HL 45: Group-III-Nitrides: Optical Properties II

Time: Wednesday 14:30–17:45 Location: H15

HL 45.1 Wed 14:30 H15

Determination of the Faust-Henry Coefficient of GaN by Raman Scattering — •Christian Röder, Gert Irmer, and Cameliu Himcinschi — TU Bergakademie Freiberg, Institute for Theoretical Physics, Leipziger Str. 23, 09596 Freiberg, Germany

In order to specify the charge carrier concentration n and mobility μ in GaN by Raman spectroscopy the Faust-Henry coefficient C should be determined with good precision. Unfortunately, the values for this parameter found in literature differ significantly. Using the standard dielectric approach we calculated the Raman lineshape of coupled phonon-plasmon modes (CPPM) depending on the Faust-Henry coefficient and scattering mechanisms respectively.
Raman intensity measurements on the A1(TO) and A1(LO) phonons of undoped GaN specimen were carried out from room temperature down to 77 K to determine the Faust-Henry coefficient. Additionally we investigated several doped GaN samples with the goal to compare the ascertained free-carrier concentrations with those derived from the Raman lineshape fitting using the previously determined value of C. The comparison gives good agreement confirming the determined Faust-Henry coefficient. Furthermore the analysis of the lineshape reveals the deformation-potential and electro-optic mechanisms as dominant scattering mechanisms in gallium nitride.
The authors would like to thank the European Union (EFRE) as well as the Free State of Saxony for financial support.

HL 45.2 Wed 14:45 H15

Auger Coefficient in GaInN-based Laser Structures — •Alexander Daniel Dräger, Carsten Netzel, Moritz Brendel, Holger Jönen, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

Todays GaInN-based light emitting devices such as LEDs and laser diodes show excellent properties in terms of quantum efficiency or threshold current in the violet-blue spectral region. With increasing wavelength towards the green this performance decreases strongly. In particular at longer wavelengths, the quantum efficiency decreases for higher current densities, called the efficiency droop. This phenomenon is still subject to intensive research and different mechanisms such as Auger recombination, losses due to dislocations and carrier escape have been named as possible explanations. We combine optical gain measurements using the variable stripe length technique with model calculations of the optical gain spectra to derive the carrier lifetime. From the dependence of the inverse effective lifetime on carrier density we determine the recombination coefficients for radiative, nonradiative and Auger recombination. The Auger coefficients we obtained are about 1-2$\times 10^{-31}$ cm^6/s for GaInN quantum wells with 2.5eV$< E_g <$3.1eV which is more than an order of magnitude lower than estimated from photoluminescence [1] and thus too low to explain the LED droop. Nevertheless, Auger recombination seems to contribute to laser threshold.

[1] Shen et. al. APL **91**, 141101(2007)

HL 45.3 Wed 15:00 H15

Exciton enhancement of recombination mechanisms in GaInN/GaN quantum well structures — •T. Langer, A. D. Dräger, H. Jönen, D. Fuhrmann, H. Bremers, U. Rossow, and A. Hangleiter — Institute of Applied Physics, TU Braunschweig

Temperature-dependent and time-resolved photoluminescence spectroscopy on highly efficient GaInN/GaN quantum well structures with low excitation power reveal the nature of radiative recombination being free exciton dominated up to room temperature. This implies a strong enhancement of radiative recombination rates of free excitons compared to free carriers, due to a higher probability of electrons and holes being at the same place simultaneously. In the low excitation regime, where screening of excitons is not important, we therefore observe a linear rather than a quadratic carrier concentration (n) dependence of radiative recombination rates. This observation, as well as the radiative rates in the whole temperature and carrier concentration range, can be described using a n-dependent correlation function g_{eh} of electrons and holes in a many body system. The radiative recombination rate turns to $Bg_{eh}(n)n^2$ in case of optical excitation ($n = p$).

We also discuss the effect of excitons on Auger recombination, whose rate is known to be proportional to n^3 for free carriers. For GaInN/GaN quantum well structures, the Auger coefficient is about $1 \cdot 10^{-31}$cm^{6}s^{-1} which appears to be too low to let Auger recombination become a significant recombination process in such structures. Nevertheless, excitonic enhancement might increase the importance of Auger recombination in these materials.

