HL 47: GaN: preparation and characterization I

Time: Thursday 14:00–17:30 Location: EW 202

HL 47.1 Thu 14:00 EW 202

Wachstum verspannungskompensierter AlGaN/GaN-Bragg-Spiegel mittels MOVPE — •Heiko Dartsch, Stephan Figge, Timo Aschenbrenner und Detlef Hommel — IFP, Universität Bremen, Otto-Hahn-Allee, 28359 Bremen

Zur Herstellung oberflächenemittierender Laserdioden (VCSEL) ist der Einsatz von hochreflektierenden Bragg-Spiegeln (DBRs) nötig. Für auf Galliumnitrid basierende Bauelemente bietet sich die Verwendung von Aluminium zur Herstellung der Niederindexschichten an. Dabei sind grundsätzlich zwei Vorgehensweisen denkbar: Zum einen in Form einer ternären AlGaN-Verbindung und zum anderen die Verwendung eines Übergitters bestehend aus binärem AlN und GaN.

Beide Ansätze wurden mittels metallorganischer Dampfphasenepitaxie (MOVPE) verfolgt. Einen entscheidenden Einfluß auf die Qualität der hergestellten Spiegel hat die Gitterfehlanpassung zwischen den Hoch- und Niederindexschichten, welche bei höheren Aluminiumgehalten zur Relaxation der Schichten führen kann. So weisen auf GaN-Templates gewachsene Strukturen mit ternärem Niederindexmaterial mit einer Aluminiumkonzentration von 20% bereits in hohem Maße Rissbildung auf. Durch die Verwendung einer Pufferschicht mit einem Aluminiumgehalt von 20% gelingt es hingegen vollverspannte DBR-Strukturen herzustellen, deren Niederindexmaterial 40% Aluminium enthält. Mit diesem Ansatz sind Spiegel mit Reflektivitäten von über 90% im Wellenlängenbereich um 500 nm realisiert worden. Auf der gleichen Grundlage ließen sich zudem dazu qualitativ vergleichbare DBRs mit binärer Übergitterstruktur als Niederindexschicht herstellen.

HL 47.2 Thu 14:15 EW 202

Defect structure in m-plane GaN grown on $LiAlO_2$ using metalorganic and hydride vapour phase epitaxy — •Tim Wernicke[1], Anna Mogliatenko[3], Carsten Netzel[1], Eberhard Richter[1], Arne Knauer[1], Frank Brunner[1], Markus Weyers[1], Wolfgang Neumann[3], and Michael Kneissl[1,2] — [1]FBH Berlin, Germany — [2]Institute of Solid State Physics, TU Berlin, Germany — [3]AG Kristallographie, Institut für Physik, HU Berlin, Germany

The FWHM of symmetric $(10\bar{1}0)$ XRD rocking curves of m-plane GaN grown on $LiAlO_2$ is anisotropic. By investigating the microstructure with transmission electron microscopy (TEM) we identifid basal plane stacking faults (BSF) and stacking mismatch boundaries (SMB) in the GaN layers. BSFs are aligned in-plane along the a-direction and therefore cause an anisotropic broadening of the $FWHM_{(10\bar{1}0)}$ with incidence along [0001]. SMBs have no preferential direction and hence result in an isotropic broadening of the $FWHM_{(10\bar{1}0)}$. We observed that this anisotropy can be reduced by lowering the MOVPE growth temperature. We propose that the lowering of the growth temperature leads to a reduction of BSFs which is accompanied by an increase in SMBs. The MOVPE grown layers were used as templates for the growth of 200 μm thick m-plane GaN layers by HVPE. During HVPE growth the $LiAlO_2$ substrate thermally decomposed and peeled off after cool-down. On the surface a network of cracks not being aligned to crystallographic directions was found. The layers were not transparent probably due to metallic Ga inclusions and exhibited an asymmetric bow according to the lattice anisotropy of the (100) $LiAlO_2$ surface.

