E·MRS

2014 Spring Meeting Lille, France – May 26th - 30th

SYMPOSIUM K

Challenges for Group III Nitride Semiconductors for Solid State Lighting and Beyond

Symposium Organizers:

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Challenges for group III nitride semiconductors for solid state lighting and beyond

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09:00	**Welcome Address**	
	LED and 3D GaN : A. Waag, C. C. Yang, P. Gilet and B. Witzigmann	
09:10	**Materials for Solid State Lighting** **Authors :** Stefan Lange **Affiliations :** OSRAM GmbH, Corporate Technology, Research & Innovation, Development Phosphor Materials, Schwabmünchen, Germany **Resume :** Modern Solid State Lighting (SSL) LEDs are continuously gaining importance in all kinds of applications. Virtually all lighting class LEDs use the principle of phosphor conversion to generate white or colored light and combine a solid state pump light source with a converter element comprising one or more phosphors. The vast majority, typically more than 90%, of the luminous flux originates from the emission of the phosphors. Versatile, robust and highly efficient conversion materials are therefore essential building blocks for all SSL devices. In the mid 1990s the first white conversion LEDs were introduced combining a blue (In)GaN chip and YAG:Ce3+ as a yellow down-converting phosphor. YAG:Ce3+ and derived materials are still being used today in a multitude of modern LEDs due to their excellent physical properties. Various novel material classes like e.g. (oxi-)nitrides have since been developed giving rise to a very broad range of applications such as warm white LEDs, high color gamut display backlighting or color on demand, often using multi-phosphor approaches. Over the past years, power densities and application temperatures of modern SSL products have been continuously increasing, driving well established conversion approaches close to their limits or even beyond. Novel materials and new approaches such as all inorganic converter elements are therefore crucial for future applications.	K.I 1

add to my program (close full abstract)

start at	Subject	Num.
09:40	**Multiple-section core-shell InGaN/GaN quantum-well nanorod light-emitting diode array** **Authors :** Che-Hao Liao, Charng-Gan Tu, Chia-Ying Su, Wen-Ming Chang, Horng-Shyang Chen, Yu-Feng Yao, Chieh Hsieh, Hao-Tsung Chen, Chih-Kang Yu, Yean-Woei Kiang, Chih -Chung (C. C.) Yang **Affiliations :** National Taiwan University, Taipei, Taiwan **Resume :** With the nano-imprint lithography and the pulsed growth mode of metalorganic chemical vapor deposition, a regularly-patterned, c-axis nitride nanorod (NR) light-emitting diode (LED) array of uniform geometry with m-plane core-shell InGaN/GaN quantum wells (QWs) is formed. In the pulsed growth for an NR of a constant cross section size, the sources of groups III and V are switched on and off alternatively with fixed supply durations. By varying the supply duration of group III source (TMGa) in the pulsed growth process, the NR cross section can be tapered for growing another section of NR of a different cross-sectional size. Based on this growth technique, a multiple-section GaN NR of changing cross-sectional size can be obtained. When InGaN/GaN QWs are deposited on the sidewalls of the NR, the indium contents and QW thicknesses are different in different sections of different cross-sectional sizes due to different strain relaxation conditions. In this situation, the emission wavelengths of the QWs from different sections are different, leading to multiple -color emission of such an NR array. The pulsed growth conditions for controlling	K.I 2

the cross section tapering are to be discussed. Also, the NR growth speeds of different cross-sectional sizes will be compared. The mixture of multiple-color emissions from such an NR into quasi-white light will be demonstrated.

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10:10 **Coffee break**

10:30 **Does Nanowire LED become a reality?**

Authors : Philippe Gilet
Affiliations : Aledia, 17 rue des Martyrs, Building M23, 38054 Grenoble Cedex 09, France

Resume : The high-brightness, packaged LED market is forecasted to reach US$15 billion by 2016. However, significant cost-reduction breakthroughs are needed to allow continued market growth. Up to now, the driving forces were first an increase of the performances in terms of lm/W (which is now clamped close to the maximum theoretical value) and secondly an increase of the substrate sizes in order to decrease the lumen cost. But conventional LEDs (either on sapphire or on silicon) suffer from large lattice and thermal coefficient mismatches between the active area and the substrates that prevents LED industry to continue to benefit from cost reduction thanks to the scaling effect. Wide-bandgap gallium nitride nanowires are considered to be able to change the paradigm and are foreseen as attractive building blocks for high efficiency and low cost solid-state lighting applications. In this paper, we will present an overview of this innovative technology. First, we will review the different device designs used and we will associate them with their corresponding market segments. Then a comparison of the different growth methods (MOCVD, MBE…) will be presented and discussed regarding the different nanowire geometries obtained. A focus will be performed on the different electrical, optical and structural performances of the nanowires obtained so far. Finally, devices performances at a single nanowire scale and macro device will be presented.

K.I 3

add to my program **(close full abstract)**

11:00 **Growth of InGaN/GaN core-shell structures by molecular beam epitaxy**

Authors : S. Albert 1, A. Bengoechea-Encabo 1, M. Sabido-Siller 1, M. Müller 2, G. Schmidt 2, S. Metzner 2, P. Veit 2, F. Bertram 2, M. A. Sánchez-García 1, J. Christen 2, E. Calleja 1
Affiliations : 1. ISOM-Dept. Ing. Electrónica, ETSIT, Univ. Politécnica, 28040 Madrid, Spain 2. Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, 39106 Magdeburg, Germany

Resume : InGaN alloys, with a band gap from 0.7 eV to 3.4 eV, alloys are perfect candidates for optoelectronic devices, such as solar cells and light emitting diodes. Up to now, most research effort was focused on InGaN planar growth along the c-plane orientation, which is known to suffer from a high density of non-radiative defects due to the lattice and thermal mismatch between GaN and InGaN. A way to overcome these limitations is the growth of nanocolumnar structures. The self-assembled and selective area growth of GaN nanocolumns (NCs) has been demonstrated by various epitaxial techniques such as metal organic vapour phase epitaxy (MOVPE) and hydride vapour phase epitaxy. In particular, self assembled and selective area growth (SAG) of axial InGaN/GaN nanocolumnar structures by plasma assisted molecular beam epitaxy (PAMBE) has been demonstrated. As an alternative approach to axial structures, the growth of InGaN/GaN core-shell structures has been proposed and achieved some years ago by MOVPE, in order to take advantage of the large sidewall active area and the non-polar character of the m-planes that greatly enhances emission or absorption in respect to the axial (polar) case. This work demonstrates for the first time (to our knowledge), the growth by PAMBE of InGaN/GaN core-shell structures on etched GaN microrods arrays using a combination of top-down principle (patterned GaN template on sapphire) and a bottom-up (epitaxy) process to overgrow on the patterned microrod array.

K.I 4

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11:15 **Position-controlled MOVPE growth and electro-optical characterization of core-shell InGaN/GaN microrod LED structures**

Authors : Tilman Schimpke 1 2, Martin Mandl 1 2, Michael Binder 1, Dominik Scholz 1, Xue Wang 2, Jana Hartmann 2, Andreas Waag 2, Xian Kong 3, Achim Trampert 3, Markus Müller 4, Benjamin Max 4, Frank Bertram 4, Jürgen Christen 4, Hans-Jürgen Lugauer 1, M. Strassburg 1
Affiliations : 1. OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany 2. Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66,

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38106 Braunschweig, Germany 3. Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany 4. Institut für Halbleiterphysik, Otto-von-Guericke-Universität, Universitätsplatz 2, 39106 Magdeburg, Germany

Resume : Today's InGaN-based white LEDs suffer from efficiency reduction ("droop") at elevated current densities. Core-shell microrods (MR), with quantum wells (QW) covering their entire surface, enable a drastical increase in active area scaling with the rod's aspect ratio, which is a viable and cost effective route to mitigate the droop by reducing the local current density. MRs were grown in a large volume metal-organic vapor phase epitaxy (MOVPE) reactor. GaN-on-sapphire templates with a thin, patterned SiO2 mask for position control were used as substrates. Out of the mask openings, pencil-shaped n-doped GaN MR cores were grown under conditions favouring 3D growth. In a second growth step an InGaN QW was deposited around the cores under 2D growth conditions. The QW emission on the different facets was studied using resonant temperature dependent photo- and low temperature cathodoluminescence measurements. The crystal quality of the MRs was investigated by transmission electron microscopy showing the absence of extended defects in the 3D core. LED structures were obtained by depositing p-doped GaN as the outermost shell layer. In order to fabricate LED chips, dedicated processes were developed to accommodate for the special requirements of the 3D geometry. Electrical luminescence spectra of ensembles of several hundreds of MRs show distinct emission peaks, which vary strongly with drive current. The peaks were assigned to the QWs on different facets of the MR structures.

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11:30 **Influence of silane on the growth of 3D GaN columns and core-shell LEDs**

K.I 6

Authors : Xue Wang 1, Johannes Ledig 1, Xiang Kong 2, Jana Hartmann 1, Lorenzo Caccamo 1, Matin Sadat Mohajerani 1, Martin Mandl 1 3, Tilman Schimpke 1 3, Achim Trampert 2, Gerhard Lilienkamp 4, Winfried Daum 4, Martin Straßburg 3, Hergo-H. Wehmann 1, Andreas Waag 1
Affiliations : 1 Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany; 2 Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany; 3 Osram Opto Semiconductors GmbH, Leibnizstraße 4, 93055 Regensburg, Germany; 4 Institute of Energy Research and Physical Technologies, Clausthal University of Technology, Leibnizstraße 4, 38678 Clausthal, Germany

Resume : In recent years, GaN columnar core-shell light-emitting diodes (LEDs) are considered to be one of the possible candidates for highly efficient solid state lighting. Arrays of dislocation free uniform Ga-polar GaN columns and high aspect ratio core-shell LEDs have been realized on patterned SiO¬x/GaN/sapphire templates by metal organic vapor phase epitaxy (MOVPE) using a continuous growth mode. During the GaN column growth, silane is injected into the reactor to realize the n-type doping. Silane flow increases in addition the vertical growth rate substantially and averts the height limitation of GaN column growth. However, the silane injection results in a Si segregation on the column sidewalls. If the Si-content in this GaSiN layer is too high, the growth of the subsequent shell structure, e.g. QW and p-GaN, can be hindered. Reducing the silane flow during growth leads to improved quality of the free spacer layer, QWs and p-doped GaN. However, the height of columns is then limited and a high aspect ratio can't be achieved. In order to avoid this height limitation and simultaneously realize high quality shell structures, a new growth method has been developed, which has successfully solved these issues. The thin GaSiN layer is investigated by Auger electron microscopy and transmission electron microscopy on the nano-scale. The optical and electrical properties of the core-shell LEDs are measured by cathodoluminescence and by an SEM based nano-manipulator setup, respectively.

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11:45 **Photonic Crystal Effects in Light Emission from Ordered Core Shell InGaN/GaN Nanorods**

K.I 7

Authors : C.J. Lewins 1, S.M. Lis 1, E.D. Le Boulbar 1, I. Girgel 1, P.R. Edwards 2, R.W. Martin 2, P.A. Shields 1, and D.W.E. Allsopp 1*
Affiliations : 1. Dept. Electrical & Electronic Engineering, University of Bath, Bath, BA2 7AY, UK; 2. Dept. of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, UK; *Email: D.Allsopp@bath.ac.uk

Resume : III-nitride core-shell LEDs are considerable topical interest. Their advantages include providing a low cost means of fabricating non-polar LEDs in which the quantum efficiency is not degraded by the Quantum-Confined Stark Effect and increasing the area of the active region over its planar equivalent,

potentially reducing the current density in the device and hence droop. A further potential advantage is the ability to engineer the direction of the light output through photonic crystal (PhC) effects, but this requires creating more regular shaped core-shell structures than hitherto achieved. This paper reports the demonstration of previously unobserved strong PhC effects in core shell nanorod LEDs by measurements of the angle-resolved photoluminescence. Highly ordered arrays of regularly shaped InGaN/GaN core-shell LEDs were fabricated by inductively coupled plasma etching GaN cores of different height from an n-GaN template and subsequent MOVPE growth. The resulting uniformly shaped core-shell structures had m-plane sidewalls capped by a {10-11} faceted nanopyramid with a widened region at their intersection with the sidewalls. It was found that shorter core-shell structures operate in a diffractive PhC regime as the in-plane wave vectors of the optical modes before diffraction were independent of azimuthal direction. In arrays of taller core-shell devices light emission occurs at wave vectors that vary with PhC lattice direction, indicating a strong photonic operating regime. FDTD simulations confirm the existence of this strong PhC regime which is associated with the formation in the core-shell array of Bloch modes that couple only weakly with the underlying GaN buffer layer.

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12:00 **Lunch break**

13:30 **Growth and characterization of nanowire-based LEDs** K.I 8

Authors : Jonas Ohlsson 1 3, Zhaoxia Bi1 , Rafal Ciechonski 2, Kristian Storm 1, Bo Monemar1, and Lars Samuelson 1´2 3
Affiliations : 1. Lund University, Solid State Physics/Nanometer Structure Consortium, Lund, Sweden 2. Glo AB, Ideon Science Park, Lund, Sweden and Sunnyvale, CA, USA 3. QuNano AB, Ideon Science Park, Lund, Sweden

Resume : Nanowires offer a generic method for realization of dislocation-free GaN grown on either silicon or sapphire substrates, using conventional, high dislocation density, planar GaN as seeding layer. We are using a thin silicon-nitride mask with holes in the range 80-250 nm in diameter and initiate growth under selective-area-growth conditions yielding preferential axial growth of dislocation-free GaN nanowires in the c-direction, [0001]. By modifying growth conditions such that radial growth dominates, we can have the thin nanowires act as ideal substrates on top of which we grow radial LED-device structures on the m-planes (10-10) of the original needle, leading to ideal radial pn-junctions containing single or multiple quantum wells for carrier recombination. We can also choose to grow the second step in a mode that yields 3D nanostructures, which offers very interesting opportunities for growth of ternary μ-substrates and device layers of high crystal quality, for instance InGaN for realization of longer-wavelength emission, or AlGaN for UV-emission. In this talk we show the status of this technology as well as results of a multitude of characterization methods as performed within the EU-funded project "Nanowires for Solid State Lighting – NWs4LIGHT".

