HL 96: GaN: Growth and doping

Time: Friday 9:30–12:15 Location: H15

HL 96.1 Fri 9:30 H15

Dependence of band gap bowing of epitaxial $In_xGa_{1-x}N$ on composition, strain and ordering effects by first-principles calculations — •Ying Cui, Sangheon Lee, Gerard Leyson, Christoph Freysoldt, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung, Max-Planck-Str. 1, 40627 Düsseldorf

The band gap of $In_xGa_{1-x}N$ alloys does not only depend on the In composition, but also on the strain state and the ordering of In atoms. We performed a theoretical study to disentangle the different effects. According to our results, the band gaps of $In_xGa_{1-x}N$ alloys show parabolic behavior in compressive regions and linear dependence in the tensile regions. We further find a universal bowing behavior in $In_xGa_{1-x}N$ alloys for the whole In content range under constant relative strain. Inhomogeneous In distributions lead to a narrower band gap, but are energetically unfavorable. Based on the calculated results, an interpolating form for the band bap as a function of ordering, biaxial strain and chemical content for $In_xGa_{1-x}N$ alloys is suggested. Our results provide guidance to determine the band gaps of $In_xGa_{1-x}N$ alloys under real experiment conditions.

HL 96.2 Fri 9:45 H15

Ordering phenomena in $In_xGa_{1-x}N$ grown epitaxially on GaN(0001) — •Sangheon Lee, Christoph Freysoldt, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Str. 1, 40627 Düsseldorf

The spatial distribution of In in $In_xGa_{1-x}N$ epitaxial layers attract much attention, as In compositional fluctuations are often invoked to explain the realization of the high-efficiency blue light-emitting diodes ($x \simeq 0.15$) despite the large number of threading dislocations. However, the mechanisms determining the spatial distribution of In in the fully grown $In_xGa_{1-x}N$ epitaxial layers are not well understood. We therefore developed an effective crystal growth modeling technique that combines a semi-grand-canonical Monte Carlo simulation with an *ab-initio* parameterized empirical force field. We elucidate local strain effects on the spatial distribution of In in coherent $In_xGa_{1-x}N$ grown epitaxially on GaN(0001), with particular attention to the effect of the surface. In particular, we observe a strong tendency towards ordering in $In_xGa_{1-x}N$ of $x < 0.33$, resulting in a stack of $\sqrt{3} \times \sqrt{3}$ patterned InGaN monolayers. The effect of temperature on the ordering and thermodynamics is discussed, revealing that the ordering phenomena persists at real growth temperatures. The ordering phenomena are identified as a key factor that determines characteristic In compositional fluctuations in $In_xGa_{1-x}N$ epitaxial layers with varying total indium contents.

HL 96.3 Fri 10:00 H15

Island nucleation during double pulsed growth of InN with RF-MBE — •Andreas Kraus, Uwe Rossow, Heiko Bremers, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

Although InN is predicted to have outstanding material properties the data obtained experimentally are more or less disappointing. In particular the carrier mobility is much lower than predicted. Since the growth of InN is very difficult, this discrepancy is most likely due to the low quality of the investigated material. Recently, the quality of MBE-grown InN has been improved by applying pulsed source fluxes. In our recent work we presented a double-pulsed growth method, where periodically the equivalent of less than one monolayer In is followed by a distinct time of nitridation. With this method a surface morphology made of huge and atomically flat grains (≈ 2 μm in diameter) was achieved.

To get a deeper understanding of this growth behavior a series of samples with various numbers of periods was grown. The growth was monitored in-situ by reflection high energy electron diffraction and by optical reflectometry. Ex-situ the samples were characterized by atomic force microscopy, scanning electron microscopy and high resolution X-ray diffraction.

At small period numbers only little islands with dendritic features at their boundaries are visible. These grains evolve to the huge ones that were observed previously. If the period number is large enough that the grains meet each other, they coalesce to a closed surface.