HL 45.4 Wed 15:15 H15

Excitonic dielectric function of hexagonal GaN — •Steve Lenk and Erich Runge — Institut für Physik und Institut für Mikro- und Nanotechnologien, Technische Universität Ilmenau, 98693 Ilmenau, Germany

We calculate the dielectric function of hexagonal GaN including the A-, B-, and C-excitons using a multi-valence band formalism. The importance of excitons for the interpretation of reflectance spectroscopy of GaN was emphasized by several experimental groups, but only recently theoretical calculations were presented [1]. We derive the dielectric function from a numerical solution of an initial value problem [2] via an exponential split-operator method, taking into account the full 6x6 valence band structures of several parametrizations. We present the complex dielectric function as well as the deduced reflectivity spectra of the excitons in GaN. These results show qualitative and quantitative agreement with recent experimental studies.

[1] A. T. Winzer, G. Gobsch, and R. Goldhahn, Phys. Rev. B **74**, 125207 (2006).

[2] S. Glutsch, *Excitons in Low−Dimensional Semiconductors*, Springer Heidelberg (2004).

[3] S. L. Chuang and C. S. Chang, Phys. Rev. B **54**, 2491 (1996).

HL 45.5 Wed 15:30 H15

Ortsaufgelöste Photolumineszenz- (PL), Elektrolumineszenz- (EL) und LBIC- (Light Beam Induced Current) Messungen an einer InGaN/GaN-LED auf Silizium(111)-Substrat — •Martin Thunert, Thomas Hempel, Armin Dadgar und Jürgen Christen — Otto-von-Guericke-Universität Magdeburg, Germany

Eine mittels MOVPE gewachsene InGaN/GaN-LED wurde anhand ortsaufgelöster EL-, PL- und LBIC-Messungen untersucht. Das Lumineszenzspektrum zeigt einen breiten Peak um 477 nm mit einer Halbwertsbreite von 0,14 eV. Durch auftretende Fabry-Perot-Interferenzen wurde die Schichtdicke der LED berechnet. Die EL-Messungen ergeben bei Stromstärkeerhöhung eine stärkere Intensitätszunahme des höherenergetischen Spektralbereiches relativ zum niederenergetischen.

Der Vergleich zwischen der EL- und der PL-Messung zeigt die unterschiedlichen Einflüsse der Ladungsträgerinjektion und -verteilung, sowie der Absorption auf die Lumineszenz der LED. Aus der Temperaturabhängigkeit der PL-Spektren wurden die Aktivierungsenergien zweier Prozesse berechnet, welche zu einem Abfall der PL-Intensität bei Temperaturerhöhung führen. Bei tiefen Temperaturen (4 K) wurde ein linearer Zusammenhang zwischen PL-Intensität und Anregungsdichte nachgewiesen.

Anhand der LBIC-Messung wurden elektrische Eigenschaften der LED in der Nähe des p-n-Übergangs untersucht. Vergleichende Messungen zeigen, dass Fehler in der Metallkontaktierung hohe Einbrüche der EL-Intensität verursachen, wohingegen sie das LBIC-Signal nicht beeinflussen.

15 Min. Coffee Break

HL 45.6 Wed 16:00 H15

Untersuchungen von gezielt belasteten, blauen InGaN-MQW-LEDs mittels EL, μ-EL, simultanem μ-PL/Raster-LBIC und FE-REM — •T. Fey, T. Hempel und J. Christen — Institut für Experimentelle Physik, Otto-von-Guericke-Universität, 39106 Magdeburg

Es wurden sowohl mechanisch als auch elektrisch belastete, kommerzielle, blaue InGaN-MQW-LEDs mittels EL, μ-EL, simultanem μ-PL/Raster-LBIC(Light Beam Induced Current) sowie FE-REM untersucht. Bei den mechanisch belasteten LEDs konnte sowohl im FE-REM als auch in der μ-EL kein eindeutiger Einfluss auf die Bauelemente nachgewiesen werden. Im Gegensatz dazu zeigten viele der elektrisch belasteten Proben eine inhomogene Intensitätsverteilung und

ein Ansteigen des Sperrstromes. Bei diesen geschädigten LEDs konnte in Sperrrichtung Lumineszenz detektiert werden. Diese Lumineszenz in Sperrrichtung steht in örtlicher Korrelation zu dunklen Bereichen in Durchlassrichtung. In Übereinstimmung dazu zeigen die simultanen μ-PL/LBIC Messungen ein deutliches Ansteigen des LBIC und ein Einbruch der MQW-Lumineszenz in diesen defekten Bereichen. Bei Untersuchungen einer defekten LED konnte ebenfalls Lumineszenz in Sperrrichtung mit gleicher spektraler Verteilung detektiert werden. Wir danken der Firma PerkinElmer Elcos GmbH für die freundliche Unterstützung.