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14:00 **III-nitride based Nanowire Arrays: Simulation of Electrical and Optical Properties** K.I 9

Authors : Bernd Witzigmann
Affiliations : University of Kassel, Computational Electronics and Photonics Group, Electrical Engineering/Computer Science Department, Wilhelmshöher Allee 71 D-34121 Kassel Germany

Resume : III-nitride nanowire arrays can overcome some of the limitations of planar thin-film growth. InGaN quantum wells grown perpendicular to the nano wire axis have shown to emit from blue to red color with very good efficiencies, due to tensile strain at the GaN side of the well interface, and low defect density from the growth process. Hetero interfaces parallel to the wire axis increase the active area versus wafer area ratio, which is attractive for sensing, solid state lighting or 3D-electronics applications. A closer investigation of the nanowire architecture has revealed a multitude of additional features. For the electromagnetic properties, the nanowire array constitutes a periodic or non-periodic subwavelength structure, which can be used as intrinsic anti-reflective element [1], as photonic crystal [2], or laser resonator [3]. The wire itself forms an electronic channel for 1-dimensional carrier transport, with the ability to supply carriers to a quantized element such as a quantum dot with high efficiency. The high ratio of surface to volume increases the relevance of electronic surface effects, and thereby it is important to study surface

recombination [4]. Also, hetero interfaces placed parallel to the wire axes grow in a non-polar m- or a-plane crystal orientation, which can be a desired feature for luminescent quantum wells. In this presentation, we will give an analysis of the electromagnetic properties of a periodic nanowire array on a substrate, for an application as LED or as a solar cell. Based on time- and frequency domain solutions of Maxwell's equations in three dimensions, it is shown that when a dipole emitter is placed into the structure, only weak photonic crystal effects are visible due to the strong angular variation of the emission. However, a pronounced Purcell effect can be observed for specific emitter locations, which has an impact in the quantum efficiency of an LED or a solar cell. A modal analysis identifies the modes that are suitable for high efficiency nanowire LEDs. In addition, secondary effects such as the re-absorption of electromagnetic energy and the polarization of light emission will be discussed. In the second part of the talk, the electronic properties of III-nitride based nanowire LEDs will be discussed, in particular the impact of surface recombination. Using a 3-dimensional carrier transport model that solves the continuity equations for electrons and holes, together with the Poisson equation for the electrostatic potential, surface states are introduced as charged Shockley-Read-Hall recombination centers residing in the band gap. The efficiency of the LED highly depends on the type of surface states, and some scenarios will be shown using parameters reported in literature. In addition, strategies to minimize surfac recombination in nano structured semiconductor devices will be discussed. [1] J. Wallentin et al, Science 1 March 2013: Vol. 339 no. 6123 pp. 1057-1060. [2] C. Kölper et al, Phys. Stat. Sol. A, 1-9, 2012. [3] J.C. Johnson, Nature Materials, 1, Oct. 2002, pp. 106ff. [4] F. Römer, et al, J Comput Electron DOI 10.1007/s10825-012-0424-9.

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14:30 **Carrier dynamics in GaInN/GaN quantum well and nanowire LEDs**

Authors : Daniel Sager1, Oliver Pfingsten1, Robert Köster2, Artur Poloczek2, Werner Prost2, Franz Josef Tegude2, Tobias Meyer3, Berthold Hahn3, Gerd Bacher1
Affiliations : 1Werkstoffe der Elektrotechnik & CENIDE, Universität Duisburg-Essen, Bismarckstr. 81, 47057 Duisburg, Germany, 2Halbleitertechnologie & CENIDE, Universität Duisburg-Essen, Lotharstr. 55, 47048 Duisburg, Germany, 3OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

Resume : InGaN/GaN quantum wells (QW) represent core elements in blue or green light emitting diodes (LEDs). Charge carrier separation due to an internal piezoelectric field, or defect formation are expected to influence the carrier dynamics, which might limit modulation frequency and quantum efficiency, respectively, of the devices. We present time- and spatially resolved luminescence spectroscopy combined with photocurrent measurements for getting insight into fundamental dynamical properties of GaInN/GaN multiple quantum well (MQW-) and nanowire (NW-) LEDs. For the MQW-LEDs, radiative lifetimes on the order of tens of nanoseconds are found as a result of the charge carrier separation due to the internal electric field. A distinct reduction of the recombination lifetime and a correlated increase of the photocurrent are observed in the low injection regime demonstrating tunnelling escape as an important loss mechanism limiting the device efficiency. To avoid the piezoelectric field, radial core-shell NW-LEDs are prepared with the MQW grown along the m-axis of the crystal. Photoluminescence experiments on single NWs demonstrate the absence of the internal electric field, which leads to radiative recombination lifetimes in the sub-ns regime. We demonstrate electroluminescence modulated with a frequency of several hundred MHz for a NW-LED array grown on silicon, indicating the potential of our approach for fast modulatable LEDs for communication via plastic fibres.

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15:00 **AlGaN/AlN Stranski-Krastanov quantum dots with improved luminescence internal quantum efficiency**

Authors : C.Himwas 1, M. den Hertog 1, F. Donatini 1, Le Si Dang1, R. Songmuang 1, and E. Monroy 2
Affiliations : 1. CEA-CNRS Group "Nanophysique et Semiconducteurs", Institut Neel-CNRS, 25 rue des Martyrs, 38042 Grenoble Cedex 9, France. 2. CEA-CNRS Group "Nanophysique et Semiconducteurs", INAC-SP2M, CEA-Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

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Resume : AlGaN quantum dots (QDs) have become an interesting approach for the fabrication of UV solid-state lamps since the three-dimensional carrier confinement grants certain insensitivity to nonradiative recombination processes. In this work we present a systematic study of the growth and optical properties of AlGaN/AlN QD stacks deposited by MBE and designed to fulfill the

requirements of electron-pumped UV sources emitting in the 330-240 nm spectral range. We compare structures where we varied the amount of AlGaN in the QDs, the growth temperature and the Al/Ga flux ratio. Well-defined faceted QDs were observed by STEM, with an aspect ratio similar to the 0.12 reported for GaN QDs. The nanostructures are strained on the AlN substrate within the error bars of x-ray diffraction (XRD). The Al composition measured by geometrical phase analysis is consistent with the Al/Ga flux ratio and with XRD data. The luminescence internal quantum efficiency (IQE) reaches a maximum of 50% for QDs resulting from the deposition of 1 nm of AlGaN. The IQE degradation for thicker AlGaN layers is attributed to an increase of the wetting layer and the onset of strain relaxation. The observation of near-IR intraband absorption associated to the s-pz electronic transition provides further information about the QD morphology. The optical results are interpreted in correlation with the structural data and with theoretical calculations using a three-dimensional 8-band k.p Schrodinger-Poisson solver.

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15:15 **Direct visualization of optical properties on nanometerscale of InGaN/GaN core-shell microrods**

Authors : Marcus Müller1, Benjamin Max1, Gordon Schmidt1, Silke Petzold1, Peter Veit1, Frank Bertram1, Jürgen Christen1, Martin Mandl2, Tilman Schimpke2, and Martin Strassburg2

Affiliations : 1 Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany 2 OSRAM Opto Semiconductors GmbH, Regensburg, Germany

Resume : During the last years research on III-nitride core-shell microrods has become more intense due to the possibilities for high efficient optoelectronic devices. By taking advantage of the core-shell geometry with a high aspect ratio, the effective light emitting area can be dramatically increased in comparison to conventional planar heterostructures. The core-shell microrod sample was grown by MOVPE on a GaN/sapphire template. Selective area growth using an SiO2 structured masking layer has been applied for the formation of the GaN microrods. The change of growth parameters to conditions adequate for 2-dimensional growth forms large pyramidal cappings. Finally, a single InGaN quantum well (SQW) was deposited. In this study we correlate the optical properties with the crystalline real structure using low temperature cathodoluminescence spectroscopy (CL) directly performed in a STEM. We observe two distinct luminescence contributions of the InGaN SQW which are directly correlated to its morphology. Highly spatially resolved CL mappings of single microrods exhibit an InGaN SQW emission at 400 nm from the non-polar facets. In contrast, the InGaN SQW on the semi-polar facets shows a longer wavelength emission.

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15:30 **Coffee break**

16:00 **Selective Area Growth of Ga-polar GaN nanocolumn by Molecular Beam Epitaxy: morphology, structure and optical emission**

Authors : A. Urban 1, J. Malindretos 1, A. Rizzi 1; M. Müller 2, G. Schmidt 2, C. Karbaum 2, P. Veit 2, F. Bertram 2, and J. Christen2

Affiliations : 1 Georg-August-University Goettingen, IV. Physikalisches Institut, Friedrich-Hund-Platz 1, 37077 Goettingen, Germany; 2 Otto-von-Guericke-University Magdeburg, Institute of Experimental Physics, Universitaetsplatz 2, 39106 Magdeburg, Germany

Resume : GaN-based nanocolumns are currently intensively studied for their potential application in high efficient optoelectronic devices. Key issues are the increased active area per wafer area and the presence of both semi-polar and non-polar facets for the growth of multi-quantum-well structures. Selective area growth (SAG) of GaN nanocolumns (NCs) by molecular beam epitaxy (MBE) on pre-patterned GaN(0001) templates is shown to provide regular arrays of Ga-polar NCs. The obtained morphology with semi-polar facets at the tip can be described within the framework of a thermodynamic picture, which provides a consistent explanation also for the growth of N-polar NCs. Dense arrays of NCs with diameter of 200-300 nm have been grown and the r-plane facets at the tips can be used as a template for the realization of GaN-based heterostructures with reduced internal electric fields as compared to conventional c-plane heterostructures. Furthermore the grown GaN NC arrays allow a post-growth preparation of optimized cross-section TEM specimens for CL investigations. A direct nano-scale correlation of the optical properties with the actual real crystalline structure of single GaN nanocolumns using low temperature

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cathodoluminescence spectroscopy in a scanning transmission electron microscope has been obtained.

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16:30 **Whispering gallery modes from nonpolar InGaN quantum wells deposited on GaN rods**

Authors : C. Tessarek 1 2, M. Heilmann 1, G. Sarau 1, and S. Christiansen 1 3
Affiliations : 1. Max Planck Institute for the Science of Light, Günther-Scharowski-Str. 1, 91058 Erlangen, Germany; 2. University Erlangen-Nuremberg, Institute of Optics, Information and Photonics, Staudtstr. 7/B2, 91058 Erlangen, Germany; 3. Helmholtz Centre Berlin for Materials and Energy, Hahn-Meitner Platz 1, 14109 Berlin, Germany
Resume : Self-catalyzed GaN rods on sapphire substrates have been grown by metal-organic vapor phase epitaxy [1]. Cathodoluminescence (CL) was used to investigate the optical properties. High quality (Q) factor whispering gallery modes (WGMs) were observed in regular, hexagonal shaped GaN micro- and nanorods [2]. WGMs with Q-factors of up to 700 and 100 are visible in the spectrum of a microrod and nanorod, respectively. Utilizing μ-photoluminescence, even higher Q-factors of up to 4000 have been observed in microrods demonstrating the high morphological quality of the rod structures [3]. The spectral position of the WGMs in a slightly tapered GaN wire can be tuned by changing the position of the fixed electron beam at the sidewall of a wire [4]. Good agreement between the calculated and measured WGMs is achieved. InGaN quantum wells (QWs) are deposited on GaN microrods. Dependent on the growth conditions, the QW emission can be adjusted from ~400-450 nm. CL is detected if the electron beam is scanning the nonpolar InGaN quantum wells. The QWs on the top facets are not optically active. It will be shown that WGMs are still present in GaN microrods covered with InGaN quantum wells. [1] C. Tessarek et al., J. Appl. Phys. 114, 144304 (2013). [2] C. Tessarek et al., Phys. Status Solidi C, accepted. [3] C. Tessarek et al., Opt. Express 21 (2013) 2733. [4] C. Tessarek et al., Jpn. J. Appl. Phys. 52 (2013) 08JE09.

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16:45 **Blue, green and yellow light – emitting diodes based on ordered InGaN nanocolumns by PAMBE**

Authors : A. Bengoechea-Encabo 1, S. Albert 1, D. Lopez-Romero 1, F. Barbagini 1, A. Torres-Pardo 2 3, J. M. Gonzalez-Calbet 2, M. A. Sanchez-Garcia 1, E. Calleja 1
Affiliations : 1. ISOM-Dept. Ing. Electrónica, ETSIT, Univ. Politécnica, 28040 Madrid, Spain; 2. Departamento de Quimica Inorgánica, Facultad de Químicas, Universidad Complutense de Madrid, 28040, Madrid, Spain; 3. CEI Campus Moncloa, UCM-UPM, Madrid, Spain A. Torres-Pardo.
Resume : InGaN light emitting diodes (LEDs) are typically based on two dimensional layers with multi quantum wells (MQW), reaching the maximum external quantum efficiency at relative low current injection. At high current injection, a strong reduction in efficiency (called droop) is observed, more acute in the green spectral range. As an alternative to planar devices, LED proposals based on self-assembled nanocolumns (NCs), involving embedded InGaN disks, have been proposed and published. However, self-assembled NCs present critical drawbacks, such as an intrinsic polycromaticity, as well as length and diameter dispersion, that difficult processing and hinder the device performance. In the last years, selective area growth of NCs by molecular beam epitaxy has been developed, achieving highly homogeneous and controllable GaN NCs with embedded disks or thick InGaN regions. In this work, we present results on the growth, processing and characterization of blue, green and yellow LEDs based on ordered NCs with thick InGaN active layers. The thickness of the InGaN region of each NC ranges from 250 nm to 500 nm, while preserving a very high crystal quality. The performance of thick active InGaN regions for nanoLEDs is evaluated from pulsed electro-luminescence operation up to 1900 A/cm2, without any traces of efficiency droop. A very small blue-shift with increasing current is observed, and the line width values are slightly higher than those measured in state of art InGaN MQW 2D LEDs.

