DF 26: Metamorphic structures: Bringing together incompatible materials I (Joint Focus Session with HL and DS)

This session is devoted to the challenge to epitaxially combine materials, which differ strongly in their basic properties like lattice constant or symmetry and hence seem to be incompatible. It shall provide a discussion forum about understanding, how such material combinations can be grown with high yield, i.e. low defect densities in the final active region, in order to realize device structures of a given material system on a substrate of another system. Examples where such combinations are needed are materials, where adequate substrates are not available, like In-rich GaInN structures for green light emitting devices on GaN, or complex device structures like multi-junction solar cells requiring the combination of incompatible layers.

Organizers: Ferdinand Scholz, Universität Ulm, and Andreas Hangleiter, TU Braunschweig.

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

Topical Talk DF 26.1 Thu 9:30 POT 251

Metamorphic III-V-on-IV structures and its application to optoelectronic devices — Yoshiaki Nakano, •Masakazu Sugiyama, and Takuo Tanemura — Department of Electrical Engineering and Information Systems, University of Tokyo, Japan

There has been a considerable interest to combine merits of different III-V semiconductors with group IV-based materials and devices. One obvious example is the integration of InGaAs FETs with Si MOSFETS for enhancing CMOS performance. Another example is the "silicon photonics" where III-V materials are integrated on silicon substrates to have them perform light emission and control functions. Such integration is brought about by either heteroepitaxy or wafer bonding. The former is regarded better in terms of manufacturablity but in general more difficult than the latter, and therefore, its applicability has been limited. In this talk, our trial of integrating III-nitrides and III-phosphides/arsenides on silicon and germanium by metal-organic vapor phase epitaxy and wafer bonding is reviewed, together with its application to light emitting, controlling, and receiving devices, including micro lasers on Si and multi-junction solar cells.

Topical Talk DF 26.2 Thu 10:00 POT 251

Two types of buffer layer for the growth of GaN on highly lattice mismatched substrates and their impact on the development of sustainable systems — Tadashi Mitsunari[1], Koji Okuno[1], Yoshio Honda[1], Shigeyasu Tanaka[2], and •Hiroshi Amano[1,3] — [1]Department of Electrical Engineering and Computer Science, Nagoya University — [2]EcoTopia Science Institute, Nagoya University — [3]Akasaki Research Center, Nagoya University

There are two types of buffer layer for the growth of commercially available GaN-based blue LEDs on a sapphire substrate. One is the low-temperature deposited AlN or GaN buffer layer and the other is the sputter-deposited AlN buffer layer. In both cases, deposition condition, thickness and the annealing condition are critical for the fabrication of high performance blue LEDs. In this presentation, detailed study on the deposition and growth process of the low-temperature deposited AlN buffer layer and the following GaN growth will be discussed. We applied the sputter-deposited AlN buffer layer for the growth of GaN on Si. Details of the quality of GaN on a sputter-deposited AlN layer will be shown.

DF 26.3 Thu 10:30 POT 251

Influence of the substrate quality on the structural properties of short-period GaN/AlGaN superlattices grown by MBE — •Felix Schubert[1], Ulrich Merkel[2], Thomas Mikolajick[1,2], and Stefan Schmult[2] — [1]NaMLab gGmbH, Nöthnitzer Straße 64, D-01187 Dresden — [2]Institute of Semiconductor and Microsystems, TU Dresden, Nöthnitzer Straße 64, D-01187 Dresden

Short-period AlGaN/GaN superlattices have been established as versatile test structures to investigate the influence of the GaN substrate quality on the structural properties of AlGaN/GaN heterostructures. Of particular interest are surface roughness, layer accuracy and aluminum mole fraction in the MBE-grown superlattices. A variety of GaN substrates prepared by MBE, MOCVD, HVPE and ammothermal growth was investigated. For the best substrate quality theoretically expected properties like narrow high-order satellite peaks and interface fringes can be recovered from high resolution x-ray diffraction scans of the superlattices.

DF 26.4 Thu 10:45 POT 251

Strain engineering in a-plane GaN - Investigations on anisotropic strain behaviors — •Matthias Wieneke, Martin Feneberg, Michael Winkler, Peter Veit, Armin Dadgar, Jürgen Bläsing, Rüdiger Goldhahn, and Alois Krost — Otto-von-Guericke-Universität Magdeburg, FNW/IEP, Universitätsplatz 2, 39106 Magdeburg

