HL 2: Nitrides: Devices

Time: Monday 9:30–13:15 Location: H31

HL 2.1 Mon 9:30 H31

Performance degradation of AlGaN/GaN (MIS)-HEMTs grown on Silicon substrate under different operational stress-conditions — •anthony calzolaro[1], rico hentschel[1], andre wachowiak[1], and thomas mikolajick[1,2] — [1]NaMLab GmbH, Dresden, Germany — [2]TU Dresden IHM, Dresden, Germany

GaN-based high electron mobility transistors (HEMTs) are excellent candidates for next-generation power electronics due to superior material properties, such as large breakdown field, high electron sheet charge density and mobility. In particular, AlGaN/GaN heterostructures grown on large diameter Si-substrates enable delivering high performances at lower cost for component production. For high material quality of the heterostructure and high voltage capability complex GaN buffer layers are grown on Si. Several technology challenges are however still faced mainly related to charge trapping during device operation in the gate and drain regions[1] or in the GaN buffer.

In our study, static and dynamic measurement techniques are applied to Metal-Insulator-Semiconductor (MIS)-HEMT devices to access potential sources of traps and related effects on device performance. MIS-HEMT and HEMT structures are compared in terms of ON-resistance degradation and threshold voltage instability upon different bias stress conditions. The influence of the GaN buffer has been also investigated by substrate back bias methods[2] and focus is given to the kinetics of charge capture and emission processes. Our study enables better understanding of device operation and provides valuable feedback for material and device process technology.

HL 2.2 Mon 9:45 H31

Metastable Negative Differential Capacitances in GaN-based pn- and tunnel-junctions — •Hartmut Witte, Aqdas Fariza, Silvio Neugebauer, Christoph Berger, Armin Dadgar, and Andre Strittmatter — Institute of Physics, Otto-von-Guericke-University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

GaN-based tunnel junctions grown by MOVPE are actively investigated to improve current spreading on the p-contact region of pn-junction devices. Low or moderate acceptor doping within the p-doped GaN layer leads to anomalous current-voltage characteristics of pn-junction devices displaying a region of negative differential resistance (NDR). The NDR appears within the low forward voltage region and correlates well with an adequate step in capacitance-voltage characteristics. Both in IV- and in CV-characteristics the NDR effect can be changed by applying voltage pulses. An additional space charge region (SPR) is identified from impedance spectroscopy as origin of the NDR. This SCR acts as a rectifying junction in series with the pn-junction with a capacitance between 10 pF and 50 pF. Capacitance transients show temperature dependent recharging effects of defects with time constants in the range of some ms. On the basis of surface potential measurements by kelvin-probe microscopy GaN:Mg defects are discussed as possible candidates for the NDR effect

HL 2.3 Mon 10:00 H31

Vertical field-effect transistors based on regular GaN nanostructure arrays — •Klaas Strempel[1], Feng Yu[1], Friedhard Römer[2], Bernd Witzigmann[2], Andrey Bakin[1], Hergo-Heinrich Wehmann[1], Hutomo Suryo Wasisto[1], and Andreas Waag[1] — [1]Institut für Halbleitertechnik (IHT), TU Braunschweig, Germany — [2]Computational Electronics and Photonics (CEP), Universität Kassel, Germany

A novel vertical field effect transistor (FET) technology based on 3D GaN nanostructures is introduced, combining the superior material properties of GaN for power electronics with a vertical device architecture and the 3D geometry of nanostructures. Previously realized devices based on top-down etched GaN nanowire arrays achieved promising properties such as normally-off operation, high current densities and excellent electrostatic control over the channel. Here, an improved design based on GaN fins is discussed. Regular fin arrays with smooth a-plane sidewalls were fabricated by a combination of ICP-DRIE and wet chemical etching. The fin dimensions could be precisely controlled via etching and small widths down to 60 nm were achieved. Flexible vertical doping profiles allow the modulation of the channel properties. Nevertheless, the three-dimensionality of the nanostructures increases the complexity of the device processing. Several processing steps have been successfully applied to fabricate vertical GaN FinFETs, including Al_2O_3 dielectric atomic layer deposition (ALD), inclined electron beam evaporation of the Cr gate, and planarization techniques. Electrical characterization of the devices will be presented.