HL 47.3 Thu 14:30 EW 202

Bestimmung der temperaturabhängigen thermischen Ausdehnungskoeffizienten von AlN — •Hanno Kröncke[1], Stephan Figge[1], Boris M. Epelbaum[2] und Detlef Hommel[1] — [1]Institut für Festkörperphysik, Universität Bremen, Otto-Hahn-Allee 1, 28359 Bremen — [2]Institut für Materialwissenschaften 6, Universität Erlangen, Martensstr. 7, 91058 Erlangen

Auf Grund der großen Bandlücke von 6,2 eV, der Härte und der Temperaturstabilität ist Aluminiumnitrid (AlN) von großem Interesse für optische Anwendungen bis in den UV-Bereich und für Hochleistungselektronik. Die Verwendung für heteroepitaktische Bauelemente scheitert bisher jedoch an der Verfügbarkeit hochqualitativer Substrate. Für eine künftige Anwendung sind daher Verspannungen und thermische Ausdehnung der Materialien von hohem Interesse.

Untersucht wurden in dieser Studie durch PVT (physical vapor transport) auf einem Substrat und auch freistehend gewachsene AlN Kristalle mittels hochauflösender Röntgendiffraktometrie. Für das Volumenmaterial wurden die c- und a- Gitterkonstanten über einen Temperaturbereich von 20 bis 1200 K vermessen. Aus diesen wurden die anisotropen, temperaturabhängigen, thermischen Ausdehnungskoeffizienten bestimmt, die aus früheren Untersuchungen nur richtungsunabhängig bekannt waren. Die Daten wurden mit Hilfe von Debye- und Einsteinmodellen angepasst und mit Werten aus anderen Verfahren verglichen. Weiterhin wurden die auf Substrat mit den freistehend gewachsenen Proben hinsichtlich Mosaizität und Korngröße verglichen.

HL 47.4 Thu 14:45 EW 202

Einfluss einer SiN-Maske auf die Qualität von a-plane GaN auf r-plane Saphir — •M. Wieneke, A. Dadgar, J. Bläsing, H. Witte, A. Krtschil, T. Hempel, P. Veit, J. Christen und A. Krost — Otto-von-Guericke-Universität Magdeburg, Postfach 4120, 39016 Magdeburg

In einer Probenserie wurde unter Variation der Abscheidedauer einer SiN-Zwischenschicht deren Einfluss auf die Beschaffenheit von a-plane GaN-Schichten untersucht, die mittels metallorganischer Gasphasenepitaxie auf r-plane Saphir gewachsen wurden. Bei längeren Beschichtungsdauern zeigen Lichtmikroskop-Aufnahmen eine deutliche Zunahme der Pit-Dichte, während die Charakterisierung der Proben mittels Röntgenbeugung eine Reduktion der ω-Halbwertsbreiten der GaN(11-20), -(10-10) und -(0002)-Reflexe jeweils von 0.25°, 0.50° und 0.40° auf 0.15°, 0.30° und 0.20° ergab. Mittels Transmissionselektronenmikroskopie konnten lokale Reduktionen der Halbversetzungen und Stapelfehler gezeigt werden. C-V-Messungen ergeben eine Netto-Störstellenkonzentration von (2-3)*10^{15} cm^{-3} auf der Oberfläche, während Halleffektmessungen Ladungsträgerkonzentrationen im Bereich von 10^{17} - 10^{18} cm^{-3} zeigen. Dies deutet auf die Auflösung der SiN-Masken und die damit verbundene Si-Dotierung an der Grenzfläche zum Substrat hin. Temperaturabhängige Halleffektmessungen weisen zwei thermische Aktivierungsenergien des Hallkoeffizienten in den Bereichen von 15-26 meV bei tiefen Temperaturen und 42-60 meV bei hohen Temperaturen auf, was auf die Dotierung mit Si und auf Stickstoffvakanzen zurückgeführt wird.

HL 47.5 Thu 15:00 EW 202

InGaN Pyramids: Towards positioned quantum dots — •Clemens Wächter, Michael Jetter, Gareth Beirne, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Allmandring 3, 70569 Stuttgart, Germany

InGaN quantum dots (QDs) are of high interest for quantum optics due to their large exciton binding energies, even more if the quantity of the QDs is controllable and the position is well known. This can be achieved for example by growing QDs on prepatterned substrates. In the nitride material system this prepattering can be reached by selective epitaxy of hexagonal pyramids on a SiO_2-masked GaN-template. The InGaN material is then deposited on these substrates, forming low dimensional structures on these pyramids. However, the research regarding these structures is still in progress. In this talk the recent efforts and results will be presented. Samples were prepared with varying InGaN growth temperature, growth pressure, cap structures and pyramid sizes. These samples were characterized using optical microscopy, scanning electron microscopy, time resolved (micro-)photoluminescense spectroscopy and cathodoluminescense spectroscopy. Using all these informations the current status and future developments will be presented.