The use of low temperature AlN interlayers (LT AlN) is a successful technique to prevent crack formation in thick c-plane GaN films, but also to reduce the density of basal plane stacking faults in semipolar GaN. Here, we studied the impact of LT AlN on a-plane GaN films grown by metal-organic vapor-phase epitaxy on 2-inch r-plane sapphire substrates. The curvature increases during the growth of tensely-strained a-plane GaN buffer layers, while it decreases after inserting LT AlN. However, an increasing asphericity evaluated by a 3-spot-curvature measurement indicates an anisotropic strain relaxation. Consequently, after cooling-down various ex-situ X-ray diffraction (XRD) measurements reveal an increase in compressive strain along the in-plane GaN m-direction, while it marginally decreases along the in-plane GaN c-direction for layers with a LT AlN interlayer. The non-biaxial strain behavior mirrors in energy shifts of the characteristic photoluminescence features which is compared to the results of 4-band $\mathbf{k}\cdot\mathbf{p}$ theory. Furthermore, XRD and transmission electron microscopy measurements exhibit a degradation in the crystalline quality of GaN layers grown on LT AlN interlayer.

DF 26.5 Thu 11:00 POT 251

Growth and characterization of non- and semipolar AlInN and possibilities for relaxed buffer layer engineering — •Ernst Ronald Buss[1], Uwe Rossow[1], Heiko Bremers[1], Tobias Meisch[2], Ferdinand Scholz[2], and Andreas Hangleiter[1] — [1]Institute of Applied Physics, TU Braunschweig, Germany — [2]Institute of Optoelectronics, Ulm University, Germany

The different a/c-ratios of group-III-nitrides open the possibility of strain engineering for relaxed buffer layers of AlInN in non- and semipolar GaN based structures. In this contribution, we present the very first results on low pressure MOVPE grown AlInN on semipolar $(11\bar{2}2)$ GaN templates, m-plane GaN templates, as well as m-plane pseudo-bulk GaN substrates. AlInN layers exhibit a macroscopic tilt due to the activation of basal plane slip for all non-c-plane orientations. For the m-plane case we will show that there is no shear of the unit cells of the different layers of the sample. Growth rates and indium incorporation efficiencies of m-plane and $(11\bar{2}2)$ oriented material could be estimated to be similar and the same as on c-plane GaN. While c- and m-plane AlInN shows extreme roughening with increasing layer thickness, $(11\bar{2}2)$ AlInN does not. Furthermore, we will present first experiments demonstrating a proof of concept of the specific relaxation of AlInN in different in-plane directions for $(11\bar{2}2)$ orientation. Depending on the indium content we are able to initiate relaxation only in $[1\bar{1}00]$ direction for 18% of indium, or $[11\bar{2}\bar{3}]$ direction for 28% of indium, respectively. All these results make AlInN quite promising for relaxed buffer layers and strain engineering for further growth.

Coffee break (15 min.)

Topical Talk DF 26.6 Thu 11:30 POT 251

Development of High Performance Semipolar GaN-based Blue and Green Lasers: Control of Stress Relaxation — •James Speck — UCSB Materials Department, Santa Barbara, CA USA

Nonpolar and semipolar GaN-based emitters have demonstrated low droop for LEDs and high performance for laser diodes. In this talk, we present two approaches to high performance blue and green laser diodes: the first using intentionally relaxed InGaN buffer layers for (11-22) oriented laser diodes and the second using selective area growth for (20-21) laser diodes.

For the relaxed (11-22) lasers we used strain compensated AlGaN/InGaN superlattice electron/hole blocking layers on intentionally relaxed InGaN buffer layers. Using this design, lasing at 447 nm was achieved with a threshold currentdensity of 7.2 kA/cm2, which is remarkably lower than previous results. Furthermore, wedemonstrate a 497 nm aquamarine-emitting semipolar (11-22)laser diode under pulsed operation.

For the coherent (20-21) lasers we used limited area epitaxy to minimize the misfit dislocation (MD) formation by preventing pre-existing TDs from entering a patterned mesa. Significant MD formation was suppressed by at least a factor of four for Al0.1Ga0.9N/GaN superlattices, enabling AlGaN-clad structures similar to those used in c-plane LDs. We then demonstrate AlGaN-clad blue (456 nm) LDs with threshold current density (Jth) of 4.5 kA/cm2 and GaN-clad true green (523 nm) LDs with Jth of 12 kA/cm2.

