HL 72: Focus Session: Extended defects in semi- and nonpolar GaN I

Semipolar GaN was sucessfully used for the realization of the green laser diode and is also a promising material for LEDs, due to the changed symmetry and binding configuration on the surface. However, growth on large area low cost substrates like sapphire typically leads to the formation of a high density of extendend defects, especially stacking faults and threading dislocations. These defects can be also formed by strain relaxation of heterostructures grown on GaN substrates with low defect density. This focus session aims to explain the mechanism for formation, methods of identification and growth methods for reduction of such defects as well as optoelectronic devices grown defect reduced GaN. (Organizers: Ulrich Schwarz, Fraunhofer IAF Freiburg, Tim Wernicke, TU Berlin)
Morning session: Origin and identification and reduction of defects in semipolar GaN / Semipolar heterostructures and devices

Time: Thursday 9:30–13:15 Location: H13

Topical Talk HL 72.1 Thu 9:30 H13
Defect reduction methods for GaN heteroepitaxial films grown along semipolar orientations — •Philippe Vennéguès — Centre de Recherche sur l'Heteroepitaxis et ses Applications, rue Bernard Gregory 06560 VALBONNE FRANCE

Heteroepitaxially-grown semipolar GaN films contain a high density of extended structural defects, mainly basal stacking faults, which prohibit their use for the fabrication of efficient optoelectronic devices. After a short description of the microstructure and of the origin of the crystalline defects, this presentation will focus on a few methods which have been developed to improve the crystalline quality. Thanks to transmission electron microscopy, the behavior of the defects and the mechanisms resulting in the reduction of their density are investigated. Two main efficient defect reduction techniques will be presented: epitaxial lateral overgrowth and growth on inclined facets. Problems encountered in the implementation of such growth techniques and the perspective towards the developments of high quality heteroepitaxial GaN templates will be presented.

Topical Talk HL 72.2 Thu 10:00 H13
Identification of defects in semipolar GaN and (Al,Ga,In)N by cathodoluminescence spectroscopy — •Klaus Thonke[1], Ingo Tischer[1], Matthias Hocker[1], Manuel Frey[1], and Ferdinand Scholz[2] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, 89081 Ulm, Germany — [2]Institute of Optoelectronics, Ulm University, 89081 Ulm, Germany

The growth of nitride semiconductor layers on semipolar planes typically introduces specific crystalline defects in relatively high concentrations. These defects create local strain, deteriorate the electrical properties, and act as nonradiative recombination centers. Mainly basal plane stacking faults of I_1 and I_2 type are introduced, terminated eventually by prismatic stacking defects or dislocations. To correlate specific types of defects with the commonly observed multiple mostly broad sub-bandgap luminescence emission bands, optical methods with very high spatial resolution in the range of few 10 nm are required. Here, either transmission electron microscope (TEM) or low-energy scanning electron microscope (SEM) based cathodoluminescence (CL) setups yield valuable information. By spatial correlation of CL maps with high-resolution TEM micrographs recorded on exactly the same sample cross section, direct correlation can be obtained. These defects also affect the incorporation of dopant atoms like Mg, or of In and Al atoms when quantum well structures are grown. We discuss the most prominent cases, and look also into the characteristic shift of the emission bands with changes in the (Al,Ga,In) composition.

Topical Talk HL 72.3 Thu 10:30 H13
Stacking fault elimination in heteroepitaxial semi-polar GaN — •Armin Dadgar — Institut für Experimentelle Physik, Otto-von Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg

Heteroepitaxially grown semi- and non-polar GaN layers typically suffer from high densities of stacking faults or require elaborate growth techniques as epitaxial lateral overgrowth. Recently a simple method to eliminate stacking faults of the dominant I1 type by the insertion of AlN interlayers in GaN has been demonstrated for GaN layers inclined towards the m-plane. For semipolar GaN layers with different inclination angles X-ray diffraction and TEM studies of GaN / AlN layer stacks show in detail the annihilation of stacking faults, but also the generation of short segments of I2 type stacking faults.