HL 47.6 Thu 15:15 EW 202

Optical and magnetic properties of different Mn centers in GaMnN — •Enno Malguth, Axel Hoffmann, and Wolfgang Gehlhoff — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

The potential realization of a ferromagnetic spin-coupling in dilute magnetic semiconductors requires a wide band gap material doped with magnetic ions and with a high concentration of free carriers. Against this background, optical and magnetic experiments were performed on GaMnN samples co-doped with Mg and Si. We observed Mn in the charge states 2+, 3+ and 4+. In detail, we studied the stability of these charge states as a function of the concentration of Mn and of p- or n- co-doping. Our observations can be explained coherently by a shift of the Fermi level. A number of different Mn^{4+} centers were observed in photo luminescence spectra. We give a tentative identifi-

cation of Mn^{4+} related complexes on the basis of temperature, excitation and magnetic field dependent measurements as well as electron spin resonance. Excitation mechanisms of Mn^{4+} were investigated by means of photo luminescence excitation spectroscopy indicating that the internal excitation of Mn^{3+} may be part of an efficient excitation process.

HL 47.7 Thu 15:30 EW 202

Herstellung und Implantation von ^{172}Lu(^{172}Yb) in GaN und Messung bei tiefen Temperaturen — •Riccardo Valentini und Reiner Vianden — Helmholtz - Institut für Strahlen- und Kernphysik, Nußallee 14-16, 53115 Bonn

Für optoelektronische Bauteile werden Halbleiter mit großer Bandlücke verwendet, die mit Seltenen Erden dotiert sind. Um deren Verhalten nach der Implantation zu untersuchen, hat sich die Methode der γ-γ-Winkelkorrelation (PAC) bewährt. Ein geeignetes Isotop zur Untersuchung solcher Halbleiter ist ^{172}Yb.

Die Herstellung des Mutterisotops ^{172}Lu erfolgt durch Bestrahlung einer Thulium-Folie mit ^{4}He, ^{169}Tm(α,n)^{172}Lu, am Bonner Isochron-Zyklotron und die Implantation in GaN am Bonner Isotopenseparator, d.h. Herstellung und Implantation finden vor Ort statt.

Es soll die Temperaturabhängigkeit der Hyperfeinfelder für ^{172}Lu(^{172}Yb) in GaN untersucht werden. Wir führen Messungen bei tiefen Temperaturen zwischen 75 K und 295 K in einem Displex durch. Zu erwarten ist generell eine Zunahme der Wechselwirkungsfrequenz. Der Verlauf bei Temperaturen um 100 K konnte bisher noch nicht eindeutig geklärt werden. Die Messungen werden auf einer PAC-Anlage durchgeführt, die das Material LSO als Szintillator benutzt. Dadurch kann eine bessere Energieauflösung, eine höhere Anisotropie und eine kürzere Messzeit als mit anderen Szintillatormaterialien erzielt werden.

15 min. break

HL 47.8 Thu 16:00 EW 202

Recombination dynamics in coalesced a-plane GaN ELO structures investigated by high spatially and ps-time-resolved cathodoluminescence microscopy — •B. Bastek[1], F. Bertram[1], J. Christen[1], T. Wernicke[2], M. Weyers[2], and M. Kneissl[3] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg — [2]Ferdinand-Braun-Institut für Höchstfrequenztechnik, Berlin — [3]Institute of Solid State Physics, Technical University Berlin