HL 2.4 Mon 10:15 H31

Realizing tunnel junctions in semiconductors with bandgap higher than 5 eV for electro-optical applications — •Luca Sulmoni[1], Christian Kuhn[1], Martin Guttmann[1], Johannes Glaab[2], Norman Susilo[1], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

A highly conductive UV transparent layer is needed to overcome the poor current spreading of p-electrodes in deep UV LEDs. This is mainly caused by the high sheet and contact resistance of the transparent p-AlGaN layers and results in very large operating voltages. A promising alternative to standard p-electrodes is the injection of holes into the heterostructure by means of efficient tunnel junctions (TJs) allowing for low resistivity n-contacts on both sides of the device. This way, a transparent top n-layer can be used as an excellent native current spreading layer and a metal reflector could be used to enhance the light extraction. We have successfully demonstrated AlGaN-based TJ-LEDs emitting at 271 nm grown entirely by MOVPE. A GaN-based thin interlayer was implemented to facilitate carrier tunneling at the TJ interface. Without interlayer, current injection and light emission was possible but at extremely high operation voltages exceeding 40 V and low current levels. Typically, the operation voltages and the output powers of a 0.35 mm^2 TJ-LED featuring an GaN interlayer of 8 nm are 24 V and 1.3 mW, respectively, measured at 20 mA on wafer in cw operation. A maximum EQE of 1.4% is reached at 40 mA.

HL 2.5 Mon 10:30 H31

Small-area current injection in GaN-based light emitters with tunnel junctions — •Christoph Berger, Silvio Neugebauer, Cleophace Seneza, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke-Universität Magdeburg, Deutschland

MOVPE-grown GaN:Mg/GaN:Ge tunnel junctions enable surface emitting devices such as LEDs and laser diodes with low absorption losses. Efficient activation of hydrogen passivated Mg acceptors requires a combination of in-situ activation directly after the GaN:Mg growth step and ex-situ thermal annealing at 800°C after mesa etching to enable hydrogen out-diffusion from the sidewalls. Excellent lateral current spreading in large area LEDs is confirmed by a homogeneous electroluminescence distribution across the whole mesa area. By optimization of the doping profile, tunnel junction LEDs with negligible increase in bias voltage compared to conventional LEDs with Ni/Au contacts were realized. Light output at 430 nm wavelength through the p-contact region is enhanced by ~70% due to better transparency of the GaN:Ge with regard to the semitransparent Ni/Au contact. Application of these GaN:Mg/GaN:Ge tunnel-junctions in small-area light emitters like μ-LEDs (diameter $< 50\ \mu m$) or vertical-cavity surface-emitting lasers. A first remarkable result is pulsed operation of such devices at current-densities up to 10 kA/cm^2. We will further report on lateral current confinement to realize injection areas below 10 μm.

HL 2.6 Mon 10:45 H31

Poole-Frenkel-ionization of acceptors in $Al_{0.76}Ga_{0.24}N$:Mg short-period superlattices — •A. Muhin[1], C. Kuhn[1], M. Guttmann[1], J. R. Aparici[1], L. Sulmoni[1], T. Wernicke[1], and M. Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

For efficient light extraction in UVC light emitting diodes (LED), transparent p-doped $Al_xGa_{1-x}N$ layers with $x \geq 0.6$ are needed. AlGaN:Mg with such high Al mole fraction exhibits very high acceptor ionization energies leading to a very poor electrical conductivity. Nevertheless, LEDs with $Al_{0.81}Ga_{0.19}N$ short-period superlattices (SPSL) p-side could be operated at current densities up to

4.7 kAcm^{-2}. This work investigates the vertical resistivity (ρ_V) of $\mathrm{Al_{0.86}Ga_{0.14}N/Al_{0.65}Ga_{0.35}N:Mg}$ SPSLs. The vertical resistivity of the p-AlGaN-layers was extracted from the IV-characteristics of UVC-LEDs with varied SPSL thickness. The results show that ρ_V is not constant but decreases with the electric field which reaches values up to 10^6 Vcm^{-1}. The influence of such high electric fields on the electrical resistivity can be described by the Poole-Frenkel-effect (PFE), which leads to a field-enhanced dopant ionization. Our investigations of the field dependent ρ_V are in good agreement with the predictions made by PFE theory and provide a deeper understanding of conduction mechanisms in AlGaN:Mg SPSLs with high Al content.

