HL 41: GaN: preparation and characterization II

Time: Thursday 9:30–13:00 Location: BEY 154

HL 41.1 Thu 9:30 BEY 154

Growth delay in GaInN/GaN multi quantum wells — •Heiko Bremers, Lars Hoffmann, Holger Jönen, Uwe Rossow, and Andreas Hangleiter — TU Braunschweig, Institut für Angewandte Physik Mendelssohnstr. 2, 38106 Braunschweig

We have grown MQW (multi quantum well) structures under different growth conditions in a MOVPE reactor (AIXTRON 200RF). The combination of high resolution x-ray diffraction with TEM measurements allow the determination of structural parameters of the layered system. By a systematic variation of thickness of QW and V/III ratio we have observed a growth delay in period length (i.e. QW + barrier thicknss). This growth delay of 70 s relates to missing thickness of approximately 1 nm. Based on the obsevation that the TMI (tri methyl indium) flux exhibits a linear relationship with the period length as well as to the indium concentration in the QW we will try to present a model which explains the origin of this growth delay. Finally we will compare these results to PL measurements.

HL 41.2 Thu 9:45 BEY 154

Spectrally and time resolved cathodoluminescence spectroscopy of AlN grown on sapphire by high-temperature MOVPE — •Martin von Kurnatowski[1], Barbara Bastek[1], Juergen Christen[1], Thomas Hempel[1], Outi Rentilä[2], Viola Küller[2], Frank Brunner[2], and Markus Weyers[2] — [1]Otto-von-Guericke-Universität Magdeburg — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik Berlin

We present spectrally and ps-time resolved cathodoluminescence studies of AlN epilayers grown on sapphire by high-temperature MOVPE. The spatially averaged 5 K luminescence spectrum shows bright near band gap (NBG) emission dominated by a sharp (D^0, X) peak at 5.94 eV. Apart from that, a broad luminescence band occurs at lower energies. It consists of two parts, centered at 3.0 eV and 3.8 eV, assigned to an O-DX-center and a Si defect, respectively. The intensity of the emission caused by Si-defects is characterized by a thermal activation, described by an activated Arrhenius-function. An activation energy of 48 meV is determined. Due to this behavior, the Silicon defects are interpreted as DX-centers as well.

For the analysis of the recombination kinetics and its temperature dependence periodic excitation was performed in ps-CL using rectangular e-beam pulses. Appropriately matched repetition frequencies ranging from MHz down to below 1 kHz and matched puls length were chosen, depending on the actual kinetics timescale. For the 3.0 eV band a strongly non-exponential decay is found with time constants ranging from the ns- to the ms-range.

HL 41.3 Thu 10:00 BEY 154

Control of MOVPE InGaN quantum dot density and emission wavelength and applications in light emitting structures — •Christian Tessarek, Timo Aschenbrenner, Stephan Figge, Joachim Kalden, Kathrin Sebald, Jürgen Gutowski, and Detlef Hommel — Institut für Festkörperphysik, Universität Bremen, Otto-Hahn-Allee 1, 28359 Bremen

InGaN quantum dots (QDs) are very promising for the application in laser structures emitting in the blue to green spectral region due to the expected lower threshold currents in comparison to a quantum well (QW) based device.

Our approach to form capped InGaN QDs is a two-step growth method [1] which is composed of an InGaN nucleation layer (NL) followed by an (In)GaN protection layer. There are indications that spinodal decomposition is the driving force for the transition of the NL into self-assembled QDs.

We will show how the emission wavelength can be tuned from 440 nm to 520 nm by varying the NL thickness and the In content in the protection layer. Atomic force microscope and photoluminescence (PL) results reveal a QD density dependence on the NL growth temperature.

The strong room temperature PL emission intensity of the QDs promises an improvement in device performance compared to QW based devices. We will demonstrate the successful implementation of these InGaN QDs into light emitting diodes and laser structures.

