are explored by performing atomic force microscopy, bias dependent electric force microscopy and scanning surface potential microscopy in tapping mode. The conductive layers exhibit a low contact potential whereas the enhanced contact potential difference for resistive GaN layers might be associated not only to the Fermi-level position but also to surface band bending and surface charges.

HL 50.9 Wed 12:15 POT 251

Conoscopic study: Influence of birefringence on the state of polarization in GaN samples — •Ines Trenkmann, Lukas Uhlig, Matthias Wachs, and Ulrich T. Schwarz — Chemnitz University of Technology, Experimental Sensor Science, Reichenhainer Str. 70, 09126 Chemnitz, Germany

GaN with its wurtzite crystal structure is an optical anisotropic material. In a conoscopic setup, the birefringent sample is placed between two crossed polarizers and the state of polarization of the emerging beam is compared to the polarization of the initial ray. Fringes and the typical black bands of the isogyre characterize the obtained conoscopic interference pattern, which depend on the sample thickness, the cone of the incident light ray and the difference between both refractive indices $\Delta n = n_e - n_o$. We compare experimental obtained pattern with simulated images using refractive indices from various studies that are obtained by variable angle spectroscopic ellipsometry [1, 2] and prism coupling technique [3]. The observed differences are discussed considering growth induced crystal strain. Additionally measurements of epitaxial GaN on sapphire show the influence of the sapphire substrate on the observed changes of the state of polarization [4].

References: [1] S. Shokhovets, R. Goldhahn and W. Richter, J. Appl. Phys. 94, 307 (2003). [2] S. Ghosh, P. Waltereit and K. H. Ploog, Appl. Phys. Lett. 80, 413 (2002). [3] G. Yu, H. Ishikawa and M. Umeno, Jpn. J. Appl. Phys. 36, L1029 (1997). [4] I. Trenkmann, L. Uhlig, M. Wachs, C. Mounir, U. T. Schwarz, submitted.

HL 50.10 Wed 12:30 POT 251

Anisotropic dielectric function of nonpolar AlGaN up to 20eV — •Michael Winkler[1], Shigefusa F. Chichibu[2], Ramon Collazo[3], Zlatko Sitar[3], Maciej D. Neumann[4], Norbert Esser[4], Rüdiger Goldhahn[1], and Martin Feneberg[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg — [2]Institute of Multidisciplinary Research for Advanced Materials, Tohoku University — [3]Department of Materials Science and Engineering, North Carolina State University — [4]Leibniz-Institut für Analytische Wissenschaften - ISAS

The linear optical response of nonpolar $(10\bar{1}0)$ $Al_xGa_{1-x}N$ epitaxial films is 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. Their optical properties were measured by spectroscopic ellipsometry up to 20eV performed at the synchrotron Metrology Light Source (MLS) of the PTB in Berlin for two different configurations: One with the [0001]-direction parallel and one perpendicular to the plane of incidence. By modeling the multilayer samples including surface roughness and anisotropy the ordinary and extraordinary dielectric functions were obtained. High energy interband transitions are thus traceable as function of x in the $Al_xGa_{1-x}N$ system allowing assignments of features to certain parts of the band structure.

HL 50.11 Wed 12:45 POT 251

Photon statistics of high-β gallium nitride nanobeam lasers — •Stefan T. Jagsch[1], Noelia Vico Triviño[2], Gordon Callsen[1], Stefan Kalinowski[1], Ian M. Rousseau[2], Jean-François Carlin[2], Raphaël Butté[2], Axel Hoffmann[1], Nicolas Grandjean[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, D-10623 Berlin — [2]École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

The search for an ultimate nanolaser is a central goal in nanophotonics, and has led to cutting edge research at the crossroads between device physics and quantum optics. Such nanolasers employ cavity-enhanced light-matter coupling in order to greatly reduce the lasing threshold, desirable for future on-chip nanophotonic applications. Nitride nanobeam cavities grown on silicon present an ideal system to study such high spontaneous emission coupling factor (β) lasers under realistic device conditions (room temperature & ambient atmosphere) [1]. In a detailed, temperature dependent optical and quantum-optical characterization we show that classical lasing indicators are at best ambiguous for high-β devices, while photon statistics remain a sensitive indicator of the lasing transition. By analysing the temperature dependent carrier confinement in the gain medium, we can explain thresholdless lasing by the temperature- and excitation power dependent interplay of 0D and 2D gain contributions [2].

[1] Triviño et al. Nano Lett. 15(2), 2015
[2] Jagsch et al. arXiv:1603.06447