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Poster session : D. Cherns

17:00 **MOVPE growth mechanisms of catalyst-free self-organized GaN columns**

Authors : Xue Wang 1, Johannes Ledig 1, Uwe Jahn 2, Hergo-H. Wehmann 1, Tilman Schimpke 1 3, Martin Stra?burg 3, Andreas Waag 1
Affiliations : 1 Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66,

K.PI 1

38106 Braunschweig, Germany; 2 Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany; 3 Osram Opto Semiconductors GmbH, Leibnizstraße 4, 93055 Regensburg, Germany

Resume : Since several years, 3D columnar structures of III-V semiconductors attract considerable attention because they have the potential to be applied in novel optoelectronic and electronic devices. In the present work, the growth mechanisms of catalyst-free self-organized GaN columns on sapphire by metal organic vapor phase epitaxy (MOVPE) have been investigated in details. Temperature- and time-dependent growth was performed. The influence of the carrier gas on the growth of columns is discussed. The growth behavior of GaN nucleation seeds and columns can be characterized by two different kinetic regimes. The thermodynamic energy barriers of nucleation as well as for surface diffusion limitation are quantitatively estimated. No height limitation of the columns is observed in the investigated time region. Using pure nitrogen as carrier gas, Ga droplets accumulate on the top of columns and they are converted into a high quality solid GaN during the cool down phase due to nitridation. On the other hand, hydrogen as carrier gas can improve the optical quality of the overall GaN columns substantially and increase the vertical growth rate. In this case, no indication of Ga droplets could be detected. Furthermore, silane doping during the growth promotes the vertical growth in both cases. The morphology of GaN nucleation seeds and columns is investigated by scanning electron microscope. Their optical characters are characterized by room temperature cathodoluminescence.

add to my program **(close full abstract)**

17:00 **High luminescence efficiency of Eu-Doped GaN**

Authors : Yong Tae Kim 1, Ji -Ho Park 2, and Akihiro Wakahara 2
Affiliations : 1. Semiconductor Materials and Devices Lab., Korea Institute of Science and Technology, Hwarangno 14-gil 5, Seoul, Korea; 2. Department of Electronics and Information Engineering, Toyohashi University of Technology, 1-1 Hibarigaoka, Toyohashi, Japan

Resume : Rare earth ion (REI)-doped III-nitride has been very attractive for next generation high luminescence photonics. In this work, Eu-doped GaN (GaN:Eu) films are grown by plasma assisted molecular beam. RHEED pattern indicates that when the III/V ratio exceeds 1 the growth mode changes from 3D to step-flow/2D and the Eu content in GaN film is abruptly decreased from 0.75 to 0.02 at.%. Luminescence properties have been investigated with relation to the Eu concentration in the GaN:Eu film. Transition peaks from the 4f n shell of Eu3+ ions are observed at 585-595, 596-610, 611-629, 630-645 and 660-670 nm, which are assigned as 5D0 7F0, 5D0→7F1, 5D0→7F2, 5D1→7F4 and 5D0→7F3. Among these transitions, the dominant one is the 5D0→7F2 transition due to the selection rule, and the two peaks observed at 621 and 622.6 nm in the 5D0→7F2 transition are indexed as α and β. The intensity of β is relatively stronger than peak α when the Eu concentration is below 0.4 at.%. However, when the Eu concentration exceeds 0.4 at.% the α peak becomes stronger than that the β peak. These results suggest that the competition of relative intensities between α and β depends on the Eu concentration and the luminescence sites. From the luminescence efficiency of 5D0→7F2 transition, it is found that the PL efficiency is obviously increased by the 2 order of magnitude when the Eu concentration does not exceed 1 at.%. Therefore, we will discuss relationship between the luminescence efficiency and the Eu concentration in detail.

K.PI 2

add to my program **(close full abstract)**

17:00 **Temperature dependence of the luminescence bands of GaN films grown by close space sublimation**

Authors : L.A. Hernandez-Hernandez 1, J. R. Aguilar-Hernandez 1, F. de Moure-Flores 1 2, R. Mendoza-Perez 3, G. S. Contreras-Puente 1, O. de Melo 4, A. Escamilla-Esquivel 1, G. Santana 5
Affiliations : 1. Escuela Superior de Física y Matemáticas – Instituto Politécnico Nacional, Edificio No. 9, U.P.A.L.M., San Pedro Zacatenco, C.P. 07738 México D.F.; 2. Facultad de Química, Universidad Autónoma de Querétaro, Querétaro C.P. 09790 México; 3. Universidad Autónoma de la Ciudad de México, Av. Prolongación San Isidro 151, Col San Lorenzo Tezonco, C.P. 09790 México D.F.; 4. Facultad de Física de la Universidad de La Habana, Colina Universitaria, 10400, La Habana, Cuba; 5. Instituto de Investigación en Materiales Universidad Nacional Autónoma de México, Coyoacan, C.P. 04510 México D.F.

K.PI 3

Resume : The studies on the photoluminescence properties as a function of temperature of GaN films grown by sublimation (Close Space Vapor Transport - CSVT) on quartz substrates are presented. Unusual luminescence bands at

temperature of 12 K were observed. The intense luminescence band at 3.312 eV is the zero phonon line (ZPL) normally associated to free-to-bound exciton transition. Three phonon replica separated by an energy of 69 meV ± 1 meV are observed. This fact accounts for the phonon coupling of the E1 (TO) vibrational mode (558 cm-1) to the transition at 3.312 eV.

add to my program **(close full abstract)**

17:00 **Optical and structural properties of GaN grown by Closed-Space Vapor Transport**

Authors : L.A. Hernandez-Hernandez 1, J. R. Aguilar-Hernandez 1, F. de Moure-Flores 1 2, R. Mendoza-Perez 3, G. S. Contreras-Puente 1, O. de Melo 4, A. Escamilla-Esquivel 1, G. Santana 5

Affiliations : 1. Escuela Superior de Física y Matemáticas – Instituto Politécnico Nacional, Edificio No. 9, U.P.A.L.M., San Pedro Zacatenco, C.P. 07738 México D.F.; 2. Facultad de Química, Universidad Autónoma de Querétaro, Querétaro C.P. 09790 México; 3. Universidad Autónoma de la Ciudad de México, Av. Prolongación San Isidro 151, Col San Lorenzo Tezonco, C.P. 09790 México D.F.; 4. Facultad de Física de la Universidad de La Habana, Colina Universitaria, 10400, La Habana, Cuba; 5. Instituto de Investigación en Materiales Universidad Nacional Autónoma de México, Coyoacan, C.P. 04510 México D.F.

Resume : We report in this work on the structural and optical properties of GaN films grown by the Closed-Spaced Vapor Transport (CSVT) technique. The samples were deposited on quartz substrates using GaN powder as material source, which were contained inside a semi-hermetic cell made of graphite in a low pressure atmosphere. We present the characterization obtained through X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and Photoluminescence (PL) measurements. XRD results exhibit the growth of low quality hexagonal GaN, while SEM image shows GaN clusters over the entire substrates surface. Concerning EDS measurements they indicated that non-stoichiometric GaN films with non-intentional carbon (C) impurification were obtained. Finally, PL measurements under UV excitation (He:Cd laser λ=325 nm), as a function of temperature in the range 15-300 K, allowed to confirm the presence of PL emission at room temperature. We observed the presence of different emission bands in the visible region: the yellow (YL) band at 2.20 eV, and the blue (BL) band, 2.7-3.0 eV, both of them are related to undoped and C-doped GaN defects. On the other side, the green (GL-2) band, at 2.36 eV, is related to Ga-rich GaN crystals. At low temperature, it was possible to observe PL emission above 3.1 eV, these bands are mainly associated to donor-acceptor pairs (DAP) and bound exciton. A deeply discussion of the results are presented and discussed.

K.PI 4

add to my program **(close full abstract)**

17:00 **The role of Si during the growth of GaN micro- and nanorods**

Authors : C. Tessarek 1 2, M. Heilmann 1, A. Haab 3, H. Hardtdegen 3, C. Dieker 4, E. Spiecker 4, S. Christiansen 1 5

Affiliations : 1. Max Planck Institute for the Science of Light, Günther-Scharowski-Str. 1, 91058 Erlangen, Germany; 2. University Erlangen-Nuremberg, Institute of Optics, Information and Photonics, Staudtstr. 7/B2, 91058 Erlangen, Germany; 3. Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany; 4. University Erlangen-Nuremberg, Center for Nanoanalysis and Electron Microscopy, Erlangen; 5. Helmholtz Centre Berlin for Materials and Energy, Hahn-Meitner Platz 1, 14109 Berlin, Germany.

Resume : Self-assembled GaN micro- and nanorods on sapphire substrates have been grown by metal-organic vapor phase epitaxy. It will be shown that the rods grow via a self-catalyzed vapor-liquid-solid (VLS) growth mode [1]. A large variety of rod structures can be achieved with heights up to 50 µm, diameters from 10 nm to a few µm and densities up to 10^8 cm-2. The presence of Si during growth of the GaN rods has a strong influence on the aspect ratio. Furthermore, Si improves the rod morphology yielding to rods with a regular hexagonal shape, smooth sidewall facets and sharp edges. Several experiments will be presented to clarify the role of Si during the growth of GaN rods. Structural investigations were carried out utilizing energy dispersive X-ray spectroscopy in combination with transmission electron microscopy. A thin SiN layer exists on the sidewall facets of the GaN rods. Si-N has a larger binding energy compared to GaN and the SiN layer acts as an antisurfactant for GaN. These effects stabilize the sidewall facets promoting vertical growth. The influence of the SiN layer on the InGaN quantum well growth, on the thermal stability and on physical etching experiments will be discussed. Finally, a model will be presented summarizing the role of Si during the VLS GaN rod growth [2].

K.PI 5

[1] C. Tessarek et al., J. Appl. Phys. 114, 144304 (2013). [2] C. Tessarek et al., Cryst. Growth Des., submitted.

add to my program **(close full abstract)**

17:00 **Stark effect in GaNAsBi/GaAs quantum wells operating at 1.55 µm** K.PI 6

Authors : C. Bilel*, M. M. Habchi, A. Rebey, and B. El Jani
Affiliations : University of Monastir, Faculty of Sciences Unité de Recherche sur les Hétéro-Epitaxies et Applications (URHEA), 5019 Monastir, Tunisia E-mail: * chakroun_bilel01@yahoo.fr

Resume : The effect of an applied stationary electric field on the band structures of GaNAsBi/GaAs quantum wells has been investigated using self-consistent calculations. Such study based on the optimization of N and Bi contents can be useful to improve physical proprieties of emitters or photodetectors devices operating at 1.55 µm. We have examined the quantum confined Stark effect on the shape of the confining potential, the Fermi level, the subband energies and their corresponding wave functions as well as their occupations, and the charge density distributions. We have also determined the oscillator strength and the absorption coefficient of the inter-subband transitions and their dependences on the applied perturbation. Keywords: Stark effect; GaNAsBi/GaAs QWs; band structures; self-consistent calculations.

add to my program **(close full abstract)**

17:00 **Investigations of in-situ reflectance during MOVPE of GaN on GaAs (100)** K.PI 7

Authors : J. Laifi 1, N. Chaaben 1, H. Bouazizi 1, N. Fourati 2, C. Zerrouki 2, A. Bchetnia 1 and B. El Jani 1.
Affiliations : 1. Unité de Recherche sur les Hétéro-Epitaxies et Applications, Faculté des Sciences de Monastir 5019, Université de Monastir, Tunisia; 2. Cnam, Laboratoire de Physique, EA2405, 2 Rue Conté, 75003, Paris, France. Corresponding authors: chaabennoureddine6@gmail.com.

Resume : The growth of GaN layers by metal organic vapor phase epitaxy (MOVPE) on (100) GaAs substrates was performed at growth temperature range from 500 to 600 °C. Laser reflectometry (LR) at 632.8 nm wavelength was employed for in situ monitoring of all growth steps. Experimental reflectivity traces were simulated to determine the surface roughness profiles during the first growth stage of GaN. The simulation results show that the surface roughness increases to reach a limit value depending on growth temperature. Due to surface roughness profile in first growth stage, the time-dependence growth rate was found non negligible. This growth kinetic evolution at first growth stage was taken account to give more precise measurements of growth rate at different growth temperatures. From these investigations the thermal activation energy of growth process was found at around 0.178 eV. The in-situ reflectance analysis where correlated with those obtained by ex-situ spectral reflectance (SR) and Atomic Force Microscopy (AFM) that showed good accordance. The all used analyses techniques showed better surface morphology when the GaN buffer layer is grown at lower temperature, while three dimensional (3D) island growth was observed at higher temperature. Keywords: GaN, GaAs substrate, MOVPE, in-situ reflectance, AFM.

add to my program **(close full abstract)**

17:00 **MOVPE of GaN on high-index GaAs substrates** K.PI 8

Authors : J. Laifi 1, N. Chaaben 1, H. Bouazizi 1, C. Zerrouki 2, N. Fourati 2, A. Bchetnia 1 and B. El Jani 1.
Affiliations : 1. Unité de Recherche sur les Hétéro-Epitaxies et Applications, Faculté des Sciences de Monastir 5019, Université de Monastir, Tunisia; 2. Cnam, Laboratoire de Physique, EA2405, 2 Rue Conté, 75003, Paris, France. Corresponding authors: chaabennoureddine6@gmail.com.