15 min. break

HL 2.7 Mon 11:15 H31

Enhanced light extraction and internal quantum efficiency for fully-transparent AlGaN-based UVC LEDs on patterned-AlN/sapphire substrate — •Martin Guttmann[1], Anna Ghazaryan[1], Luca Sulmoni[1], Norman Susilo[1], Eviathar Ziffer[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Light emitting diodes (LEDs) in the UVC spectral range utilize highly absorbing p-GaN contacts and low aluminum mole fraction p-AlGaN layers to enable low operating voltages. However, to realize high power LEDs a UVC-transparent p-side in combination with a highly reflective p-contact is necessary to increase the light extraction efficiency (LEE). In this paper, we have investigated the effect of the aluminum mole fraction in the $\mathrm{Al}_x\mathrm{Ga}_{1-x}\mathrm{N/Al}_y\mathrm{Ga}_{1-y}\mathrm{N}$ p-superlattice (p-SL) ($0.32 < x < 0.65$ and $0.40 < y < 0.71$) and the influence of the p-contact metal reflectivity on the electro-optical properties of LEDs emitting around 265 nm. A five-fold increase of the external quantum efficiency (EQE) with a maximum value of 3.1% was observed for LEDs with UVC-transparent p-SL ($x = 0.65$) and reflective indium contacts. In order to separate this improvement in the EQE into LEE and internal quantum efficiency (IQE), ray-tracing simulations were performed. The increased EQE can be partially ascribed to a 2.5-fold improved LEE in combination with a 2-fold increase of the IQE for the UVC-transparent $\mathrm{Al_{0.65}Ga_{0.35}N/Al_{0.71}Ga_{0.29}N}$ p-SL.

HL 2.8 Mon 11:30 H31

Study of heavy-ion irradiation induced degradation on AlInN/GaN on Si High- Electron-Mobility Transistors (HEMTS) — •Seshagiri rao Challa[1], Nahuel Vega[2,3,4], Christian Kristukat[2,3], Nahuel a Müller[2], Mario Debray[2,3], Gordon Schmidt[1], Jürgen Christen[1], Florian Hörich[1], Hartmut Witte[1], Armin Dadgar[1], and André Strittmatter[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Gerencia de Investigación y Aplicaciones, CNEA, Argentina — [3]Escuela de Ciencia y Tecnología, Universidad Nacional de San Martín(UNSAM), Argentina — [4]Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET), Argentina

75 MeV sulfur-ion irradiation induced degradation on AlInN/GaN on Si high electron mobility transistor (HEMT) structures are systematically studied for ion fluences ranging from 2.8×10^{12} cm^{-2} to 5.5×10^{13} cm^{-2}. Ion stopping range, ionization vs displacement energy loss profile, and recoil atom distributions were simulated using SRIM software tool (Stopping and range of ions in matter). Transfer curves show a reduction of on-state current, off-state current (buffer leakage), and a positive threshold voltage shift with higher fluences as well as an increase of vertical conductivity by up to eight orders of magnitude. μ-PL measurements show an intensity reduction of the donor bound exciton (D0,X) emission in the GaN buffer layer with increasing fluences. Although performance is degraded, all HEMTs remain fully functional even at highest irradiation levels, which makes them an attractive choice to space applications.