HL 96.4 Fri 10:15 H15

MBE growth and characterization of AlN and $Al_xGa_{1-x}N$ with various x. — •Christopher Hein[1], Andreas Kraus[1], Heiko Bremers[1], Uwe Rossow[1], Kamran Forghani[2], Ferdinand Scholz[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, TU-Braunschweig, Germany — [2]Institut für Optoelektronik, Universität Ulm, Germany

Devices based on AlN have gained interest owing to their potential in optoelectronic devices, namely fast detectors, and as a starting material for GaN quantum dot growth. Our experiments include Riber 32P PA-MBE grown AlN layers and $Al_xGa_{1-x}N$/GaN MQW's. The samples were grown on MOVPE AlN and GaN templates. They were characterized in-situ using RHEED and an infrared reflectometry setup for thickness analysis. XRD measurements served as ex-situ determination of the structural quality and the composition of our MQW's. The growth temperature behaviour of $Al_xGa_{1-x}N$ was investigated with a series of samples in the range of 700 to 850°C. The surface morphology was investigated using SEM and AFM. We found that for optimized Al fluxes in the nucleation layer, the epilayer surface morphology could be improved. Two growth modes have been investigated, the continuous mode which can easily lead to droplet formation and a metal pulsed method which further increases the possible Al/N flux ratio before droplet formation. We also discuss XRD analysis and UV-PL studies of our MQW samples.

HL 96.5 Fri 10:30 H15

InGaN quantum wells grown on 2" semipolar GaN — •Tobias Meisch[1], Sabine Schörner[2], Junjun Wang[1], Klaus Thonke[2], and Ferdinand Scholz[1] — [1]Institut für Optoelektronik, Universität Ulm, 89081 Ulm — [2]Institut für Quantenmaterie, Arbeitsgruppe Halbleiterphysik, Universität Ulm, 89081 Ulm

We have grown high quality (10-11) GaN and (11-22) GaN on (11-23) and (10-12) patterned sapphire respectively. The patterning of the substrate was done by reactive ion etching to produce periodic trenches about 1.5 μ m deep and 1.5 μm wide, revealing a c-plane-like facet on one side. All other facets are subsequently covered with SiO2 to inhibit epitaxial growth. In the following MOVPE process, GaN nucleates on this unmasked side facet, grows out of the trench and forms a coalesced semipolar surface. By decreasing the trench depth to 400 nm, we could reduce the RMS of the surface roughness by about a factor of two. First experiments on depositing InGaN quantum wells on the homogeneous GaN surface show much lower indium incorporation on the (11-22) plane as compared to the conventional c-plane. However, by a substantial increase of the indium flux, the QW emission could be shifted to 520 nm. Using comparable growth conditions, QWs on (10-11) GaN show an emission wavelength of 482 nm and a much higher intensity.

Coffee break

HL 96.6 Fri 11:00 H15

Towards identification of the shallow donor oxygen in AlN photoluminescence spectra — •Martin Feneberg[1], Benjamin Neuschl[2], Klaus Thonke[2], Matthias Bickermann[3], and Rüdiger Goldhahn[1] — [1]Abt. Materialphysik, Inst. für Exp. Physik, Otto-von-Guericke-Universität Magdeburg — [2]Gruppe Halbleiterphysik, Inst. für Quantenmaterie, Universität Ulm — [3]Leibniz-Institut für Kristallzüchtung, Berlin

In photoluminescence spectra of wurtzite AlN, several bound exciton emission bands can be observed. Recently, one of them could be identified as being related to substitutional silicon on aluminum site [1]. In this study, we present a correlation of secondary ion mass spectroscopy and photoluminescence at liquid helium temperature of a variety of AlN single crystals. From our analysis we tentatively assign a bound exciton line as being related to substitutional oxygen on nitrogen site. For this defect, DX center formation is expected, what is discussed in light of our experimental findings.

[1] B. Neuschl, et al. Phys. Stat. Sol. B 249, 511 (2012).

HL 96.7 Fri 11:15 H15

Activation of a new europium center in Europium-implanted GaN by both Mg and Si codoping — •Jayanta Kumar Mishra[1],

Torsten Langer[1], Uwe Rossow[1], Stepan Shvarkov[2], Andreas Wieck[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, TU Braunschweig — [2]Angewandte Festkförperphysik,Ruhr-Universitfät Bochum, Germany

Rare earth ions implanted into GaN are promising for optoelectronic applications. They show luminescence in the visible range while the luminescence from this material system is sharper as well as independent of temperature due to intra 4f transition of rare earth ions. To improve the emission efficiency we implanted Europium in GaN codoped with Mg at dose range from $10^9 cm^{-2}$ to $10^{14} cm^{-2}$ with an energy of 100 keV. The red emission from $^5D_0 \rightarrow ^7F_2$ of europium was remarkably enhanced by Mg codoping. It further enhances by both Mg and Si codoping. The typical Eu^{3+} luminescence in GaN at 2.000 eV (620 nm) is not found to be dominant. A new peak which is already present in europium-implanted Mg-doped GaN at 2.0047 eV (618.9 nm) is enhanced about ten times. This peak is found to be more than three times more intense than the typical 620 nm line of Mg-doped GaN:Eu. A new site dominates in the spectrum especially in the $^5D_0 \rightarrow ^7F_2$ transition range which is different from the sites present in undoped GaN:Eu. The excitation process of europium ions is proposed to take place through a donor-acceptor pair related energy transfer mechanism.