Resume : GaAs substrates with various crystallographic orientations (100), (111)A, (112)A and (113)A were used to grow low temperature GaN by metal organic vapor phase epitaxy (MOVPE). In this work we attempt to provide an understanding of GaN buffer layer as a function of substrate orientation at the growth temperature range of 500-600°C. The substrates were loaded together in the reactor to grow GaN layers at the same conditions on each substrate. The growth on GaAs (100) was in-situ monitored by laser reflectometry (LR). The thicknesses of samples were ex-situ determined by spectral reflectivity (SR). Surface morphology and roughness of samples was investigated by atomic force microscopy (AFM). The nitridation of substrates at 550°C during 10 min leads to GaN nucleus deposition showing clear morphological differences. By keeping the same nitridation conditions, a series of GaN samples were grown for different growth temperature on each substrate. The morphological observations show GaN islands formation where their density and size vary greatly with growth temperature and substrate orientation. The AFM analyses show that GaN surface

roughness depends on substrate orientation. From SR measurements, the GaN growth rates were extracted for each substrate orientations. The Arrhenius plots of growth rate versus temperature give specific activation energy for each orientation indicating anisotropy of GaN growth. Keywords: High index GaAs, GaN, MOVPE, growth rate, Activation energy.

add to my program (close full abstract)

17:00 **The partial decomposition study of GaN at 1200 °C under N2**

Authors : H. Bouazizi, N. Chaaben, J. Laifi, C. Saidi, A. Bchetnia and B. El Jani.
Affiliations : Unité de Recherche sur les Hétéro-Epitaxies et Applications, Faculté des Sciences, Université de Monastir, 5019, Tunisia. Corresponding authors: chaabennoureddine6@gmail.com

Resume : The partial decomposition of GaN was studied in metal organic vapor phase epitaxy (MOVPE) reactor at 1200 °C under N2. The surface changes during GaN decomposition were in-situ monitored by laser reflectometry. The GaN decomposition was investigated in different stages and the kinetic of decomposition was studied as a function of initial GaN thickness. To give a good comparison between decomposed samples and with the as grown samples, we kept almost the same decomposed thickness at around 0.6 µm. Based on scanning electron microscope (SEM), high resolution X-ray diffraction (HRXRD), spectral reflectance (SR) and Photoluminescence (PL), the properties of GaN samples before and after decomposition were compared. Lower decomposition rate and lower surface degradation were observed for higher initial GaN thickness that is associated for complete coalesced GaN. The in-situ reflectance shows relatively good contrast with very pronounced oscillations which is in good agreement with SR measurements and surface state observations by SEM. It was also found that in the best case the surface does not significantly damaged and the optical and crystalline properties of the as grown and decomposed GaN are very similar. In particular, HRXRD gives almost the same full width at half maximum (FWHM) of (00.2) and (10.2) RCs for the as grown and decomposed GaN having higher initial thickness. Keywords: Partial decomposition, GaN, In situ-reflectance, Thickness, Decomposition rate.

K.PI 9

add to my program (close full abstract)

17:00 **First study of AlGaN thermal decomposition under H2**

Authors : N. Chaaben, H. Bouazizi, J. Laifi, C. Saidi, A. Bchetnia and B. El Jani.
Affiliations : Unité de Recherche sur les Hétéro-Epitaxies et Applications, Faculté des Sciences, Université de Monastir, 5019, Tunisia. Corresponding authors: chaabennoureddine6@gmail.com

Resume : We studied the thermal decomposition of low Al content AlGaN under H2 in MOVPE vertical reactor operated at atmospheric pressure. A series of decomposed samples were studied where the Al content and decomposition temperature are varied. Different stages of decomposed GaN and AlGaN were observed. The surface changes in GaN and AlGaN were in-situ monitored by laser reflectometry and ex-situ characterized by optical microscope (OM) and scanning electron microscopy (SEM). Critical decomposition temperature of AlGaN was found to increase with Al content which confirms the higher stability of AlGaN with more Al incorporation. The kinetic decomposition of AlGaN was studied in temperature range of 1000-1200°C that gives activation energy of thermal decomposition process of about 1.513 eV which is larger than that of GaN that is around 0.387 eV at the same decomposition conditions. The room temperature photoluminescence (PL) analyses showed UV band with almost position compared to the as grown indicating that Al content in AlGaN does not significantly change after partial decomposition. They also showed that the yellow band intensity increases after partial decomposition of AlGaN. Keywords: Thermal decomposition, AlGaN, Temperature, In situ-reflectance, Yellow band.

K.PI 10

add to my program (close full abstract)

17:00 **Enhancement of optical characteristics of green-emitting spherical Lu3Al5O12: Ce3+ phosphor**

Authors : Young-Hyun Song 1, Eun-Jun Chung 1, Mong-Kwon Jung 2, Takaki Masaki 1, Dae-HoYoon 1
Affiliations : 1. School of Advanced Materials Science & Engineering, Sungkyunkwan University, Suwon 440-746, Republic of Korea; 2. Hyosung Corporation, R&D Business Labs, Anyang 431-080, Republic of Korea

K.PI 11

Resume : High quality and single-phase spherical Lu3Al5O12 phosphor materials are prepared with a solution method using spherical Al2O3. This technique makes it possible to obtain pure phase and allows enhancement of Lu3Al5O12 phosphor. The Lu3Al5O12: Ce3+ phosphor using spherical Al2O3 shows a higher emission intensity than other ones. The phosphor-converted white LEDs were realized with Lu3Al5O12: Ce3+ phosphor, which shows a high

CRI value with a high luminous efficacy. This phosphor and the synthesis method are expected to be promising candidates for realizing the white LEDs.

add to my program (close full abstract)

17:00 **Effect of series resistance and interface states density on the electrical characteristics of (Mo/Au)/AlGaN/GaN heterostructures**

Authors : M. Mostefaoui 1 2, H. Mazari 1, S. Mansouri 1, Z. Benamara 1, R. Khelifi 1, N. Benseddik 1, K.Ameur 1, N. Benyahya 1, J.M. Bluet 3, W. Chikhaoui 3
Affiliations : 1. Laboratoire de Microélectronique Appliquée, Département d'électronique,Université Djillali Liabès de Sidi Bel-Abbes, 22000 Sidi Bel-Abbes, Algérie; 2. Unité de Recherche en Energies Renouvelables en Milieu Saharien, Centre de Développement des Energies Renouvelables, P.O. Box 478, Adrar, Algeria; 3. Université de Lyon, Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, INSA de Lyon, Villeurbanne F-69621, France.

Resume : In this study, we investigate the electrical characteristics of (Mo/Au)/AlxGa(1-x)N/GaN heterostructures (x=0.24) grown by Low Pressure Metal Organic Chemical Vapour Depostion on SiC substrates. The current-voltage (I-V) at room temperature, The frequency dependence capacitance voltage (C-V) and conductance voltage (G/ω-V) of the (Mo/Au)/AlxGa(1-x) N/GaN heterostructures was analyzed . C-V and G/ω-V measurements were carried out over a frequency range of 10 kHz to 1MHz. The series resistance (Rs) and interface states density (Nss) have been investigated by using the forward and reverse bias current–voltage (I–V), capacitance–voltage (C–V) and conductance–voltage (G/ω-V) measurements at room temperature. In order to determine the density distribution of Nss profile, we applied the high–low frequency (CHF–CLF) methods. Experimental results confirmed that the Nss, Rs were important parameters strongly influenced on the electrical properties of the (Mo/Au)/AlxGa(1-x)N/GaN heterostructures.

K.PI 12

add to my program (close full abstract)

17:00 **GaN:Pr3+ nanostructures for red solid state light emission**

Authors : J. Rodrigues 1, M. Felizardo 2, E. Alves 2 3, A. J. Neves 1, G. Tourbot 4, T. Auzelle 4, B. Daudin 4, M. Boćkowski 5, K. Lorenz 2 3, T. Monteiro 1
Affiliations : 1. Departamento de Física & I3N, Universidade de Aveiro, 3810-193 Portugal; 2. IST, Instituto Superior Técnico, Campus Tecnológico e Nuclear, Universidade de Lisboa, EN10, 2695-066 Bobadela LRS, Portugal; 3. IPFN, IST, Lisboa, Portugal; 4. CEA/CNRS Group,"Nanophysique et Semiconducteurs", INAC, CEA/Grenoble, 17 rue des Martyrs, Grenoble Cedex 9, 38054, France; 5. Institute of High Pressure Physics, Polish Academy of Sciences, 01-142 Warsaw, Poland

Resume : Gallium nitride (GaN) is a wide band gap semiconductor exhibiting exceptional properties for solid state lighting. Moreover, GaN appears as an excellent host for the incorporation of lanthanides allowing covering a wide emission range of the electromagnetic spectrum by an appropriate choice of the dopant ion. With an intra-4f 2 electronic configuration, Pr3+ is known to be an efficient red emitter in wide band gap hosts. In GaN films the intensity of the dominant transition between the 3P0->3F2 multiplets is known to suffer a strong reduction with increasing temperature (~80% from 14 K to room temperature (RT)) in implanted samples annealed at ~1000 ºC. In order to increase the luminescence efficiency by minimizing the nonradiative processes alternative, approaches were adopted such as the annealing at high temperatures and high N2-pressures (HTHP) and the use of low dimensional structures, namely GaN nanowires (NWs) and quantum dots (QDs). In particular, NWs offer some advantages over traditional layered structures, mostly due to their ability to be grown on various and cheap substrates such as silicon. Higher extraction efficiency is also expected when compared with the planar structures. In this work, a comparative study of the red Pr3+ emission is performed for GaN films, NWs and QDs. All the samples exhibit the sharp 3P0->3F2 transition at RT and in the HTHP-annealed films the emission can be observed with the naked eye. The role of the implantation and thermal annealing parameters on the red luminescence will be discussed.

K.PI 13

add to my program (close full abstract)

17:00 **The High Internal Quantum Efficiency of GaN epilayers grown on β-Ga2O3**

Authors : Mufasila M. Muhammed, Idris A. Ajia, Yoshikatsu Morishima, Yoshihiro Yamashita, Shinkuro Sato, Akito Kuramata, and Iman Roqan
Affiliations : Mufasila M. Muhammed; Idris A. Ajia; Iman Roqan - King Abdullah University of Science and Technology, Thuwal, Saudi Arabia. Yoshikatsu Morishima; Yoshihiro Yamashita; Shinkuro Sato; Akito Kuramata -Tamura Corporation, Sayama, Saitama 350-1328, Japan

K.PI 14

Resume : The efficiency of III-Nitride-based devices mainly depends on the line defect density. It is crucial to reduce the density of the line defects. β-Ga2O3

has recently been proposed as an alternative to the more ubiquitous substrates, including Al2O3 and SiC, because it combines the high transparency of sapphire with the conductivity of SiC and circumvents their undesirable properties. In addition, the lattice mismatch in β-Ga2O3 is estimated to be just 10%. Here, we show that high internal quantum efficiency (IQE) is reached in a high-quality crystal GaN film, grown on a monoclinic (-201)-oriented β-Ga2O3 substrate by metalorganic vapour phase epitaxy. Photoluminescence measurement shows very weak yellow band and intense bandedge emission with a high IQE of ~40%, which is quite remarkable compared with the IQE of GaN epilayers grown on sapphire. Time-resolved spectroscopy and Raman measurements were used to investigate the effect of nonradiative recombination due to defects. Atomic force microscopy (AFM) analysis shows that the mean square value of the roughness is 0.68 nm, which is indicative of a very smooth surface. AFM shows the dislocation density of the film to be in the range of 2 to 8 × 108 cm2. X-ray diffraction (XRD) measurements evaluate the epitaxial structure and strain, indicating that GaN films grown on β-Ga2O3 are single crystalline wurtzite along the c-axis. The width of the rocking curve (0.16 arc) indicates that the quality of the crystal is high.

add to my program **(close full abstract)**

17:00 **Decoupling the residual stress induced by lattice mismatch and CTE mismatch in GaN-based LED**

Authors : Y. C. Lin and C. Y. Liu
Affiliations : Dept. of Chemical Engineering and Materials Engineering, National Central University, Jhong-li, Taiwan, R. O. C

Resume : The net electric field in the InGaN multi-quantum wells (MQWs) would greatly affect the lighting efficiency and the optical performance of the GaN-based LED. The built-in field, polarization field, carrier screening field and the applied electric field are known to be the major electrical fields in the InGaN MQWs of the GaN-based LEDs. Among the above four electrical fields, the polarization field is directly related to the GaN/InGaN epitaxial processes. The piezoelectric polarization is caused by both lattice mismatch (LM) and CTE mismatch (thermal stress; TM) between InGaN wells and GaN barriers or GaN epilayers and sapphire substrate after heteroepitaxial process. In the past, many researchers reported that the magnitude of the LM-induced piezoelectric field is larger than the TM-induced piezoelectric field by one order. In this work, we measured the residual stress induced by lattice mismatch and CTE mismatch in GaN-based LED by Raman spectrum. The obtained residual stresses can bring out the piezoelectric fields induced by lattice mismatch and CTE mismatch by direct piezoelectricity. Surprisingly, we find that TM-induced piezoelectric field is dominant factor over the LM-induced piezoelectric field. We believed that the theoretical in-plane stress caused by lattice mismatch is possibly relaxed by the threading dislocations formation. The detail relaxation mechanism of LM-induced stress by the dislocation formation will be discussed in this talk.

K.PI 15

add to my program **(close full abstract)**

17:00 **Influence of indium composition on the Efficiency of InxGa(1-x)N Single-junction solar cell**

Authors : M. Mostefaoui 1 2,*, H. Mazari 1, S. Khelifi 2, N.Sahouane,A.Rouabhia 2
Affiliations : 1. Unité de Recherche en Energies Renouvelables en Milieu Saharien, Centre de Développement des Energies Renouvelables, P.O. Box 478, Adrar, Algeria; 2. Laboratoire de Microélectronique Appliquée, Département d'électronique, Université Djillali Liabès de Sidi Bel-Abbes, 22000 Sidi Bel-Abbes, Algérie.

Resume : In this work, the solar power conversion efficiency of InxGa(1-x)N single-junction solar cell was investigated. Indium gallium nitride materials (InxGa(1-x)N) have been extensively studied for use in photovoltaic devices because their energy band gaps are between 0.7 and 3.4 eV the wide band-gap range make these materials useful for fabricating high-performance multi-junction solar cells. It is theoretically possible to achieve the record performance 50% with this only material system .For each value of xIn , an optimization of photovoltaic parameters for the solar cell (ICC, VCO , η and FF) is carried out. The value xIn=0.6 is obtained as the most pertinent parameter which provide us with the optimal efficiency. A simple optimized junction can reach conversion efficiency from > 20%. We have used the software SCAPS to simulate a Single-junction solar cell. We compared the results of our simulation with the results of other theoretical calculations published in the literature and analysed the causes of the differences among these results.