[1] T. Yamaguchi et al., phys. stat. sol. (c) 4, No. 7, 2407-2410 (2007)

HL 41.4 Thu 10:15 BEY 154

Kathodolumineszenz-Mikroskopie an InGaN/GaN Pyramiden — •Frank Bertram[1], Sebastian Metzner[1], Jürgen Christen[1], Michael Jetter[2], Clements Wächter[2] und Peter Michler[2] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Stuttgart Universität

Die optischen Eigenschaften von InGaN Nanostruturen wurden mittels hochorts- und spektralaufgelöster Kathodolumineszenz untersucht. Regelmäßig in Feldern angeordnete, hexagonale GaN Pyramiden wurden auf einem GaN/Saphir-Substrat mit Hilfe von MOVPE und Photolithographie gewachsen. Die sechs semipolaren $\{1\bar{1}01\}$ Pyramidenfacetten wurden mit einem nominell 6 nm dicken InGaN SQW überwachsen. Das ortsintegrale KL Spektrum zeigt eine breite InGaN Lumineszenz zwischen 1.9-2.6eV sowie eine sehr intensive (D^0,X)-Linie vom GaN. Die InGaN Lumineszenz stammt ausschließlich von den Pyramiden. An der Basis und insbesondere an der Pyramidenspitze leuchtet der InGaN-SQW besonders intensiv. Die InGaN-KL ist an der Basis deutlich durch horizontal verlaufende Intensitätssprünge moduliert welche mit Wellenlängenänderungen einhergehen. Geringere Intensitäten korrelieren eindeutig mit kürzeren Wellenlängen. Die Wellenlänge variiert hier um einen Wert von 55 0nm. Im oberen Pyramidendrittel spaltet die InGaN Bande in zwei separate Linien auf. Eine Wellenlänge um 590 nm tritt bevorzugt an den Kanten/Spitze auf. Dagegen tritt eine KL von 530 nm im Facettenzentrum auf. Diese Änderungen lassen sich mit Dicken-/Konzentrationsänderungen des QW erklären.

15 min. break

HL 41.5 Thu 10:45 BEY 154

Transport freier Exzitonen in HVPE-GaN — •Martin Noltemeyer[1], Frank Bertram[1], Jürgen Christen[1], Tim Wenicke[2], Christian Hennig[2], Markus Weyers[2] und Michael Kneissl[2,3] — [1]Otto-von-Guericke-Universität Magdeburg — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik Berlin — [3]Technische Universität Berlin

Mittels hoch orts- und ps-zeitaufgelöster Kathodolumineszenzspektroskopie (KL) wurde der nanoskopische laterale Transport freier Exzitonen (FX) in HVPE gewachsenen, dicken GaN-Schichten untersucht. Dazu wurden die Diffusionslänge λ_{FX} und die Lebensdauer τ_{FX} in Abhängigkeit von der Temperatur gemessen. Hieraus wurde die FX-Beweglichkeit berechnet, deren Temperaturabhängigkeit Informationen über die zugrunde liegenden Streumechanismen liefert. Die FX-Diffusionslänge wurde mittels KL-Linescans senkrecht zur Kante einer 160 nm dicken, rechteckigen Ti-Maske und numerischer Anpassung mit der analytischen Lösung der 1d-Diffusionsgleichung bestimmt. Weit entfernt von den Ti-Masken wurden an derselben Probe Lumineszenztransienten aufgenommen und die anfängliche Lebensdauer $\tau_{FX}(T)$ ermittelt. Mit fallender Temperatur (300 K bis 5 K) nimmt λ_{FX} monoton zu, während τ_{FX} von 1,3 ns auf 300 ps fällt. Daraus folgt eine monotone Zunahme der Beweglichkeit mit sinkender Temperatur um mehr als drei Größenordnungen (30.000 cm^2/Vs bei 5 K). Die charakteristische Abnahme der Beweglichkeit bei tiefen Temperaturen aufgrund der Streuung von Elektronen und Löchern an ionisierten Störstellen, tritt bei den elektrisch neutralen freien Exzitonen nicht auf.

HL 41.6 Thu 11:00 BEY 154

Defect-related cathodoluminescence in ELOG GaN structures — •Ingo Tischer[1], Martin Schirra[1], Martin Feneberg[1], Rolf Sauer[1], Klaus Thonke[1], Thomas Wunderer[2], and Ferdinand Scholz[2] — [1]Institut für Halbleiterphysik, Universität Ulm, 89069 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89069 Ulm

Defect-related luminescence was studied in a sample having selectively overgrown triangular shaped GaN stripes with stable $\{1\bar{1}01\}$ facets. This sample was intentionally grown under unfavourable conditions in order to provoke a high density of light emitting structural defects. Spatially resolved cathodoluminescence of both the semi-polar $\{1\bar{1}01\}$ facets and the cross section was recorded. Different emission bands between 3.16 and 3.35eV were observed and systematically investigated using monochromatic CL images and CL linescans with low electron

excitation energies to push the spatial resolution to the limit of 40nm. Some of the spectral features are complementary to each other, while others appear commonly in certain regions. A detailed discussion of the spectral and spatial distribution of these defect-related transitions and their possible structural origin will be presented.