HL 2.9 Mon 11:45 H31

InGaN/GaN microLED arrays as a novel illumination source for imaging and microscopy — •Jan Gülink[1,2], Michael Fahrbach[1,2], Daria Bezshlyakh[1,2], Hutomo Suryo Wasisto[1,2], and Andreas Waag[1,2] — [1]Institute of Semiconductor Technology (IHT), Technische Universität Braunschweig, Hans-Sommer-Str. 66, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Technische Universität Braunschweig, Langer Kamp 6a, D-38106 Braunschweig, Germany

Gallium nitride-based light emitting diodes (LEDs) have developed over the last two decades into highly efficient, cost-effective and compact light sources. While solid state lighting has been the dominant application so far, a number of other applications can take advantage of the LED's benefcial properties, including displays, optical communication, sensing and manipulation in life sciences, and structured illumination.

In this work, we report on a novel light source based on two different top-down fabrication technologies on a planar gallium nitride(GaN)-based LED wafer. We realized highly localized light sources with pitches in the range of 2 microns to 100 microns with individual pixel control, a so-called microLED array. The LED array consists of 64 pixels. The technological details of the 3D processing steps to create the microLED arrays are presented in detail. The microLED arrays were then transferred via flip-chip bonding to PCBs including the driver circuit and their brightness, emission pattern and modulation speed were investigated.

HL 2.10 Mon 12:00 H31

Blue micro-LEDs on Si(111) for optogenetic applications — •Silvio Neugebauer[1], Jürgen Bläsing[1], Armin Dadgar[1], André Strittmatter[1], Martin Deckert[2], Bertram Schmidt[2], Michael Lippert[3], and Frank Ohl[3] — [1]Institute of Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute for Micro and Sensor Systems, Otto-von-Guericke-University Magdeburg, Germany — [3]Department of System Physiology and Learning, Leibniz Institute for Neurobiology Magdeburg, Germany

Optogenetics is a technique that builds on light-sensitive proteins to control neural activity in genetically modified neurons. In order to circumvent problems associated with the use of single optical fibers for excitation, arrays of miniaturized LEDs on a flexible host are a viable solution allowing in addition for a light-patterning approach. In this study we have optimized InGaN/GaN LED heterostructures on Si(111) substrates with low total layer thickness and their processing into micro-sized LEDs for the integration onto flexible polyimide membranes. Special emphasis was put on obtaining stress-free wafers after growth and to keep the thickness of the layer stack below 5 μm. Subsequently, arrays of circular μLEDs with diameters from 60-160 μm were fabricated. Devices exhibit constant J-V characteristics for the range of diameters investigated. We will further report on full-wafer removal of the silicon substrate to obtain freestanding μLEDs that can be transferred one-by-one onto a polyimide optical electrode.

HL 2.11 Mon 12:15 H31

AlGaN-based deep UV LEDs grown on high temperature annealed epitaxially laterally overgrown AlN/sapphire — •Norman Susilo[1], Eviathar Ziffer[1], Sylvia Hagedorn[2], Leonardo Cancellara[3], Sebastian Metzner[4], Bettina Belde[1], Frank Bertram[4], Sebastian Walde[2], Luca Sulmoni[1], Martin Guttmann[1], Tim Wernicke[1], Jürgen Christen[4], Martin Albrecht[3], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Institute of Solid State Physics, Technische Universität Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany — [3]Leibniz-Institut für Kristallzüchtung, Germany — [4]Institute of Physics, Otto-von-Guericke-Universität Magdeburg, Germany

The structural and electro-optical properties of AlGaN-based deep ultraviolet light emitting diodes (UV-LEDs) on as grown and on high temperature annealed (HTA) planar AlN/sapphire and epitaxially laterally overgrown (ELO) AlN/sapphire with and without HTA are investigated and compared. After high temperature annealing LED heterostructures on both template types show improved structural and electro-optical properties. The output powers (measured on-wafer) of UV-LEDs emitting at 265 nm were 0.03 mW (planar AlN/sapphire), 0.8 mW (planar HTA AlN/sapphire), 0.9 mW (ELO AlN/sapphire), and 1.1 mW (HTA ELO AlN/sapphire) at 20 mA, respectively. These results show that HTA ELO AlN/sapphire templates provide a viable approach for the fabrication of efficient UV-LEDs, improving both the internal quantum efficiency and the light extraction efficiency.