HL 45.7 Wed 16:15 H15

Optical and structural investigations of pendeo-epitaxial AlGaN layers by spectrally resolved cathodoluminescence microscopy — •G. Schmidt[1], B. Bastek[1], T. Hempel[1], F. Bertram[1], J. Christen[1], V. Küller[2], A. Knauer[2], F. Brunner[2], H. Rodriguez[2], M. Weyers[2], and M. Kneissl[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Berlin, Germany

The ternary alloy AlGaN is a promising candidate for optoelectronic devices emitting in the deep UV. However, due to the large lattice and thermal mismatch, AlGaN layers grown on sapphire exhibit a high density of dislocations. In order to reduce this density AlGaN layers have been grown by pendeo-epitaxy. For this approach an AlN layer is directly grown on sapphire and subsequently patterned, resulting in a stripe structure parallel to [10$\underline{1}$0] with a trench width of 1.9μm and a ridge width of 1.1μm. The pattern was overgrown by a fully coalesced MOVPE AlGaN layer. We present the microscopic optical properties of the pendeo-epitaxial AlGaN layers. The spatially integrated cathodoluminescence (CL) spectrum exhibits two dominant peaks at 3.939eV and 4.326eV, respectively. Spatially resolved CL proved a correlation between the wavelength distribution and the trench pattern. The high energetic luminescence originates from the areas above the AlN ridges and the low energetic intensity from the area above the trenches, suggesting local different Al incorporation. Furthermore, the strain relaxation in growth direction is imaged by cross-sectional CL.

HL 45.8 Wed 16:30 H15

Dielectric function of AlInN nearly lattice-matched to GaN — •Egidijus Sakalauskas[1], Pascal Schley[1], Georg Rossbach[1], Rüdiger Goldhahn[1], Hannes Behmenburg[2,3], Christoph Giesen[2], Michael Heuken[2,3], Christoph Hums[4], and Alois Krost[4] — [1]Institut für Physik, TU Ilmenau — [2]Aixtron AG — [3]Institut für Theoretische Elektrotechnik, RWTH Aachen — [4]Institut für Experimentalphysik, Otto-von-Guericke Universität Magdeburg

$Al_{1-x}In_xN$ material with ∼18 % indium content is lattice matched to GaN and has lot of potential applications for photonic and electronic devices. In our work we carry out a comprehensive study of high-quality MOCVD-grown c-plane $Al_{1-x}In_xN$ films with In content ranging from 14 to 22 %. High resolution X-ray diffraction measurements revealed that AlInN films are pseudomorphically grown to GaN. Ellipsometry studies were conducted on the AlInN samples in the photon energy range from 1 to 10 eV. For the first time, complex effective ordinary dielectric function (DF) of AlInN nearly lattice-matched (LM) to GaN was extracted and the critical points of the band structure were determined. The pronounced optical transitions in the high-photon energy part of the DF indicate already promising optical quality of the AlInN films. The sharp onset of the imaginary part of the DF defines the direct absorption edge which is red-shifted for the AlInN samples with higher In content. High frequency dielectric constants were estimated from the real part of the DF in the transparent region. The band gap values are evaluated including the influence of strain.

HL 45.9 Wed 16:45 H15

Phase separation in AlGaN layers grown on SiN interlayers — •Kim Juliane Fujan[1], Benjamin Neuschl[1], Ingo Tischer[1], Martin Feneberg[1], Klaus Thonke[1], Martin Klein[2], Kamran Forghani[2], and Ferdinand Scholz[2] — [1]Institut für Halbleiterphysik, Universität Ulm, 89069 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89069 Ulm

For high quality AlGaN templates *in-situ* SiN interlayers are a possible method to decrease the dislocation density effectively. Immediately after such a SiN layer, the growth re-starts in a 3D-like mode, before the layers smoothen again. We report on a low temperature photoluminescence and cathodoluminescence study with high spatial resolution on a series of such AlGaN layer structures. We find signatures of anisotropic aluminum incorporation efficiency for different facets especially immediately after the interlayer deposition. In cathodoluminescence we directly can spatially resolve this phase separation, which vanishes for layer thicknesses of $\sim 1\,\mu$m and more. Influence of layer homogeneity (roughness) and possible growth mechanisms are discussed in detail.