HL 41.7 Thu 11:15 BEY 154

Optical properties of GaN nanorods grown catalyst- and mask-free on r-plane sapphire — •Joachim Kalden, Kathrin Sebald, Moritz Seyfried, Tobias Voss, Jürgen Gutowski, Timo Aschenbrenner, Gerd Kunert, Carsten Kruse, Stefan Figge, and Detlef Hommel — Institute of Solid State Physics, University of Bremen, P.O. Box 330 440, D-28334 Bremen, Germany

In the UV spectral region GaN is an up-and-coming material system for the realization of nanostructures with high crystalline quality. So far, such nanorods have been realized by either applying a mask or using a catalyst. Both approaches lead to an unintentional doping and the creation of deep centers, the latter one reducing the efficiency of the near-band edge emission. We present GaN nanorods which were grown catalyst- and mask-free in two steps. After nitridation via metal-organic vapor phase epitaxy the nanorod growth is realized via molecular beam epitaxy. These nanorods have brilliant optical properties. Microphotoluminescence measurements are performed at temperatures between 4 and 300 K. The excitonic emission band reveals several distinct lines which can be attributed to donor-bound (D^0X) and acceptor-bound (A^0X) excitons, respectively. The full width at half maximum (FWHM) of the D^0X emission is 1.2 meV, proving the high crystalline quality. Furthermore, the free exciton is visible as a shoulder already at 4 K, while no yellow defect-related luminescence occurs. Microphotoluminescence experiments on single nanorods reveal strong luminescence intensity up to room temperature.

HL 41.8 Thu 11:30 BEY 154

Optical and magnetic properties of Gd doped GaN — •Ole Hitzemann[1], Martin Kaiser[1], Enno Malguth[1,2], Markus R. Wagner[1], Jan H. Schulze[1], Wolfgang Gehlhoff[1], Axel Hoffmann[1], Shalini Gupta[2], Ian T. Ferguson[2], Martin Röver[3], Dong-Du Mai[3], and Angela Rizzi[3] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, USA — [3]IV. Physikalisches Institut and Virtual Institute of Spin Electronics (VISel), Georg-August Universität Göttingen, Germany

Gd doped GaN is of high interest for spintronics because it shows a ferromagnetic behavior with a high magnetic moment per Gd atom as well as good conductivity at RT. To investigate the coupling mechanism behind the strong magnetization we examined MOCVD and MBE grown samples of epitaxial layers of this diluted magnetic semiconductor containing Gd at concentrations ranging from 10^{18} cm^{-3} to 10^{21} cm^{-3}. p-type and n-type co-doping allowed the investigation of the effect of the position of the Fermi level. We present high resolution photo luminescence (PL) spectra of a doublet peak at 1.7876 eV with a FWHM of 40 μeV in all Gd doped samples which we associate with an internal Gd^{3+} transition. The relatively long time constant of 3.5 ms found in time resolved PL experiments confirms the attribution to an intra f-shell transition. Excitation spectra of this luminescence reveal efficient excitation bands between 2.0 and 2.6 eV. The results are discussed in terms of a bound state that might play a significant role in the ferromagnetic behavior reported for GaGdN.

15 min. break

HL 41.9 Thu 12:00 BEY 154

Swift heavy ion irradiation induced recrystallization of implanted GaN — •Anne-Katrin Nix[1], Sven Müller[1], Ulrich Vetter[1], Christina Trautmann[2], and Hans Hofsäss[1] — [1]II. Physikalisches Institut, Universität Göttingen, Germany — [2]Gesellschaft für Schwerionenforschung, Darmstadt, Germany

Preparing GaN:Mg by ion implantation is a widely used technique of doping, but results in a high level of lattice defects. Thermal annealing can be used for recrystallization, but sample decomposition often hampers the annealing effect. Here, we present swift heavy ion irradiation as an alternative annealing method. Due to high electronic energy loss along the ion track, the sample is locally heated during a time span of 10^{-12} seconds. Thus, surrounding material stays unaffected. Implanted GaN samples were irradiated with several ion species at different energies with the objective to vary the electronic energy loss. Directly after implantation and after irradiation, the photoluminescence excited with a laser emitting in the UV-regime was examined at low temperature. The obtained spectra are compared to well known spectra of GaN and GaN:Mg. An annealing effect is seen after 578 MeV Cr-irradiation. GaN samples were irradiated with 668 MeV Ni-ions with varying fluences, obtaining a similar electronic energy loss compared to 578 MeV Cr-ions, with the goal to examine a fluence dependence of the annealing process. In addition, irradiation with light ions, and thus much lower electronic energy loss, was performed with the aim of analyzing a possible threshold value of the electronic energy loss.