HL 72.4 Thu 11:00 H13
Enhanced stacking fault induced indium diffusion on semipolar gallium nitride based ridges — •Matthias Hocker[1], Ingo Tischer[1], Klaus Thonke[1], Junjun Wang[2], Robert A.R. Leute[2], Ferdinand Scholz[2], Johannes Biskupek[3], Willem van Mierlo[3], and Ute Kaiser[3] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, D-89081 Ulm, Germany — [2]Institute of Optoelectronics, Ulm University, D-89081 Ulm, Germany — [3]Central Facility of Electron Microscopy, Ulm University, D-89081 Ulm, Germany

Semipolar indium gallium nitride (InGaN) quantum wells are promising candidates for long wavelength output light emitting devices with increased efficiency. For this purpose, gallium nitride (GaN) based non-*c* plane structures are overgrown with several InGaN quantum wells. With increasing number of quantum wells on top of these structures, a higher density of stacking faults and dislocations leads to an enhanced incorporation and diffusion of indium towards the ridge of these structures.

Samples with different structures were investigated by spatially and spectrally resolved cathodoluminescence (CL), transmission electron microscopy (TEM), and energy dispersive X-ray spectroscopy (EDX). The CL measurements allow to identify indicators of these defects to avoid tedious TEM measurements.

Coffee break

Topical Talk HL 72.5 Thu 11:30 H13
Strain and Relaxation in Nonpolar and Semipolar GaN-based LEDs and Laser Diodes — •Kathryn Kelchner, Shuji Nakamura, Steven DenBaars, and James Speck — Materials Department, University of California, Santa Barbara, USA

Due the noncentrosymmetric nature of the hexagonal wurtzite crystal structure, heterostructures employing InN and AlN alloys on the (0001) basal plane of GaN experience large internal electric fields due to discontinuities in spontaneous and piezoelectric polarizations. Alternative crystal orientations that are nonpolar or semipolar in nature may offer improved device performance, however are also subject to anisotropic in-plane strain of lattice mismatched layers which may impact device design due to limits in critical thickness. In this talk, we will overview some of the basic mechanisms of strain relaxation of InGaN and AlGaN layers on nonpolar and semipolar GaN, including dislocation glide along the basal plane, prismatic slip, and crack formation. Measurement techniques for determining onset and degree of strain relaxation in addition to other materials and growth issues for LED and laser diodes on intentionally strain-relaxed buffers will also be covered.

Topical Talk HL 72.6 Thu 12:00 H13
Semipolar GaN substrate grown on patterned sapphire substrate by hydride vapor phase epitaxy — •Kazuyuki Tadatomo, Keisuke Yamane, Narihito Okada, Hiroshi Furuya, and Yasuhiro Hashimoto — 2-16-1 Tokiwadai, Ube, Yamaguchi, Japan

This paper presents the growth of thick semipolar {10-11}, {11-22}, and {20-21} GaN layers on n, r, and {22-43} patterned sapphire substrates (PSSs), respectively, by hydride vapor phase epitaxy. The reduction rate of the dislocation density varied with growth planes. For {10-11} GaN layers, the dislocation density drastically decreased at over 100 *m, which was as fast the reduction rate as in the case of the c-plane. It was revealed that the reduction rate of the dislocation density could be controlled by the proper selection of the growth plane. We obtained a freestanding GaN of 2 inch diameter. Thick GaN growth led to the self-separation of the GaN layer from the PSS during cooling process. The separation plane formed at the interface between GaN and PSS, which is different from the case of a conventional c-plane GaN/sapphire. The separationability of the GaN layer from the PSS depended on the selective growth area of the sapphire sidewall. A freestanding semipolar GaN substrates were then obtained.

HL 72.7 Thu 12:30 H13

Optical properties of MBE grown cubic AlGaN/GaN double quantum well structures — •Tobias Wecker, Christian Mietze, Dirk Reuter, and Donat J. As — Department of Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

The spatial separation of electrons and holes in $Al_xGa_{1-x}N/GaN$ quantum well structures due to polarization effects can be avoided by growing cubic quantum well samples in the (001) direction. Therefore the optical recombination efficiency in quantum well structures can be increased compared to the hexagonal phase with their strong spontaneous polarization along the hexagonal c-axis [1].