The characteristic epitaxial lateral overgrowth (ELO) domains of fully coalesced a-plane GaN layers were directly imaged by highly spatially and spectrally resolved cathodoluminescence microscopy (CL) at 5 K. The patterned layers were grown by MOVPE on r-plane sapphire substrate and stripe masks oriented in the [01$\bar{1}$0] direction. In the area of coherent growth (I) the broad basal plane stacking fault (BSF) emission centered at 3.41 eV dominates the spectra. Also in the region (II) of coalescence the BSF luminescence dominates, however, the intensity increases by one order of magnitude compared to area (I). In complete contrast, in the stripes associated with the laterally grown domains (III) in [0001] direction, exclusively an intense and sharp (D^0,X) emission at 3.475 eV is observed. ps-time-resolved CL of the free excitons (FX) recorded from this domains (III) decays bi-exponentially. The initial lifetime of 180 ps is primarily given by the capture of FX by impurities to form bound excitons (BE). With rising temperature this capture time constant decreases as $T^{-1/4}$ and reaches a minimum of 104 ps at T = 60 K. Above 60 K, i.e. when FX starts to dominate the BEs, the lifetime increases rapidly to a value of 240 ps for 300 K.

HL 47.9 Thu 16:15 EW 202

Influence of strain on the growth of thick InGaN layers — •J. Stellmach, M. Leyer, M. Pristovsek, and M. Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

The growth of high quality InGaN alloys is critical for a number of various optoelectronic device applications like LEDs and laser diodes. Nevertheless, the exact growth mechanisms of InGaN with high indium content is still not fully understood.

In the present study the growth of thick InGaN layers was systematically investigated. InGaN films with thicknesses between $\sim$35 nm and $\sim$200 nm were grown on GaN templates with metal-organic vapour phase epitaxy (MOVPE). The group III partial pressures of 1.1 Pa for TMGa, 0.45 Pa for TMIn and the V/III-ratio of 1600 were kept constant. The growth temperature was varied between 750 °C and 800 °C. The growth of InGaN layer was characterized by in-situ spectroscopic ellipsometry (SE). Up to temperatures of 790 °C structural analysis by XRD showed two strained layers with different indium content. The formation of the layer structure was investigated by varying the growth times at 770 °C. In the first 500 s (35 nm) a rough (rms=9 nm) and pseudomorphically strained InGaN layer with low indium content (4 %) is formed. Between 500 s and 1000 s this strained layer becomes smoother (rms=3.4 nm). For thicknesses beyond the In content increases (8 % at 84 nm) and reaches 11 % at 200 nm. We propose that the transition from a first layer with a low indium content to a second layer with an higer indium content is due to a gradual release of strain.

HL 47.10 Thu 16:30 EW 202

Spatially and spectrally resolved cathodoluminescence of hexagonal GaN pyramids covered by InGaN single quantum wells — •S. Metzner[1], B. Bastek[1], F. Bertram[1], T. Hempel[1], J. Christen[1], M. Jetter[2], T. Tsifotidis[2], and P. Michler[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institut fuer Halbleiteroptik und Funktionelle Grenzflaechen, Stuttgart University, Germany

Masking with polystyrene micro spheres, self organized hexagonal GaN pyramids terminated by the six {1$\bar{1}$01} facets were selectively grown by metal-organic vapor phase epitaxy. An InGaN single quantum well (SQW) capped with a GaN layer was deposited on top. The spatially averaged cathodoluminescence (CL) spectrum shows an intense (D^0,X) line from GaN and a broad emission band between 2.0 - 2.6 eV originating from the InGaN SQW. The CL from the masked area reveals a blue-shifted (D^0,X) GaN emission at 3.4925 eV (FWHM = 5.8 meV) corresponding to a compressive stress of 0.8 GPa. In contrast, the (D^0,X) GaN emission of the pyramid facets is more intense, broadened, and red-shifted with respect to fully relaxed GaN. This red-shift decreases from base (3.4398 eV) to top of the pyramids by about 20 meV, indicating strain relaxation and strong local impurity incorporation at the slower growing facets. The InGaN luminescence exclusively emitted on the pyramids shows a monotonous blue-shift of about 100 meV from base (2.3542 eV) to top of the facets. Smaller SQW thickness and/or lower In content can explain the observed blue-shift towards the tip. The impact of polarization fields further enhances this effect.