K.PI 16

add to my program **(close full abstract)**

17:00 **Optical and structural characterization of heat treated InGaN/GaN SQW and MQW for quantum well intermixing**

Authors : T. C. Esteves 1, J. Rodrigues 1, M. Sousa 1, C. Nico 1, M. B. Lourenço 2, A. Redondo-Cubero 2, N. Franco 2, M. J. Soares 1, A. J. Neves 1, M. R. Correia 1, K.P. O'Donnell 3, E. Alves 2, K. Lorenz 2, T. Monteiro 1
Affiliations : 1. Departamento de Física e I3N, Universidade de Aveiro, Campus Universitário de Santiago,3810-193 Aveiro, Portugal; 2. IPFN, Instituto Superior Técnico, Campus Tecnológico e Nuclear, Estrada Nacional 10, P-2695-066 Bobadela LRS, Portugal; 3. SUPA Department of Physics, University of Strathclyde, Glasgow, G4 0NG, Scotland,UK

Resume : Single and multiple InGaN/GaN quantum-wells (SQW, MQWs) are well recognized by their relevance in solid-state lighting. However, the LEDs based on these structures exhibit reduced internal quantum efficiency in the green region, due to pyro- and piezo-electric fields which cause the quantum confined Stark effect (QCSE) to separate electrons from holes. To improve the efficiency in the green spectral region we attempt to promote quantum well intermixing (QWI) in a controlled way to achieve graded QWs and mitigate the QCSE [1]. Furthermore, the grading of the QW layer composition is also expected to reduce Auger effects [2], which are still somewhat controversial in III-N. The idea is to combine low fluence ion implantation with thermal annealing treatments in order to enhance the QWI efficiency. Prior to the implementation of these studies a comprehensive investigation of the effects of heat treatments on the optical and structural SQW and MQW structures should be realized. As-grown and thermally annealed InGaN/GaN SQW and MQWs were examined by photoluminescence (PL), X-ray diffraction (XRD) and Rutherford Backscattering Spectrometry/Channelling (RBS/C). PL emission is stable for annealing up to 1000 ºC confirming the low diffusion coefficients in III-N materials and underlining the necessity of ion implantation to enhance QWI. Annealing at 1100 ºC in a N2:NH3 or pure N2 atmosphere, promotes strong changes in the PL spectra with a loss of the QW luminescence limiting the viable annealing temperatures in subsequent studies of QWI. [1] O'Donnell, K. P., et al., Phys. Stat. Sol. RRL 6, (2012) 49. [2] Vaxenburg, R., et al., Appl. Phys. Lett., 103 (2013) 221111.

K.PI 17

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17:00 **First-principles study of the structural, electronic, and optical properties of the ZnO/GaN heterojunction**

Authors : M. Zemzemi 1 and S. Alaya 1 2
Affiliations : 1. Laboratory of Physics of Materials and Nanomaterials applied at Environment, Faculty of Sciences in Gabes, Gabes University, Erriadh City, Zrig, 6072 Gabes, Tunisia 2. King Faisal University, College of Science, Physics Department 31982 Hofuf, Saudi Arabia

Resume : Light-emitting diodes (LEDs) based on wideband gap semiconductor have attracted considerable attention due to its potential optoelectronic applications in illumination, mobile appliances, automotive and displays. The most important factor in realizing high-quality heterostructure devices is the structural relationship between the semiconductors forming the heterojunctions, because the lattice mismatch causes extended defects with detrimental effects at the interface. For this reason using materials with close lattice parameters is essential for fabricating high-quality heterostructure devices. With a large direct band gap of 3.37 eV and a large exciton binding energy of 60 meV, ZnO has attracted much attention for its application in optoelectronics applications, such as LEDs, photodetector and laser diodes. The fabrication of high-quality p-type ZnO remains great challenge. Many researchers reported on the heterojunction LEDs with n-type ZnO grown on p-type materials of Si, GaN and conducting oxides [M.Zemzemi and S. Alaya, Superlattice Microst. 2013]. GaN is the one which has very close lattice parameters to ZnO, with a lattice mismatch of 1.8%. Many experimental studies have reported growth, processing, and fabrication of n-ZnO/p-GaN heterojunction LED devices. We complete these studies by a theoretical work in the framework of the Density Functional Theory. We are interested in this study of the ZnO/GaN heterojunction to calculate the electronic and optical properties.

K.PI 18

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17:00 **Modeling the emission characteristic of single 3D core-shell LEDs using ray tracing**

Authors : Johannes Ledig, Merten Popp, Hergo–H. Wehmann, Andreas Waag
Affiliations : Institut für Halbleitertechnik, Technische Universität Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany.

K.PI 19

Resume : Three dimensional light emitting diodes (LEDs) with a core-shell geometry are supposed to be substantially advantageous over conventional

planar LEDs. With pitches of several µm and sidewall dimensions larger than the wavelength, photonic crystal effects are not expected to dominate and wave simulations are not needed to calculate the light propagation. However, the photons will undergo a multiple reflection on their way out which needs to be known in detail if such µm-structures are to be optimized for light extraction. Photon path simulations of a single 3D structure are performed by means of a ray tracing software with a specially implemented camera. This delivers orthogonal images of the modeled structure and by rotating it around the model in a series of observation angles it is also used to create Lambert’s plots of the angle resolved emission data comparable to the far-field. Hexagonal columns with an aspect ratio of 5 have been modeled including a truncated pyramid at the top - representing the semi-polar facets and the c-plane top facet of the GaN columns grown by MOVPE. The ray tracing simulations were performed for an air ambient and a small spherical light source placed in the center of the column or close to its sidewall facet at 90% distance from the center. 2D images and Lambert's plots obtained by the orthogonal camera shows the emission characteristic with respect to reflection and refraction from a point source at different positions inside the structure.

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17:00

Effects of Current-Crowding-Induced Self-Accelerating Thermal Process on Optical Degradation of GaN-Based Light-Emitting Diodes

Authors : Eunjin Jung, Seongjun Kim, Young-un Gil, Seonghoon Jeong, Hyunsoo Kim
Affiliations : School of Semiconductor and Chemical Engineering, Semiconductor Physics Research Center, Chonbuk National University, Jeonju 561-756, Korea

Resume : The rapid optical degradation of GaN-based light emitting diodes (LEDs) should be carefully taken into consideration due to its detrimental effect on product performance. According to a number of previous studies, the degradation kinetics could be due to failure of the LED chips and deterioration of the packaging materials. These observed mechanisms play a crucial role in degrading LEDs depending on the stress condition. It is likely that the rapid degradation of LEDs involves multiple degradation kinetics instead of a single mechanism. However, systematic studies investigating the rapid optical degradation of LEDs and corresponding degradation kinetics are still lacking. In this study, we investigated the reliability characteristics and degradation kinetics of relatively less slowly degraded LEDs (aged at 100 mA, 100 ℃, LED-A) and rapidly degraded LEDs (aged at 200 mA, 100 ℃, LED-B). The LED-A and LED-B showed a different degradation rate of 3.0×10^{-4} and 2.7×10^{-3} h^{-1}, respectively, in which the degradation rate corresponds to a slope of optical output power versus time plots. The corresponding degradation kinetics were also different depending on the stress current, i.e., the generation of nonradiative recombination defects was mainly responsible for the degradation of the LED-A, while multiple degradation kinetics including a drastic increase of defects, contact failure, and chip detachment from the lead frame were responsible for the rapid optical degradation of the LED-B. The origin of the multiple degradation kinetics could be due to the current-crowding effect, which causes local heating of the device and hence a self-accelerating thermal process. The rapidly degraded LEDs consistently showed a very large junction temperature from 36 ℃(pristine) to 74 ℃ (failed). These results show that the LEDs should be avoided when current crowding occurs under harsh conditions in reliable lifetime testing and/or for practical use.

K.PI 20

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17:00

Impact of Schottky contacts on the electrical characteristics of single channel Al0.2Ga0.8N/GaN high electron mobility transistor with Al0.3Ga0.7N as back barrier

Authors : Kuldeep Takhar, P. Bhattacharya, K. Ghosh, S. Ganguly, D. Saha and Apurba Laha
Affiliations : Department of Electrical Engineering and Center of Excellence in Nanoelectronics, Indian Institute of Technology Bombay, Mumbai 400076, India

Resume : AlGaN/GaN based HEMT are widely used for high power switching, microwave power and radio frequency (RF) low noise amplifier applications due to its unique material properties. However, there are several challenges that require significant research to meet the modern technological demands. One of the most critical parameters that significantly degrades the performance of AlGaN/GaN based HEMT is large leakage current caused by inferior Schottky gate contact and buffer induced leakage. In present study, we carried out systematic investigation of large number of metals (e.g. Ni, Ni/Au, Pt, Pt/Al, Pd, Ag, Cr and Ti) and metal/semiconductor multilayers (e.g Ge/Ni/Ge/Ni/Au) based Schottky contacts on AlGaN/GaN heterostructure grown by PA-MBE on Sapphire

K.PI 21

substrates. Interestingly, estimated Schottky barrier heights for various metals exhibit no systematic correlation with respect to metal work functions, inferring pinning of Fermi level at interface due to metal-induced-gap-states (MIGS). Introduction of several buffer layers such as MgO, Gd_2O_3, TiO_2 and Ge between AlGaN and metal contacts shows significant impact on Schottky barrier height which, we believe, could be due to de-pinning of Fermi levels. Optimized Schottky contact shows reverse bias (1V) leakage current as low as <1x10^-7A at 30°C. Furthermore, use of $Al_{0.3}Ga_{0.7}N$ (~10nm) as back barrier beneath $Al_{0.2}Ga_{0.8}N$/GaN HEMT improves breakdown voltage up to 200V which is almost 4 times higher than that of without back barrier.

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17:00 **Synthesis of GaN fine powder from $Ga(NO_3)_3{\cdot}xH_2O$ by DC arc thermal plasma** K.PI 22

Authors : Tae-Hee Kim, Sooseok Choi, Ye-seul Na (presenter) and Dong-Wha Park*
Affiliations : Department of Chemistry and Chemical Engineering and Regional Innovation Center for Environmental Technology of Thermal Plasma (RIC-ETTP), Inha University, 100 Inha-ro, Nam-gu, Incheon 402-751, Republic of Korea

Resume : Light emitting properties of gallium nitride (GaN) have considerable interest due to its quantum confinement effect in light emitting diodes (LEDs). Most optical displays are currently fabricated by growing GaN on substrate. However, the mismatches in lattice parameters and thermal expansion coefficients result in high dislocation densities in GaN films. Therefore, high purity and single phase GaN particles are strongly required to make uniform surface of optical displays by utilizing the fluorescent property of GaN with printing method using fine powder. In this work, GaN fine powder was synthesized by the arc thermal plasma. Gallium nitrate hydrate ($Ga(NO_3)_3{\cdot}xH_2O$) and ammonia (NH_3) were used as precursor to form GaN and melamine ($C_3H_6N_6$) was employed as an anti-oxidant. Unlike pure Ga ingot and Ga_2O_3 powder, ($Ga(NO_3)_3{\cdot}xH_2O$) is an abundant and economical material for the synthesis of GaN nanoparticle. In addition, $C_3H_6N_6$ is effective reactant to get rid of oxygen and hydrogen from ($Ga(NO_3)_3{\cdot}xH_2O$) raw material. Carbon generated from the decomposition of $C_3H_6N_6$ consumes oxygen of raw material and suppresses the formation of H_2O. The input power of argon thermal plasma was about 6 kW at the fixed arc current of 300 A. Synthesis process was performed at atmospheric pressure. $Ga(NO_3)_3{\cdot}xH_2O$ and $C_3H_6N_6$ were rapidly reacted in the high-temperature area of thermal plasma jet. All side of a reaction chamber where products were collected was cooled by cooling water. Synthesized GaN was analyzed as monoclinic crystal structure with a weak peak intensity in XRD (X-ray diffraction) pattern. Although fine GaN particles were identified by TEM measurement, they were agglomerated each other. Therefore, the improvement of crystallinity and the suppression of agglomeration are required in future work.

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17:00 **Heteroepitaxial growth and electric properties of scandium nitride films on m-face sapphire substrates** K.PI 23

Authors : Takeshi Ohgaki, Ken Watanabe, Isao Sakaguchi, Shunichi Hishita, Ohashi Naoki, Hajime Haneda
Affiliations : Environment and Energy Materials Research Division, National Institute for Materials Science

Resume : Scandium nitride (ScN) films were grown on m-face sapphire substrates by a molecular beam epitaxy method, and their crystalline orientation, crystallinity and their electric properties were examined. Epitaxial ScN films with an orientation relationship (110)ScN || (10-10)a-Al_2O_3 and [001] ScN || [1-210]a-Al_2O_3 were obtained regardless of difference of crystal structure, and their crystal orientation anisotropy were negligible small. The crystallinity and Hall mobility of the films were drastically improved by applying high-temperature growth. The carrier concentration and Hall mobility of the ScN films grown at 900°C ranged from 1019–1021 cm-3 and 80–140 cm2•V-1•s-1, respectively. The increase in carrier concentration with decrease in Hall mobility caused by carrier scattering of the ionized shallow donors was observed in the film grown under Sc-rich conditions. These results indicate that high-temperature growth and an m-face sapphire substrate were suitable for growth of high-quality ScN films.

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17:00 **Pulsed Laser Deposition of GaN Thin Film on Solution Processed ZnO Buffer Layer** K.PI 24

Authors : Hao-Yu Wu, Yu-Wen Cheng, Yu-Zhong Lin, Chien-Ting Liu, Pin-Chun Shen and Ching-Fuh Lin

Affiliations : Graduate Institute of Photonics and Optoelectronics, National Taiwan University

Resume : Recently gallium nitride (GaN) has become one of the most popular materials for the fabrication of UV-Visible LEDs, UV-detectors and high power, high frequency devices. Zinc oxide (ZnO) is a promising buffer layer material for GaN epitaxy due to its small lattice mismatch. The other important characteristic of ZnO is easy to be etched by acid. After GaN growth on ZnO, we could bond it with another high thermal conductive substrate such as Si, and then transfer the thin film by etching ZnO layer with acid. ZnO film can be deposited via following methods such as MBE, ALD, or sputter. However, high vacuum and high temperature environment is essential for the mentioned methods. In contrast, hydrothermal method presents good quality of ZnO film fabrication in non-vacuum environment, much lower process temperature and high potential of large scale manufacture. Avoiding ZnO volatilization, we use pulsed laser deposition to deposit GaN thin film which is no corrosive gas during process. The morphology of ZnO buffer layer and GaN films was examined using SEM, and the crystallinity of the films was examined by XRD. In contrast to GaN grown on sapphire without any buffer layer, the one grown with ZnO buffer layer has better crystallinity due to the low lattice mismatch of ZnO and GaN. The FWHM of the GaN on ZnO XRD pattern was 0.3758(degree).