HL 96.8 Fri 11:30 H15

Nonradiative recombination due to Ar implantation induced point defects in GaInN/GaN quantum wells — •Torsten Langer[1], Hans-Georg Pietscher[1], Holger Jönen[1], Uwe Rossow[1], Heiko Bremers[1], Dirk Menzel[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig — [2]Institut für Physik der Kondensierten Materie, Technische Universität Braunschweig

We quantitatively investigate nonradiative recombination at point defects via temperature dependent time-resolved photoluminescence spectroscopy on argon implanted MOVPE-grown GaInN/GaN single quantum wells (QW). An implantation dose dependent (doses: 10^{11} cm^{-2} - 10^{13} cm^{-2}) reduction of nonradiative lifetimes from several nanoseconds (unimplanted sample) to less than 100 ps at room temperature is observed. This shortening of nonradiative lifetimes is attributed to nonradiative recombination due to increased implantation induced defect densities. An effective hole capture coefficient can be estimated to about 10^9 cm^{3}s^{-1} via the measured nonradiative lifetimes and simulated (SRIM) defect densities. The thermal stability of the defects is analyzed using rapid thermal annealing at 800°C in order to recover the crystal from implantation damage. At high temperatures, nonradiative recombination in the barriers becomes dominant: defect density dependent losses with an activation energy equal to half the difference between the GaN band gap and the peak position of the QW luminescence are observed.

HL 96.9 Fri 11:45 H15

Influence of Si- and Ge-doping on the properties of AlGaN layers — •Christoph Berger, Hartmut Witte, Armin Dadgar, Jürgen Bläsing, Peter Veit, Annette Diez, and Alois Krost — Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Magdeburg

We investigate n-doping of $Al_{0.2}Ga_{0.8}$ layers using silane and germane as dopants. For this purpose doped AlGaN films with thicknesses of about 400 nm were grown on an undoped $Al_{0.2}Ga_{0.8}$-buffer. With both dopant sources, it was possible to achieve electron concentrations of nearly 10^{20} cm^{-3} as determined by Hall-effect measurements. However, when doping was applied, an increase in tensile stress was observed by means of in-situ curvature measurements. This effect becomes more pronounced at higher dopant fluxes and higher dislocation densities of the buffer. For Si-doping this effect is similar to GaN, where Si-doping is known to lead to dislocation climb. On the contrary, it can be shown that for Ge-doping the tensile stress is caused by a change in alloy composition as determined by X-ray diffraction. With higher Ge-fluxes, the Al-concentration of the film increases, consequently the Ge-doped film grows tensely strained on the buffer. Interestingly, the influence on the composition also depends on the dislocation density.

HL 96.10 Fri 12:00 H15

Optical properties of highly Ge doped GaN — •Christian Nenstiel[1], Max Bügler[1], Stephanie Fritze[2], Armin Dadgar[2], Hartmut Witte[2], Antje Rohrbeck[2], Jürgen Bläsing[2], Gordon Callsen[1], Alois Krost[2], and Axel Hoffmann[1] — [1]Institut für Festkörperphysik, TU-Berlin, Hardenbergstrasse 35, 10623 Berlin, Germany — [2]Institut für Experimentelle Physik, Fakultät für Naturwissenschaften

In this contribution a systematic study of highly doped GaN:Ge is presented and compared to highly doped GaN:Si. The samples were grown by MOVPE on sapphire substrates. All samples consist of AlN/AlGaN seed followed by an undoped GaN buffer layer. Subsequently, an approximately 700 nm thick doped layer was grown. The doping has been varied resulting in a variation of free carrier concentration from 8 x 10^17 to 1.9 x 10^20 cm^-3 measured by Hall-effect. The X-Ray Diffraction and Raman measurements show a high structural quality and homogeneous incorporation of Ge even at the highest doping concentration. On the Nomarski microscopy images is a smooth surface visible with just a small amount of pits. The Photoluminescence data at 7K shows a strong broadening and blue shift of the luminescence with increasing Ge content, additionally the luminescence decay time increases. The results demonstrate that free carrier concentrations up to 1.9 x 10^20 c^m-3 are achievable with Ge doping maintaining a high crystal quality.