HL 47.11 Thu 16:45 EW 202

MOVPE of m-plane InGaN/GaN buffer and LED structures on $LiAlO_2$ — Hannes Behmenburg[1], Tzu-Chi Wen[2], Yilmaz Dikme[1], Christof Mauder[2], Lars Khoshroo[2], Mitch Chou[3], Mikalai Rzheutskii[4], Evgenii Lutsenko[4], Gennadii Yablonskii[4], Joachim Woitok[5], Holger Kalisch[2], Rolf Jansen[2], and •Michael Heuken[1,2] — [1]AIXTRON AG, Aachen, Germany — [2]Electrom. Theory, RWTH Aachen, Germany — [3]Mat. Sci. & Opto-Elect. Eng., Sun Yat-Sen Univ., Taiwan — [4]Inst. of Phys., NASB, Minsk, Belarus — [5]PANalytical B.V., Almelo, The Netherlands

M-plane GaN growth on $LiAlO_2$(100) is one possibility to deposit nonpolar material and leads to a more efficient recombination in MQW structure. A short in-situ nitridation in a nitrogen/ammonia atmosphere as the first step is essential for the deposition of GaN in the m-plane mode. The surface was sealed with a thin Mg-doped InGaN layer. A 220 nm thick GaN:Mg and a 500 nm thick GaN layer to protect the sensitive substrate grown under H2 atmosphere complete the investigated buffer. In 2Theta/Omega scans only m-plane GaN was detected, and rocking curves of the symmetric (1-100) reflex revealed an improvement in quality with increasing thickness of the InGaN:Mg layer up to 100 nm. Above this critical thickness, the line width deteriorated. The same trend was observed by AFM measurements which showed a minimum surface roughness of 11.4 nm root mean square. Blue InGaN LED structures on such buffers showed photoluminescence wavelengths which were independent of excitation intensity and exhibited a high degree of polarization.

HL 47.12 Thu 17:00 EW 202

Cathodoluminescence Microscopy of GaN Nanopyramids grown on Si(111) — •F. Bertram[1], S. Metzner[1], J. Christen[1], H. Tang[2], J. Lapointe[2], and J.A. Bardwell[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]nstitute for Microstructural Sciences, National Research Council Canada, Ottawa, Canada

A 10 nm thick AlN buffer MBE grown on Si(111) was patterned into an array of hexagonal pads with openings from 0.5 to 1.5 um. The subsequent GaN overgrowth was carried out in both, the vertical and the lateral direction forming distinct GaN nanopyramids terminated by {10-12} side facets. The GaN pyramids were covered with an InGaN

quantum well for the purpose to form an InGaN quantum dot at the very top. A lateral pyramid size of about 1 um and a height of about 800 nm is obtained independent from the mask size. The spatially integrated cathodoluminescence (CL) spectrum of a single pyramid at 5 K exhibits multiple sharp emission lines over a wide spectral range from 357 to 500nm. No CL emission was observed outside the pyramids. Intensity mappings across the pyramids show clear 6 fold symmetry. The intensity drops significantly at the edges of the pyramid. The top region of the pyramids exhibit a bright hexagonally shaped contrast dominated by GaN emission. On the contrary, the InGaN luminescence is very intense at the base of the pyramids. The InGaN intensity decreases and the emission blue-shifts from 405 to 375nm, from the base to the top of the pyramid.

HL 47.13 Thu 17:15 EW 202

Thermodynamics and adatom kinetics of non-polar GaN surfaces. — •Liverios Lymperakis and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung, Max-Planck-Strasse 1, 40237, Düsseldorf, Germany

III-Nitride based nanowires have recently attracted considerable interest due to their potential applications for novel nano-optoelectronic devices. The shape and size of the nanostructure as well as the quality of the grown material depends strongly on the atomistic mechanisms taking place on the facets of the nanowires during growth. GaN nanowires usually grow having the c-axis as axial direction while the side facets are expected to exhibit non-polar surfaces. While extensive and detailed theoretical studies on the thermodynamics and kinetics of the polar c-plane GaN surfaces exist, a detailed analysis which will combine thermodynamics and kinetics of the non-polar α- and m-plane surfaces is still lacking. We have therefore performed planewave pseudopotential calculations within the density functional theory in order to study the thermodynamics and the adatom kinetics on α- and m-plane GaN surfaces. The mapping of the potential energy surface for the Ga adatoms (minority species for N rich growth) reveals a strong anisotropy for the diffusion barriers for both a- and m-plane surfaces. For N adatoms (minority species for Ga rich growth) our results show a subsurface diffusion channel which becomes activated already at low growth temperatures. Based on these results we have been able to explain recent experimental observations on the growth anisotropy of GaN non-polar surfaces as well as on the growth of GaN nanowires.