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17:00 **GaN Film Without Stress by Pulsed Laser Deposition and Post-annealing Process** K.PI 25

Authors : Yu-Wen Cheng, Hao-Yu Wu, Yu-Zhong Lin, Pin-Chun Shen, Chien-Ting Liu, and Ching-Fuh Lin
Affiliations : Graduate Institute of Photonics and Optoelectronics, National Taiwan University

Resume : In recent years, gallium nitride (GaN)-based III-V semiconductors have captured much attention due to their potential applications in UV visible light-emitting diodes, laser diodes, and high electron mobility transistors. However, the residual stress on epitaxial film may cause the deterioration of device's internal quantum efficiency, electrical properties, and optical properties. Therefore, we develop a novel method to obtain the strain-free GaN film. We use pulsed laser deposition (PLD) to grow high temperature GaN directly without buffer layer. After growing GaN film, we use high-temperature furnace to anneal it to relieve stress. By post-annealing treatment, we find out that GaN film undergoes three stages: phase transition stage, strain-alteration stage, and thermal decomposition stage. In the first stage, GaN film transfers from rock salt phase to Wurtzite phase. In the second stage, the stress of GaN starts to change and a strain-free GaN film can be obtained under specific annealing temperature. In the final stage, the GaN starts to undergo thermal decomposition when annealing temperature is too high. Comparing with the traditional growth technique, which contains residual stress, we can collocate PLD growth GaN with post-annealing process to obtain strain-free GaN film. Subsequently, the strain-free GaN can be used to grow strain-free epitaxial layer to attain better performance than the one with residual stress.

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17:00 **Correlation of recombination processes with structural properties in InGaN/GaN based core-shell microLEDs** K.PI 26

Authors : M. S. Mohajerani 1, X. Wang1, J. Hartmann 1, L. Caccamo 1, J. Ledig 1, K. Hecht 1, T. Schimpke 2, M. Mandl 2, M. Strassburg 2, H. Schuhmann 3, M. Seibt 3, G. Lilienkamp 4, W. Daum 4, H.-H. Wehmann 1, A. Waag 1
Affiliations : 1. Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany 2. Osram Opto Semiconductors GmbH, Leibnizstraße 4, 93055 Regensburg, Germany 3. Physikalisches Institut, Halbleiterphysik, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany 4. Institut für Energieforschung und Physikalische Technologien, Leibnizstr. 4, D-38678 Clausthal, Germany

Resume : During recent years a three-dimensional core-shell approach has been considered as a promising way to produce large emitting area, m-plane light emitting diodes (LEDs). Non-polar m-plane nitrides benefit from the lack of the piezoelectric field and electron-hole separation which cause a reduction of radiative recombination efficiency in the active region of LEDs. However, present core-shell microLEDs practically are not as efficient as conventional c-plane layer LEDs, therefore many attempts are still going on to improve the structural quality and consequently internal quantum efficiency (IQE). For this purpose, influences of different growth parameters and intermediate layers should be investigated in detail. In this study, we explored optical properties of our core-shell InGaN/GaN microLEDs grown by metal-organic vapor phase epitaxy (MOVPE) by means of photoluminescence (PL) spectroscopy and analyze

recombination mechanisms in correlation with a quality of different structures. The interface of the core, investigated by transmission electron microscopy (TEM) and Auger electron spectroscopy (AES), showed great influence on the radiative recombination of a first quantum well (QW). Activation energies of nonradiative channels, excitonic binding energies, and their localization were determined by the temperature-dependent PL. Together with the power-dependent PL, we provide an insight into the relative values of IQE for our state of the art core-shell structures.

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17:00 **Photoelectrochemical properties of TiO2 coated InGaN layer for water splitting application**

Authors : Lorenzo Caccamo 1, Jana Hartmann 1, Xue Wang 1, Hao Zhou 1, Matin Sadat Mohajerani 1, Sanjeev Kumar Gurram 2, Günter Bräuer 2, Hergo-H. Wehmann 2, Hao Shen 1 and Andreas Waag 1
Affiliations : 1. Institut für Halbleitertechnik, Technische Universität Braunschweig, Hans-Sommer-Straße 66, 38106 Braunschweig, Germany; 2. Fraunhofer Institute for Surface Engineering and Thin Films, Bienroder Weg 54e, 38108 Braunschweig, Germany

Resume : Direct conversion of solar energy into chemical energy via water photoelectrolysis is an attractive and challenging issue. Many efforts are being made to develop semiconducting materials that have a significant light absorption in the visible range, good electrical properties and chemical stability. TiO_2, matches the requirement of chemical stability over a wide range of pH values, but due to its large band gap it is transparent for visible light. On the other hand InGaN is a promising candidate since its band gap can be tuned to absorb the visible light. However, the chemical stability of n-doped InGaN was found to be a key aspect under high acidic and basic solutions. In this study, we explored the photoelectrochemical properties of TiO_2 coated InGaN layers as a function of the TiO_2 layer thickness. Undoped $In_XGa_{(1-X)}N$ layers (x~0.3) were grown on GaN/sapphire templates by metal-organic vapor phase epitaxy (MOVPE). Subsequently, the undoped TiO_2 amorphous layers were deposited by atomic layer deposition (ALD). The optical and electrical properties of TiO_2/InGaN stacks were investigated using photoluminescence (PL), optical absorbance in the ultraviolet to visible range and current-voltage measurements. The stability was tested under simulated solar light (1 sun AM 1.5 g) over one hour of illumination. The stability of amorphous TiO_2 was found to be dependent on the solution that was employed: the layers were dissolved more effectively at low pH values.

K.PI 27

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17:00 **Characterisation of 3D-GaN/InGaN Light Emitting Diodes using Electron Microscopy.**

Authors : Ian Griffiths 1, David Cherns 1, Martin Mandl 2, Tilman Schimpke 2, Martin Strassburg 2.
Affiliations : 1. School of Physics, H H Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol, BS8 1TL, United Kingdom 2. Osram Opto Semiconductors GmbH, Leibnizstrasse 4, 93055 Regensburg, Germany

Resume : The development of 3D GaN/InGaN microstructures is of interest for use in high efficiency light emitting diodes (LEDs) for solid state lighting applications. Creating core-shell structures with InGaN Quantum Wells on the m-facets, compared to conventional c-plane films, will lead to not only a higher active region, but also a lower density of defects. The non-polar nature of the active region will lead to reduced piezoelectric fields, further increasing the efficiency. Core-shell GaN/InGaN microstructures have been grown by Metal Organic Vapour Phase Epitaxy (MOVPE) on patterned GaN on Sapphire substrates. The resulting arrays have been processed to create operational devices. The LEDs show several peaks in the overall optical emission varying with applied current as well as differing emission properties for adjacent microstructures on the same chip. Further characterisation has been performed using both Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM). This has allowed the study of both the internal structure and composition profile of the structures Studies of selected microstructures by TEM have shown the presence of a low density of basal plane defects nucleating at the interface between the defect free n-GaN core and the quantum well (QW) layer. The nature of these defects has been studied, along with the compositional variations between adjacent microstructures. The results have been correlated with variations in optical emission.

K.PI 28

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17:00 **Structure and luminescence properties of GaN-core/ZnO-shell nanowires**
Authors : Sunghoon Park, Soohyun Kim, Taeseop Hong and Chongmu Lee*
Affiliations : Department of Materials Science and Engineering, Inha University, Yonghyeondong, Nam-gu, Incheon 402 - 751, Republic of Korea
Resume : The effects of thermal annealing in an oxygen atmosphere on the photoluminescence properties of GaN-core/ZnO-shell nanowires have been examined. GaN-core/ZnO-shell nanowires were synthesized using a two-step process: thermal evaporation of GaN powders in an oxidizing atmosphere on Au-coated Si substrates followed by atomic layer deposition of ZnO. The photoluminescence measurement showed that GaN nanowires had an emission band centered at ~365 nm. In contrast, GaN/ZnO core-shell nanowires had an emission band centered at a~380 nm. The intensity of the main emission was enhanced by annealing the GaN/ZnO core-shell nanowires at 600 °C in an argon atmosphere and enhanced further by annealing in an oxygen atmosphere. The underlying mechanism for the enhancement of the emission intensity is also discussed.
K.Pl 29

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17:00 **Submicron confocal Raman and photoluminescence spectroscopy of In-rich InGaN light-emitting structures**
Authors : V.V. Strelchuk 1, O.F. Kolomys 1, A.S. Romanyuk1, and A.E. Belyaev 1, V.N. Pavlovskii 2, E.V. Lutsenko 2
Affiliations : 1. V. Lashkarev Institute of Semiconductor Physics of NASU, 03028 Kiev, Ukraine; 2. B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus
Resume : InxGa1-xN semiconductors is a promising material for optoelectronic devices such as color-tunable light-emitting structures. The spatial structural and composition inhomogeneity, indium clustering in In-rich InxGa1-xN layers significantly affect their emitting properties. In the present work spatial composition inhomogeneity in the set of single-layer In-rich (x = 0.4-1.0) InxGa1-xN(200 nm)/GaN(3 mkm) heterostructures grown by MOVPE and MBE methods were studied at submicron scale. Obtained results of the changes in emitting spectral parameters of InxGa1-xN layers using scanning in the plane as well as on the depth of samples were explained by the existence of structural-deformation and compositional disordering. On the base of energy peak positions of InxGa1-xN/GaN photoluminescence (PL) bands (including deformation shift) the non-uniform profiles of indium concentration distribution were obtained and interpreted. Raman spectra from InxGa1-xN/GaN heterostructures were analyzed. In-plane 2D maps and depth-profiles of indium distribution in In-rich InxGa1-xN layer were obtained. Analyzing the change in the frequency of A1(LO) (InxGa1-xN) phonon mode the indium concentrations were determined. In particular, for In0.4Ga0.6N layer indium concentration vary from 32 to 45% as well as from 36 до 42% for MOVPE and MBE samples correspondingly. Obtained concentration values are well correlated with X-ray data.
K.Pl 30

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17:00 **Temperature dependence of light emission from RE-doped semiconductors: 25 years after Favennec**
Authors : K.P.O'Donnell
Affiliations : Strathclyde U.
Resume : The temperature dependences of the emission spectra of luminescent semiconductors is of interest from both a fundamental and a practical viewpoint. It has recently been shown that a slight alteration of the accepted R/NR recombination model for the dependence of intensity on temperature and excitability on power density can produce experimental results that are far from intuitively obvious [1]. On the occasion of the 25th anniversary of the publication of Favennec?s rule [2], that widegap RE-doped semiconductors should be better light emitters at higher temperatures, we should be careful to avoid the pitfalls of extrapolation from a small set of known results. I shall explore several examples of light emission by GaN-related semiconductors in order to illustrate these points and provide an alternative description of luminescence quenching in semiconductors with particular relevance to GaN doped with rare-earth ions. [1] Michael A. Reshchikov, PHYSICAL REVIEW B 85, 245203 (2012) [2] P Favennec et al. ELECTRONC LETTERS 25, 718-9 (1989)
K.Pl 31

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17:00 **Synthesis, crystallinty and morphology of GaN@ZnO nanocomposites via Ga(OH) 3 nanostructures** K.Pl 32

Authors : Bong Kyun Kang, Sung Ryul Mang, Keun Man Song and Dae Ho Yoon
Affiliations : Sungkyunkwan University

Resume : III-nitrides nanostructures have attracted extensive attention due to their unique electronic and optical properties. Gallium nitride (GaN) has a direct wide bandgap of 3.4 eV at room temperature, and is a promising candidate material for short wavelength optoelectronic devices, such as light emitting diodes and laser diodes, as well as high power and high temperature operation devices. Compared with film and nanowires, GaN nanoparticles could be alternative hybrid integration materials with a variety of optical and electrical properties because of the flexible powder form and controlled shape or size, as well as low fabrication cost. In recent years, the fabrication of monodispersed semiconductor nanostructures has attracted extensive attention due to their distinct low effective densities, high specific surface area and potential scale dependent application in catalyst, optical devices, chemical sensor and drug delivery. The semiconductor-based photocatalysts such as TiO2, SrTiO3 and GaN have attracted extensive attention and have been used extensively to decompose water under UV light irradiation while efficiency is still low. To improve the photocatalytic activity, the semiconductor-based photocatalysts have to minimize recombination between electrons and holes as well as enhance photogenerated charge carrier via doping, large surface area and changed surface modification. In this work, monodispersed GaN nanostructures were synthesized successfully nitridation of Ga(OH)3 templates by using hydrothermal method. The GaN@ZnO nanocomposites were synthesized via hydrothermal methods. In addition, the crystal structure, morphology, optical properties and particle size of the monodispersed GaN@ZnO nanocomposites were analyzed using powder X-ray diffraction (XRD), high resolution transition electron microscope (HT-TEM), photoluminescence spectrometry (PL) and energy dispersive X-ray analysis (EDX).

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17:00 **Effect of wet chemical surface treatment on the surface photovoltage behavior of Ga-polar GaN columns**

Authors : M. Ali Deeb 1, J. D. Wei1, X. Wang 1, L. Caccamo 1, J. Hartmann 1, H.-H. Wehmann 1,W. Dziony 2, G. Lilienkamp 2, W. Daum 2, A. Waag 1
Affiliations : 1. Institute of Semiconductor Technology, Braunschweig University of Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany 2. Institute of Energy Research and Physical Technologies, Clausthal University of Technology, Leibnizstraße 4, 38678 Clausthal-Zellerfeld, Germany

Resume : Surface photovoltage (SPV) measurements are an important tool to analyze surface electronic properties of GaN surfaces. Surface states and band bending can be explored also in three dimensional (3D) GaN columns with a high spatial resolution. 3D GaN columns are usually grown with high silane flow rate, which leads to problems in overgrowth by e.g. InGaN quantum wells due to a silicon passivation of the surface. In order to get more information on the surface of GaN core before overgrowth, we performed SPV measurements. In an attempt to compare Si contaminated and Si free surfaces, SPV measurements have been performed before and after chemical etching the surface. The difference in the SPV behavior for Ga-polar GaN columns before and after etching will be presented. An initial drop of the SPV is found before etching with phosphoric acid. In contrast, a large initial rise of SPV is observed after etching as expected like high quality bulk GaN crystal. These different behaviors of Ga-polar GaN columns are attributed to the surface states originating from silicon containing layer which segregates on the GaN surfaces due to the silane flow during growth and which is removed by wet etching. Our SPV results indicate that surfaces of 3D GaN columns are modified by silane flow- induced contamination. This is also corroborated by Auger electron spectroscopy results. The problem has to be solved in order to produce high quality core-shell LEDs.