DF 26.7 Thu 12:00 POT 251

Improved X-ray diffraction simulations taking into account inhomogeneities exceeding the coherence length — •Christoph Berger, Dennis Schmidt, Jürgen Bläsing, Armin Dadgar, and Alois Krost — Otto-von-Guericke-Universität, Magdeburg, Deutschland

In many cases simulated diffraction patterns of semiconductor thin films or superlattices differ significantly from experimental data. The reason is that structural imperfections are often neglected in the simulation model. Indeed, many software packages can include the influence of compositional or thickness variations, but these variations occur on a shorter length scale than the coherence length of the diffractometer and have to be treated by dynamical theory. Including these influences often does not improve the simulation result. Due to the large area that is usually probed by the X-ray beam, one has to take into account structural variations larger than the coherence length as well, for instance lateral gradients across the wafer. These variations can be described by a sum of the diffracted intensity from the different parts of the specimen. In our method, a series of ideal simulations, each multiplied with a weighting factor, is summed up by a MATLAB routine that minimizes the deviation between the measurement and the sum of the weighted ideal simulations. The distribution of the weighting factors enables the estimation of the lateral variation width within the sample and the fit between simulated and experimental data is significantly improved.

DF 26.8 Thu 12:15 POT 251

Interactions between dislocations and overgrown v-shaped defects in GaN epitaxial layers — Phillip Weidlich[1], Michael Schnedler[1], Holger Eisele[2], Rafal E. Dunin-Borkowski[1], and •Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Due to the lack of large bulk substrates, most group III-nitride epitaxial layers have to be deposited on lattice-and thermal-mismatched substrates. The mismatch induces high dislocation concentrations. A variety of methods were invented to reduce the dislocation concentration in epitaxial GaN. Their common principle is the introduction of interfaces or inclined growth facets, which influence the line directions of threading dislocations. Inclined growth facets are also introduced by one of the most common extended defect in GaN layers, so called v-shaped defects. Therefore, we investigate the interactions between dislocations and v-shaped defects by mapping the spatial distribution and projected line directions of dislocations intersecting a cross-sectional (10-10) cleavage plane of GaN epitaxial layers using STM. The data is correlated with the spatial positions of v-shaped defects. The dislocations are found to be bent away from the inclined semipolar facets of v-shaped defects, due to a strain-induced repulsive interaction. The dislocation distribution is characterized by agglomerations and intersecting bundles of dislocations with parallel projected line directions, stabilized by many-body effects in the repulsive strain interactions.

DF 26.9 Thu 12:30 POT 251

Optical and structural investigations of the effect of barrier growth on GaInN quantum well structures — •Fedor Alexej Ketzer, Heiko Bremers, Torsten Langer, Uwe Rossow und Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

We study the influence of the growth of the barriers in GaInN multiple quantum wells (MQW) on structural and optical parameters of the wells. Therefore several MQWs were grown via low pressure MOVPE. Because the growth with H_2 as carrier gas is known to impede the incorporation of indium but is necessary during the growth of other layers, and therefore present in the reactor and structure, we investigate the effects of H_2 on the structure. We compare MQWs with different additional H_2 buffer gas flows during barrier growth with our reference samples with N_2 carrier gas. The growth parameters for the wells of all samples remain unchanged and lead to a nominal thickness of 2 nm with an indium content of 18 %. While the well thickness and indium content determined by photoluminescence do not differ for the reference samples without and the samples with H_2 buffer gas, the data of high resolution X-ray diffraction contradicts at a first glance. Here we see a drastically lower effective indium content of 7 %. This can only be explained by a strong inhomogeneity of the quantum wells and that only a small fraction of the quantum well area remains after growth. The influence of these inhomogeneities on the optical parameters and the internal quantum efficiency is discussed in detail.

DF 26.10 Thu 12:45 POT 251

Metamorphic growth of UV-B LEDs on $Al_{0.5}Ga_{0.5}N$ on AlN/Sapphire by MOVPE — •Johannes Enslin[1], Frank Mehnke[1], Martin Guttmann[1], Christoph Reich[1], Jens Rass[1,2], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Univerät Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

For AlGaN-based LEDs emitting in the UV-B spectral region between 280 nm and 320 nm relaxed buffer layers enable pseudomorphic growth of the multiple quantum well active region. In our contribution we present a study of the effects of various superlattice designs on pseudomorphic growth. The superlattice consists of 80 periods of AlN and GaN layers. We found that the thickness of the GaN layer and the relative AlN to GaN layer thicknesses (i.e. AlN/GaN ratio) are crucial for the relaxation process. 4.5 μm thick $Al_{0.5}Ga_{0.5}N$ with an AlN/GaN ratio of one exhibits high densities of pits and cracks. LEDs grown on this layer show no luminescence most likely due to these defects. UV-B LEDs grown on templates with AlN/GaN ratios ≤ 0.4 exhibit fewer pits and no cracks, but show only poor luminescence. A smooth morphology was obtained for GaN thicknesses ≤ 2 nm and AlN/GaN ratios between 0.4 and 0.8. XRD scans show a distinct superlattice reflection. Reduced densities of pits and cracks indicate metamorphic growth. The optical emission power obtained from 305 nm LEDs grown on those layers reaches values up to 2.3 mW at 60 mA.