Cubic $Al_xGa_{1-x}N/GaN$ double heterostructures were grown on 3C-SiC(001) substrates by radio-frequency plasma-assisted molecular beam epitaxy. The coupling of the two quantum wells with varying barrier thicknesses was investigated by photoluminescence spectroscopy at room temperature as well as low temperature. The good crystal quality of the samples is demonstrated by high resolution X-ray diffraction.

The strain effects for different Al contents due to the pseudomorphically strained AlGaN barriers were investigated employing photoluminescence spectroscopy and X-Ray diffraction reciprocal space maps around the (113) reflection.

[1] D.J. As, K. Lischka, "Nonpolar cubic III-nitrides", In: Henini M, "Molecular Beam Epitaxy: From research to mass production", Elsevier Inc., 2013, p.203-215, ISBN: 9780123878397

HL 72.8 Thu 12:45 H13

InGaN/GaN based semipolar light emitting diodes — •Junjun Wang[1], Matthias Hocker[2], Robert Leute[1], and Ferdinand Scholz[1] — [1]Institute of Optoelectronics, Ulm University, Germany — [2]Institute of Quantum Matter, Ulm University, Germany

Non- and semipolar III-nitrides are promising to fabricate highly efficient light-emitting devices due to a reduced piezoelectric field leading to an increased overlap of electron and hole wavefunctions. In our research, three-dimensional stripes are realized by selective area growth on patterned masks providing semipolar surfaces. We focused on improving the electrical and optical performance of the stripe light emitting diodes with the semipolar InGaN/GaN quantum wells (QWs). Defects are generated at the tip via strain relaxation during the semipolar InGaN/GaN QWs resulting in a large leakage current. It is reduced from ~5mA to ~0.3mA at a reverse bias of 5V by including a 50nm p-GaN layer before the p-AlGaN electron blocking layer (EBL). Mg doping induces lateral growth in the ~50nm p-GaN layer leading to a plateau at the tip. Under a suitable epitaxial condition, AlGaN EBL grows more vertically recovering the sharp tip with an AlGaN triangle to block the leakage current there. The growth of the undoped GaN between the QWs and p-(Al)GaN was controlled to avoid any plateau or current crowding at the tip.

HL 72.9 Thu 13:00 H13

Epitaxy of $Al_{1-x}In_xN$ on different GaN-surface orientations — •Ernst Ronald Buss, Uwe Rossow, Heiko Bremers, and Andreas Hangleiter — Institute of Applied Physics, TU Braunschweig

$Al_{(1-x)}In_xN$ with thicknesses exceeding 250 nm deposited on c-plane oriented GaN exhibits a distinct splitting of the composition and a very strong roughening of the surface. An increase in indium incorporation efficiency of $Al_{(1-x)}In_xN$ on the $(11\bar{2}l)$ side facets (l=1,2,3) of the V-pits, compared to c-plane orientation, has been frequently mentioned in the literature to be the origin of the composition splitting and strong roughening. To clarify possible dependencies $Al_{(1-x)}In_xN$ layers grown on differently oriented GaN substrates and templates, with various thicknesses have been investigated regarding surface morphology, composition splitting and orientation of the V-pits. It became apparent that the growth rates, as well as the incorporation efficiency of $Al_{(1-x)}In_xN$ are comparable for the polar (0001), and the non polar $(1\bar{1}00)$ surfaces. On semi-polar $(11\bar{2}2)$ surface $Al_{(1-x)}In_xN$ incorporates indium more efficiently as compared with (0001) and $(1\bar{1}00)$ surfaces. $Al_{(1-x)}In_xN$ grown on pitted GaN with typical $(1\bar{1}01)$ side facets does not reveal an additional composition on this semi-polar surface orientation. The formation of differently oriented V-pits in the $Al_{(1-x)}In_xN$, compared with the V-pits in other group III-nitrides, is the key to understand the seemingly intrinsic behavior of composition splitting of $Al_{(1-x)}In_xN$. These results are in perfect agreement with investigations of higher indium content inside the pits formed during growth of $Al_{(1-x)}In_xN$ with $(11\bar{2}l)$ side facets in the literature.