K.Pl 33

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17:00 **STEM-CL investigations on the influence of stacking faults on the optical emission of cubic GaN epilayers and cubic GaN/AlN multi-quantum wells**

Authors : R.M. Kemper 1 2, P. Veit 3, C. Mietze1 2, A. Dempewolf 3, T. Wecker1 2, J. Christen 3, D.J. As 1 2 and J.K.N. Lindner1 2
Affiliations : 1. University of Paderborn, Department of Physics, Warburger Str. 100, 33098 Paderborn, Germany 2. Centrer for Optoelectronics and Photonics, Warburger Str. 100, 33098 Paderborn, Germany 3. Otto-von-Guericke-Un iversity, FNW/IEP, P.O. Box 4120, D-39016 Magdeburg, Germany

K.Pl 34

Resume : Group III-nitrides like GaN, AlN and their alloys provide the materials basis for highly efficient optoelectronic and high-power devices operating at high temperatures. One of the key issues in device fabrication is the improvement of

the structural quality, because extended defects like dislocations may reduce the device performances. Cubic III-nitrides are advantageous compared to the hexagonal polytypes due to the lack of internal electric fields and are less investigated. Transmission electron microscopy (TEM) measurements give evidence that stacking faults (SFs) on the {111} planes are the predominant crystallographic defects in epitaxial films, which were grown on 3C-SiC/Si (001) substrates by plasma-assisted molecular beam epitaxy. Here we report for the first time the influence of {111} SFs on the cathodoluminescence (CL) emission characteristics of cubic GaN (c-GaN) films and cubic GaN/AlN multi-quantum wells. The correlation of the SFs and the luminescence output is evidenced with a CL setup integrated in a scanning TEM (STEM). By comparing STEM images and simultaneously measured CL signals it is demonstrated that SFs in these films lead to a reduced CL emission intensity. Furthermore, the CL emission intensity is shown to increase with increasing film thickness and decreasing SF density. This correlation can be connected to the reduction of the full width at half maximum of x-ray diffraction rocking curves with increasing film thickness of c-GaN films.

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17:00 **Phosphor-converted white light from blue-emitting InGaN microrod LEDs**

Authors : Tilman Schimpke 1 3, Martin Mandl 1 3, Ion Stoll 1, Dominik Scholz 1, Franz Zwaschka 2, Daniel Bichler 2, Barbara Huckenbeck 2, Andreas Waag 3, Hans-Juergen Lugauer 1, Martin Strassburg 1

Affiliations : 1. OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany; 2. OSRAM GmbH, Mittelstetter Weg 2, 86830 Schwabmünchen; 3. Institut f?r Halbleitertechnik, TU Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany.

K.PI 36

Resume : Core-shell III-nitride microrod (MR) light emitting diodes (LEDs) have been proposed as a possible route to overcome the efficiency droop by vastly increasing the active area, which is wrapped around the entire structure, and thus reducing the local current density. Today, the common way to achieve white light emission from InGaN LEDs is to convert a part of the emitted blue light using a phosphor, usually embedded in a silicone matrix and deposited onto the devices. A major amount of heat is generated via Stokes losses at the phosphor particles, which cannot be cooled effectively due to the low thermal transmittance of the silicone. High phosphor temperatures lead to thermal quenching and a reduced quantum efficiency of the conversion, hampering device efficiency and colour point stability. We have developed a method to deposit a fine-grained phosphor onto the sidewalls of MR structures. The improved thermal contact with the GaN material allows for improved phosphor cooling and will increase device performance. On MR samples with varying aspect ratios, a very good filling of the space between MRs was observed. Additionally, high refractive index materials were deposited on the phosphor-coated samples using standard processes. No cavities or voids were detected and the sub-µm wide gaps between phosphor grains were completely filled. The deposition of the micro-grain phosphor onto processed MR LEDs allowed studying optical properties and emission characteristics.

add to my program **(close full abstract)**

17:00 **Anomalously weak diffusion of oxygen in GaN at temperatures up to 3400 K and pressures up to 9 GPa**

Authors : A. Nikolenko 1, B. Sadovyi 2 3, V. Strelchuk 1, A. Romanyuk 1, A. Belyaev 1, S. Porowski 2, J. Weyher 2, I. Grzegory 2, I. Petrusza 4, V. Turkievich 4 and V. Kapustianyk 3

Affiliations : 1. V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine, 45, prospect Nauky, 03028 Kyiv, Ukraine; 2. Institute of High Pressure Physics PAS, Sokolowska str., 29/37, 01-142 Warsaw, Poland 3. Department of Physics, Ivan Franko National University of Lviv, 50, Dragomanova str., Lviv, 79005, Ukraine 4. V. N. Bakul Institute for Superhard Materials NAS Ukraine, 2, Avtozavodska str., Kyiv, 04074, Ukraine

K.PI 37

Resume : In this work, the bulk diffusion of oxygen in wurtzite-type GaN crystals at temperatures up to 3400 K and pressures up to 9 GPa is studied. For this purpose the GaN crystals grown by hydride vapor phase epitaxy (HVPE) and having strongly nonuniform distribution of oxygen (as revealed by photo-etching and SIMS measurements), the main donor in GaN, are used. Confocal micro-Raman spectroscopy is applied to estimate free electron concentration from the analysis of plasmon-LO-phonon coupled modes (LOPC). Thereby spatial distribution of free electron concentration is studied by lateral scanning along the cleaved surfaces of the investigated GaN crystals. Thus the HVPE GaN crystals studied are shown to contain heavily doped (n ~ 2.0÷4.0•10^19 cm-3)

and undoped (n ≤ 10^17 cm-3) areas having sharp step-like carrier concentration profiles in micrometer scale. Annealing at high temperatures and high pressures results in only slight diffusion blurring of the carrier profiles at a distance less than 10 um from the interface. Extremely small values of diffusion coefficient D ≤ 6.3•10-13 m2/s (T = 3400 K and P = 9 GPa) estimated from the measured diffusion length are in good agreement with K. Harafuji's molecular dynamic calculations [1], confirming the anomalously small diffusion coefficient in the N-sublattice of GaN. 1. K. Harafuji, T. Tsuchiya, K. Kawamura Molecular dynamics simulation for evaluating melting point of wurtzite-type GaN crystal // J. Appl. Phys. 96, 2501 (2004).

add to my program **(close full abstract)**

17:00 **Vacancy-related microstructure evolution in GaN**

Authors : M.G. Ganchenkova 1, V.A. Borodin 2
Affiliations : 1. NRNU MEPhI, Kashirskoe Sh. 31, 115409, Moscow, Russia; 2. NRC Kurchatov Institute, Moscow, 123182, Russia

Resume : The report deals with the investigation of properties and formation kinetics of vacancy-type defects in GaN. Based on the results of ab initio modelling we demonstrate that the formation of mixed Ga-N divacancies, close vacancy pairs on the nitrogen sublattice and pairs "oxygen-nitrogen vacancy" is favourable in terms of the energy gain. The relatively high mobility of nitrogen vacancies in n-type material in conjunction with the noticeable binding energies between nitrogen vacancies and other point defects provide favourable conditions for vacancy clustering. Detailed simulations in the framework of lattice kinetic Monte-Carlo approach at different temperatures and impurity (oxygen) concentrations demonstrate that nitrogen vacancy clustering can occur both homogeneously and heterogeneously (on gallium vacancies and impurities as nucleation centers), leading to the formation of small colloid gallium particles, nanovoids and oxygen nano-bubbles.

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add to my program **(close full abstract)**

17:00 **Si doping effects on structural, surface morphology and optical proprieties of GaN grown by MOCVD**

Authors : M. Bouzidi*, Z. Benzarti, I. Halidou, Z. Chine, B. El Jani
Affiliations : Université de Monastir, Faculté des Sciences Unité de recherche sur les Hétéro-Epitaxies et Applications (URHEA), 5000 Monastir, Tunisia. E-mail: * elbouzidimed16@yahoo.com

Resume : We investigated the silicon doping effects on GaN layers grown on sapphire substrate by metalorganic chemical vapor phase deposition (MOCVD). We have used silane (SiH4) to intentionally incorporate silicon during the crystal growth of GaN. The X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses were used to study the structural and surface morphology of the films. Room temperature photoluminescence spectra of Si doped GaN layers (GaN:Si) exhibited a decrease in the intensity of yellow luminescence (YL) with increasing SiH4 flow rate, which could be due to a decrease in the concentration of gallium vacancy (VGa) or VGa-related complexes. Fundamental optical band gap measured by photoreflectance showed a redshift up to a concentration of electrons of about n = 6×10^18 cm-3. Above this value, a sudden blueshift of the band gap energy was observed. This result was interpreted by the competing effects of Burstein-Moss band filling and band gap renormalization. Keywords: GaN:Si, Photoreflectance, Burstein-Moss effect, band gap renormalization, yellow luminescence, XRD, SEM.

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17:00 **Towards vertically emitting InGaN/GaN 3D nano-LEDs**

Authors : Jana Hartmann 1, Helena Franke 2, Matin Sadat Mohajerani 1, Johannes Ledig 1, Xue Wang 1, Frederik Steib 1, Martin Straßburg 3, Hergo-Heinrich Wehmann 1, Rüdiger Schmidt-Grund 2, Marius Grundmann 2, Andreas Waag 1
Affiliations : 1. Technical University Braunschweig, Institute of Semiconductor Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany; 2. University Leipzig, Institute of Experimental Physics III, Linnéstr. 5, 04103 Leipzig, Germany; T 3. OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

Resume : Defect free GaN material is a prerequisite for high efficiency light emitting diodes (LEDs) and laser diodes. Therefore, high aspect ratio vertical growth of three-dimensional (3D) GaN has been developed recently. These 3D structures are not only interesting for high efficiency LEDs, but might also be applied for vertical-cavity surface emitting lasers (VCSELs). Based on our existing 3D core-shell InGaN/GaN LED technology we are evolving structures with diameters smaller than 500 nm and combine them with a distributed Bragg reflector (DBR) in order to investigate the potential for vertically emitting 3D devices. The DBR consisting of aluminium oxide (Al2O3) and yttria-stabilized

K.PI 40

zirconia (YSZ) are fabricated by pulsed laser deposition (PLD) at 650°C. The vertical GaN based LED columns are grown by selective area growth (SAG) by metal organic vapour phase epitaxy (MOVPE) at much higher temperatures. Therefore the thermal strain and stability of the DBR has to be taken into account for combining these two technologies. As the epitaxial growth and the electrical connection of the later device is not possible directly on the dielectric DBR, we developed several approaches to position the DBR at the bottom of the 3D structures. In this work we will discuss first results of the two most promising approaches: Firstly, LED structures were re-grown on columns that have been truncated after DBR deposition and, secondly, a foil with a DBR was pressed onto the surface of the LED sample.

add to my program **(close full abstract)**

17:00 **Sol-gel Synthesis and Characterization Tm3+:NaGd(WO4)2 Blue Phosphors for White-LED application**

Authors : A.Durairajan 1 2, M.A. Valente 2*, D. Balaji 1 and S.Moorthy Babu 1
Affiliations : 1. Crystal Growth Centre, Anna University, Chennai-600025, India; 2. I3N-Aveiro, Department of Physics, University of Aveiro, Aveiro 3810 193, Portugal

Resume : Rare-earth activated inorganic phosphors have generated great research interest due to their wide application in solid state lighting (SSL) and optoelectronics. The phosphor has to fulfill the properties like high chemical stability, ease of fabrication, cost effective and less energy consumption. Down conversion from ultra violet to visible region with tri-color phosphors is the current technology for improving the white light emission. As conventional blue phosphors suffer drawbacks of chemical instability and high production cost, alkaline double tungstate based materials are seen as an alternate choice for new blue emission. For this purpose, Tm3+:NaGd(WO4)2 (Tm:NGW) blue phosphors were synthesized by soft-chemical method. The synthesized powders were characterized by powder XRD, FT-IR, Raman, SEM and spectroflourimeter respectively. The phase formation was explored by powder XRD. The various metal and tetrahedral vibrations were observed in FT-IR and Raman analysis. The size and morphology of powders with different calcination temperatures were observed in SEM analysis. Using excitation spectrum the charge transfer from the (WO4)2- band to Tm+3 ions were identified. Blue emission transition of 1D2-3F4 (455 nm) was confirmed with emission spectrum. Maximum blue emission intensity was observed for 5%Tm3+:NGW, further increase of dopant concentration leads to decrease in the emission intensity due to concentration quenching.

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17:00 **Study of Tb-doping of AlN by transmission electron microscopy**

Authors : T Walther, F Benz, HP Strunk
Affiliations : University of Sheffield, UK; University of Cambridge, UK; University of Stuttgart, Germany

Resume : We have studied AlN layers doped with ~2at%Tb by transmission electron microscopy in cross-section. The near-edge structure of electron energy -loss spectra of the Tb M edge agrees well with that reported for Tb oxides, indicating a possible co-location of Tb and O ions within the AlN matrix.

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17:00 **Preparation, structural and photoluminescence characterisation of Eu3+ doped bismuth gadolinium tungstate phosphors**

Authors : K. Pavani 1, J. Suresh kumar 1*, M. Jayasimhadri 2, M. P. F. Graça 1, M. J. Soares 1, M. A. Valente 1
Affiliations : 1. Department of Physics and I3N, University of Aveiro, 3810-193 Aveiro, Portugal; 2. Department of Applied Physics, Delhi Technological University, Delhi 110042, India.