HL 45.10 Wed 17:00 H15

Optical properties of homoepitaxial AlN — •Martin Feneberg[1], Benjamin Neuschl[1], Ramon Collazo[2], Anthony Rice[2], Zlatko Sitar[2], Jinqiao Xie[3], Seiji Mita[3], Georg Rossbach[4], Rüdiger Goldhahn[4], Marcus Roeppischer[5], Christoph Cobet[5], Norbert Esser[5], and Klaus Thonke[1] — [1]Institut für Halbleiterphysik, Universität Ulm — [2]Dept. of Mat. Sci. Engr., North Carolina State University, USA — [3]HexaTech, Inc., Morrisville, NC, USA — [4]Institut für Physik, TU Ilmenau — [5]ISAS, Berlin

Homoepitaxial c- and m-plane AlN layers, deposited by MOCVD on bulk PVT AlN are investigated by means of high resolution photoluminescence and spetroscopic ellipsometry. We find donor bound exciton lines with a full width at half maximum below 500μeV at T = 10 K. The exciton binding energy amounts to 52 meV in the c-plane sample leading to a bandgap energy of 6.092 eV (at 10 K). By spectroscopic ellipsometry we access both the ordinary and the extraordinary dielectric functions. The analysis of the sharp free exciton resonance found in the extraordinary tensor components yields a transition energy being in excellent agreement with the emission studies. The ordinary component exhibits a feature which indicates a strong contribution of exciton-phonon interaction to the absorption process.

HL 45.11 Wed 17:15 H15

Impact of stress on the optical properties of AlN layers — •Georg Rossbach[1], Pascal Schley[1], Gerhard Gobsch[1], Rüdiger Goldhahn[1], Marcus Röppischer[2], Christoph Werner[2], Christoph Cobet[2], Norbert Esser[2], Armin Dadgar[3], Matthias Wieneke[3], and Alois Krost[3] — [1]Technische Universität Ilmenau, Institut für Physik, PF 100565, 98684 Ilmenau — [2]Institute for Analytical Sciences (ISAS), 12489 Berlin — [3]Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, 39106 Magdeburg

The reversed valence-band (VB) ordering of wurtzite AlN with respect to GaN causes a strong dependence of the free excitonic transition energies on stress and a strong polarization anisotropy around the absorption edge. Here, we show that spectroscopic ellipsometry (0.9-9.8eV) is a powerful tool to determine both the ordinary and the extraordinary part of the dielectric function around the band edge of C-plane AlN layers. The investigations of films experiencing either tensile or compressive in-plane stress due to the growth on different substrates (Si, SiC and sapphire) allows us to demonstrate experimentally the stress dependence and anisotropy. The energy spacing of the three VBs at the center of the Brillouin zone is obtained from the analysis. The extracted shifts in energy are compared with the results of strain-dependent k*p calculations yielding in addition experimental values for the deformation potentials. Temperature-dependent studies reveal a strong influence of exciton-phonon interaction on the absorption.

HL 45.12 Wed 17:30 H15

Broadening mechanism of excitonic transitions in GaN nanowire ensembles — •Carsten Pfüller, Oliver Brandt, Caroline Chèze, Lutz Geelhaar, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

Nanowires (NWs) offer the possibility to integrate III/V and II/IV semiconductors of high crystalline quality even on lattice mismatched substrates such as silicon.

We investigate the photoluminescence (PL) of GaN NWs grown by plasma-assisted molecular beam epitaxy on a Si(111) substrate. The energy of the donor-bound exciton emission at 3.472 eV confirms the NWs to be unstrained. Its linewidth is typically of the order of 3 meV, which is much broader than expected for a strain-free semiconductor.

PL spectra of single NWs dispersed onto a Si(111) vary widely from wire to wire and differ significantly from ensemble spectra. While the majority of dispersed NWs experiences strain from interaction with the substrate, a few NWs exhibit sharper excitonic lines than the ensemble. These lines comprise the donor-bound exciton and free exciton emission of strainfree GaN as well as a set of sharp transitions at 3.475-3.476 eV. The same transitions are observed for as-grown, low density NW ensembles. We attribute these high-energy lines to recombination of excitons bound to surface donors. The statistically distributed distances of these donors to the surface determines the spectral energy

of the related exciton recombination and thus provide a natural explanation for the unusual broad luminescence of the unstrained NW ensemble.