HL 2.12 Mon 12:30 H31

Influence of the GaN:Mg contact layer on the performance characteristics of AlGaN based UVC LED heterostructures — •Eviathar Ziffer[1], Norman Susilo[1], Luca Sulmoni[1], Martin Guttmann[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchst-

frequenztechnik, Berlin, Germany

AlGaN based UVC LEDs emitting at 265 nm are typically capped with a thick GaN:Mg contact layer in order to achieve low resistivity, ohmic p-contacts. However, the GaN:Mg layer strongly absorbs the UVC light emitted into the p-side of the LED, thereby limiting its light extraction efficiency. In this study, we investigate the performance of UVC LEDs with different GaN:Mg layer thicknesses ranging from 5 nm to 160 nm. The heterostructures were grown by metalorganic vapor phase epitaxy and fabricated into LEDs by standard micro-fabrication techniques with highly reflective p-contacts and vanadium-based n-contacts. For thin GaN:Mg layers, an increasing operation voltage and a reduced yield of working LEDs were observed. At the same time, the on-wafer external quantum efficiency drastically increases with decreasing GaN:Mg cap thickness from 0.6 % to 2.1 %.

HL 2.13 Mon 12:45 H31

Low resistance V/Al/Ni/Au n-contacts on $\mathbf{n-Al_{0.9}Ga_{0.1}N}$ for UVC LEDs — •Verena Montag[1], Luca Sulmoni[1], Frank Mehnke[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Deep UV LEDs emitting below 230nm require high aluminum $\mathrm{n-Al_{0.9}Ga_{0.1}N}$ current spreading layers. However, the n-contacts show poor performance as the current-voltage characteristics is not ohmic and high operating voltages are needed even for moderate current densities. This is partly due to the materials lower electron affinity and to the higher activation energies of the Si-donor as the aluminum content in the n-AlGaN layers increases. In this study, the thicknesses of the vanadium and aluminum layers in V/Al/Ni/Au-based n-contacts were varied in order to improve both voltage and contact resistivity. In addition, rapid thermal annealing of the n-contacts was investigated for a wide range of temperatures under N_2 ambient. We were able to achieve contact resistivities of $3.3\cdot10^{-3}\Omega$ cm^2 and voltages as low as 2.6V at a current density of 0.1kA/cm^2. Finally, we fabricated UVC LEDs emitting at 229nm with an output power of 10μW and a voltage of 9.8V measured on wafer for a dc current at 20mA.

HL 2.14 Mon 13:00 H31

Field effect transistors with a piezoelectric AlN gate dielectric for force sensing applications — •Henning Winterfeld[1], Lars Thormählen[2], Hanna Lewitz[2], Erdem Yarar[2], Tom Birkoben[1], Nicolai Niethe[1], Nicolas Preinl[1], Henning Hanssen[3], Eckhard Quandt[2], and Hermann Kohlstedt[1] — [1]Nanoelectronics, Faculty of Engineering, Kiel University, Germany — [2]Inorganic Functional Materials, Faculty of Engineering, Kiel University, Germany — [3]Fraunhofer Institute for Silicon Technology, 25524 Itzehoe, Germany

In this work, we present the approach of using low temperature AlN in the gate stack of a MOS transistor. Placing the transistor on a cantilever in combination with the piezoelectric AlN layer allows the use as a force sensor. With this approach the piezoelectric FET was able to detect forces as low as 100 μN. Taking the scaling possibilities into account, the detection of an even wider range of forces is possible with this device. Additionally, we show a performance comparison of our sensors using AlN and AlScN as piezoelectric layers. Furthermore, the placement of the sensing material close to the channel and therefore, the amplifying properties of the transistor reduces noise and possibly allows for higher sensitivity. The CMOS compatibility of AlN would allow the incorporation of this device into standard silicon fabrication without limitations.