HL 41.10 Thu 12:15 BEY 154

Role of the parasitic Mg_3N_2 phase in post-growth activation of p-doped Mg:GaN — •Björn Lange, Christoph Freysoldt, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung, 40237 Düsseldorf, Germany

A critical issue in further improving the efficiency of modern white light-emitting diodes is the rather limited p-type conductivity achievable in GaN. The limited doping efficiency is a direct consequence of the low solubility of Mg in GaN due to the formation of the parasitic Mg_3N_2 phase. While the presence of this phase is well known and often unavoidable its consequences on the acceptor activation mechanism (H codoping with subsequent H removal) have not been studied so far. We have therefore studied the possibility to exploit these Mg_3N_2 inclusions as potential hydrogen traps by means of DFT calculations. For this, Mg_3N_2 has been modeled in the anti-bixbyite structure. The calculated structural properties are in good agreement with available experimental data. Based on these studies hydrogen has been explored in various positions and charge states. Our results show significantly higher H solubilities compared to GaN. Further a strongly bound N-H complex is identified which is more stable than the Mg-H complex in GaN. The implications for Mg activation in Mg:GaN above the Mg solubility limit will be discussed.

HL 41.11 Thu 12:30 BEY 154

Growth modes of thick InGaN films on GaN — •Martin Leyer, André Kruse, Joachim Stellmach, Markus Pristovsek, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin

We have investigated the growth of thick ($d > 10$ nm) InGaN layers grown by metal-organic vapour phase epitaxy (MOVPE). The composition was controlled by varying the growth temperature between 700 °C and 850 °C. The indium content and the strain was determined by X-ray diffraction. We observed two distinct peaks in the ω-2Θ scans for most of the samples. For lower growth temperatures a relaxed top layer was found in reciprocal space maps. For higher growth tempratures a lateral decomposed top layer was observed. The variation of the indium content with growth temperature was exponential.

We propose the following model: In a first step a smooth strained InGaN wetting layer is grown in the Stranski-Krastanov growth mode. Then a transition from 2D to 3D growth takes place. For growth temperatures below 750 °C a rough layer is grown pseudomorphic up to the crititcal layer thickness and subsequently relaxes. For growth temperatures above 750 °C a strained, but laterally inhomogeneous layer is grown.

For the strained layer the activation energy for indium incorporation was $\sim$2.2 eV and for the relaxed layer $\sim$0.6 eV. Growth rate(s) and the critical thickness(es) were obtained by in-situ ellipsometry.

HL 41.12 Thu 12:45 BEY 154

Katalysator- und maskenfreies Wachstum von GaN-Nanosäulen — •Gerd Kunert[1], Timo Aschenbrenner[1], Carsten Kruse[1], Stephan Figge[1], Detlef Hommel[1], Marco Schowalter[2] und Andreas Rosenauer[2] — [1]Institut für Festkörperphysik - Halbleiterepitaxie - Universität Bremen, 28359 Bremen, Otto-Hahn Allee, NW1 — [2]Institut für Festkörperphysik - Transmissionselektronenmikroskopie - Universität Bremen, 28359 Bremen, Otto-Hahn Allee, NW1

In den letzten Jahren gab es umfangreiche Untersuchungen in Bezug auf Galliumnitrid basierten Nanosäulen. Viele Herstellungsmethoden verwenden dabei katalysatorinduziertes Wachstum oder eine Maskierung der Oberfläche. In diesem Beitrag wird ein Verfahren präsentiert, was die Schwierigkeiten dieser Methoden in Bezug auf Materialqualität umgeht. In einem ersten Schritt wird die Saphir-Oberfläche mit r-Flächenorientierung mit Hilfe metallorganischer Gasphasenepitaxie nitridiert. Es bilden sich AlN Inseln auf dem Substrat. In einem zweiten Schritt wird das Wachstum mittels MBE durchgeführt. Das Ver-

fahren führt zu um 28° zur Oberflächennormalen geneigten Nanokristallen. Deren sehr gute kristalline Qualität wurde durch TEM-Untersuchungen gezeigt. Zeitgleich zum Wachstum der Nanokristalle wächst eine kompakte, zweidimensionale Schicht Galliumnitrid, die zur Kontaktierung späterer Bauelemente genutzt werden kann. Es wurden Nanosäulen hergestellt mit einer Länge von bis zu 3μm. Deren Dichte lässt sich zwischen 10^7cm^{-2} und 10^9cm^{-2} variieren.