Resume : A series of different concentrations of Eu3+ doped bismuth gadolinium tungstate (BGW) phosphors were synthesized by solid-state reaction method. The prepared phosphors have been characterised by X-Ray diffraction (XRD), Raman spectroscopy and photoluminescence spectroscopy (PL). It was observed that the diffraction peaks of BGW (BiGdWO6) were matched with the JCPDS card No. 33-0201. BiGdWO6 has a structure similar to the Bi2WO6 ferroelectric phase, which is the simplest member of the Aurivillius family of layered perovskites. Rietveld refinement was performed to confirm the formation of BGW phase and their lattice parameters. Raman spectra of all the samples exhibited same characteristic vibrational modes of the constituent bonds. The photoluminescence properties were studied by exciting the samples with 325 nm laser radiation. Spectral results revealed that the characteristic transitions from the excited 5D0 level to different lower lying 7FJ (J = 0, 1, 2, 3 and 4) levels of Eu3+ ion. The observed transitions were well resolved into

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(J+1/2) Stark levels due to crystal field around the Eu3+ environment in the host lattice. In addition, as the concentration of the dopant ions increases, the increase in the intensity of emission transitions increased. Temperature dependent photoluminescence in the range 70 - 300 K was recorded to find the potential applicability of BGW:Eu3+ phosphors in solid state lightening systems.

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17:00 **Computational model of 2DEG mobility in the AlGaN/GaN heterostructures**

Authors : K. K. Abgaryan, D.L. Reviznikov, I. V. Mutigullin
Affiliations : Dorodnicyn Computing Centre of RAS

Resume : Three-scale model is proposed for the calculation of 2DEG mobility in AlGaN/GaN heterostructures. First of all Fang-Howard approximation is used for the calculation of electron wavefunctions in a triangle potential well in the vicinity of the heterostructure interface. The value of 2DEG concentration is required for this calculation. This value can be estimated from the first-principles calculations. This computational model allows to calculate following 2DEG properties: energy levels, corresponding wavefunctions, potential distribution, electron concentration distribution. Knowledge of the electron concentration in 2DEG, of the wavefunctions and of the heterointerface characteristics allows one to calculate electron mobility in 2DEG. To do so, it is necessary to take into account various scattering mechanisms. Therefore there is relatively simple connection between electronic structure calculations of AlGaN/GaN heterostructure and 2DEG electron mobility calculation. Data obtained in electronic structure calculations are used in the calculation of electron mobility. Thus our three-scale model is complete.

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17:00 **STUDY OF ELECTRICAL CONDUCTIVITY AND ac DIELECTRIC PROPERTIES OF La0.8Ca0.2-XPbXFeO3 (x = 0.05, 0.10 AND 0.20) PEROVSKITE COMPOUNDS**

Authors : A. Benali 1, M. Bejar 1, E. Dhahri 1, F. Amaral 2 3, M.F.P. Graça 2, L.C. Costa 2.
Affiliations : 1. Laboratoire de Physique Appliquée, Faculté des Sciences, B.P. 1171, 3000 Sfax, Université de Sfax, Tunisie; 2. I3N and Physics Department, University of Aveiro, 3810-193 Aveiro, Portugal; 3. Polytechnic Institute of Coimbra, 3045-601 Coimbra, Portugal

Resume : Complex perovskite La0.8Ca0.2-xPbxFeO3 (x = 0.05, 0.10 and 0.15) compounds are synthesized by the sol-gel method using citric acid route. X-ray diffraction patterns show that the nanocrystalline powders present a perovskite phase with orthorhombic symmetry with Pnma space group. The tool of impedance spectroscopy was used to characterize the dielectric behavior of these compounds as a function of frequency (102-106 Hz) at various temperatures (40 - 100°C). The Z″ frequency dependence shows the presence of only one relaxation peak. The Z′ and Z″ versus frequency plots were found to exhibit a semi-circular arc. The frequency dependence of conductivity has been investigated by the Jonscher’s universal power law: , where ω is the frequency of the ac field and n is the exponent. Keywords: Perovskite, Dielectric properties, ac conductivity.

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17:00 **Charging effects on heteropolar SiC/AlN and SiC/GaN interfaces**

Authors : Malgorzata Sznajder 1, Jacek A. Majewski 2
Affiliations : 1. Faculty of Mathematics and Natural Sciences, University of Rzeszow, Pigonia 1a, 35-959 Rzeszow, Poland; 2. Faculty of Physics, University of Warsaw, ul. Hoza 69, PL-00-681 Warszawa, Poland

Resume : Thin nitride films on silicon carbide substrate constitute many technologically important devices, where the nitride/SiC interface plays particularly important role. In spite of intensive experimental efforts [1], the microscopic physics of these intriguing interfaces is mostly unknown. The heterovalent character of these interfaces, in addition to the piezo- and pyroelectric character of the junction materials, leads to polarization charges and very strong electric fields that could in turn cause changes in atomistic details of the interfaces. In this work, we present first-principles studies of the first stages of Ga, Al, and N adsorption on the C and Si terminated surfaces of hexagonal SiC, and further the studies of the formed interfaces, 4H-SiC/wz-AlN and 4H-SiC/wz-GaN. We have calculated the atomistic details of the interfaces, their formation enthalpies, valence band offsets, induced interface charges, and resulting electric fields. The present studies shed light on the physics of heteropolar SiC/nitride interfaces and provide microscopic details of interfaces’ morphology together with theoretical predictions of important parameters that are a prerequisite for reliable modeling of relevant for devise design phenomena, such as the charge and spin transport across the interface and the

K.Pl 46

thermal boundary resistance effect. [1] S. W. King, R. F. Davis, and R. J. Nemanich, Surf. Sci. 602, 405 (2008); M. Losurdo, et al., Appl. Phys. Lett. 86, 021920 (2005).

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17:00 **Electrooptic and converse-piezoelectric properties of epitaxial GaN/Si structures for Optoelectronic applications**

Authors : M. Cuniot-Ponsard 1, I. Saraswati 2 4 S-M. Ko 3, M. Halbwax 2 Y-H. Cho 3, N-R. Poespawati 4, E. Dogheche 2

Affiliations : 1. Laboratoire Charles Fabry, IOGS, CNRS, Univ Paris-Sud, 2 Avenue Augustin Fresnel, 91127 Palaiseau cedex, France; 2. Institut d'Electronique, Microélectronique et Nanotechnologie, Groupe Optoélectronique, IEMN UMR 8520 CNRS, Avenue Poincaré, 59652 Villeneuve d'Ascq, France; 3. Department of Physics and KI for the Nano-Century, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 305-701, South Korea; 4. Electrical Engineering Department, Faculty Engineering, Universitas Indonesia, 42435, Depok, Indonesia

Resume : In order to take advantage in all-optic optoelectronic devices, we have investigated the optical and piezoelectric properties of GaN films deposited on (111) silicon. Films are epitaxially grown by MOCVD, thanks to a buffer made of (Al, Ga) N intermediate layers [1]. Structural properties of GaN are analyzed using TEM and the influence of threading dislocations density is discussed. Optical properties are investigated using a prism coupling [2]. Electrooptic measurements are performed using an original technique [3]. A semi-transparent gold electrode is deposited on top of GaN layer and an alternating voltage is applied between top and bottom electrodes. The electro-optic, converse piezoelectric, and electro-absorptive coefficients are simultaneously determined from the measurement of the electric field induced variation $\Delta R(\theta)$ in the reflectivity of the Au/GaN/buffer/Si stack versus incident angle. The method also enables to determine the GaN layer polarity. The results obtained for a Ga-face [0001] GaN layer when using a modulation frequency of 230 Hz are for the electro-optic coefficients r13 = +1 pm/V, r33 = +1.60 pm/V at 633 nm, and for the transverse piezoelectric coefficient d33 = +4.59 pm/V. The value measured for the electro-absorptive variation is $\Delta ko/\Delta E$ = +0.77 pm/V. The electro-optic coefficients for GaN /Si and the electro-absorptive coefficient are measured for the first time. The converse piezoelectric value agrees with values previously reported.

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17:00 **A comparative structural investigation of MBE and MOVPE grown indium rich InGaN/GaN heterostructures**

Authors : M.P. Chauvat 1, Y. Wang 1, M. Morales, S. Valdueza-Felip 2, E. Monroy 2, and P. Ruterana 1

Affiliations : 1. CIMAP, CNRS-ENSICAEN-CEA-UCBN, 6 Blvd. Maréchal Juin, 14050 Caen, France; 2. CEA-Grenoble, INAC/SP2M/NPSC, 17 rue des Martyrs, 38054 Grenoble, France.

Resume : The InGaN alloys theoretically constitute the best family for covering the largest part of the solar spectrum for the application in photovoltaics. However, many challenges lie still across the development of nitride based solar cells: 1) InN and GaN grow at different temperatures, especially using metalorganic vapor phase epitaxy (MOVPE), ~ 500 and above 1000°C, respectively; 2) The lattice mismatch between GaN and InN is about 11%. 3) InN and GaN exhibit phase separation due mainly to the large differences in atomic radii. Therefore, the growth need to be carried out using well controlled conditions in order to deposit good crystalline quality layers. This may better be realized by molecular beam epitaxy (MBE) which uses lower temperatures than MOVPE. In this work, we have investigated the structure of InGaN layers. InGaN films with RT PL emission ranging from 450–670 nm (0.9–0.6 of Ga content) have been synthesized on (0001)GaN/sapphire templates through a continuous search of the best quality of the layer and efficiency of the devices. The TEM investigations show typical differences between the MOVPE and MBE layers. In MBE, a good control of the growth conditions may lead to smooth surfaces and homogeneous composition layers. By MOVPE a systematic phase separation is seen to take place and characteristic defects form when the In composition is above 25-30%. From this investigation, various strategies for improving the layers quality will be discussed.

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17:00 **Self-consistent electro-thermo-mechanical simulation of nitride HEMTs**

Authors : M. Auf der Maur and A. Di Carlo

Affiliations : Dipartimento di Ingegneria Elettronica Universita` di Roma "Tor Vergata", Via del Politecnico 1, 00133 Roma

K.PI 49

Resume : In this work we present fully self-consistent electro-thermo-mechanical simulation results for typical AlGaN/GaN HEMT structures, including the effects due to the passivation layers and the contact metallizations. We analyze the mechanical stress state under different dc operating conditions, looking at both mechanical energy density in the strained layers and at the resolved shear stresses on different wurtzite slip systems. We show that the mechanical stress state for different bias conditions is qualitatively and quantitatively different. In the off state, converse piezoelectric effect leads to a strong increase in energy density under the gate. The self-heating under medium and high dc power dissipation results in a relaxation of the elastic energy density. However, the stress field becomes strongly anisotropic on the (0001) plane, which induces appreciable resolved shear stress on most slip planes. In both cases, the amount of stress is strongly bias-dependent. The energy densities and shear stresses are compared with theoretical predictions of critical values, showing that both converse piezoelectric effect and dislocation glide might be relevant for device degradation.

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17:00 **High performance AlGaN channel HEMTs with a low specific contact resistance** K.PI 50

Authors : Jincheng Zhang, Xiangdong Li, Chunfu Zhang, Wei Ha, Xing Chen, Shuai Zhang, Shenglei Zhao, Xiaohua Ma, Yue Hao
Affiliations : Key Laboratory of Wide Band Gap Semiconductor Materials and Devices, School of Microelectronics, Xidian University, Xi'an 710071, People's Republic of China

Resume : Recently, great attention has been paid onto using AlGaN as channel material in order to obtain higher breakdown voltage and output power. In this poster, we grew nine epitaxial samples from sample A to I with MOCVD. To improve the crystalline quality of the samples, different Al-component channel layers and different buffer layers were investigated. Test results demonstrate that both the crystalline quality and sheet carrier density decrease dramatically as the Al component of AlGaN channel increases. Besides, graded high Al-component AlGaN buffer layers suffer serious parasitic effects. To suppress the parasitic effects and obtain a high sheet carrier density, sample E (Al0.4Ga0.6N/Al0.18Ga0.18N/GaN) was grown and a high sheet carrier density of 1.04×10^13 cm-2 and a high mobility of 852 cm2/V•s were thus obtained. The (002) and (102) FWHMs of the Al0.18Ga0.18N channel layer of sample E are 255 arc sec and 1002 arc sec, respectively. Finally, AlGaN channel HEMTs with LG = 1.5 µm, LGS = 2 µm, and LGD = 2.5 µm were fabricated on sample I (Al0.4Ga0.6N/Al0.18Ga0.18N/ AlxGa1-xN/GaN, x = 0~0.18), taking advantage of the high crystalline quality of the composite buffer layer of graded AlGaN and GaN. Electron beam evaporated Ti/Al/Ni/Au (22/140/55/45 nm) and Ni/Ti/Ni (70/80/30 nm) were then made for source/drain and gate contacts, respectively. A very low specific contact resistance of 1.327×10^-6 Ω•cm2 was obtained by TLM. To the best of our knowledge, this is the best result ever reported. Besides, a peak ID of 441.3 mA/mm with VG = 2 V, a high breakdown voltage of 225 V, and a high transconductance of 91.7 mS/mm were also obtained. These results mentioned above indicate that the AlGaN channel HEMTs are very promising in the power electronics field.

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17:00 **Impurity incorporation and yellow luminescence of nonplar, polar and semipolar GaN films** K.PI 51

Authors : S. R. Xu, J. C. Zhang, T. Jiang, X. W. Zhou, L. A. Yang, Y. Hao
Affiliations : Key Laboratory of Wide Band Gap Semiconductor Materials and Devices, School of Microelectronics, Xidian University, Xi'an 710071, People's Republic of China

Resume : Gallium nitride and its alloys with indium and aluminum nitride are very attractive materials especially due to their wide application in electronic and optoelectronic devices. The majority of conventional GaN devices are grown with respect to the c-plane. The polarization fields in multiple quantum well structures along the polar c-axis cause a significant band bending and thus give rise to the spatial separation of electrons and holes. This situation leads to a reduced optical emission efficiency of light-emitting diodes (LEDs), as well as an undesirable redshift in the emission spectra from the quantum wells. So there have been considerable interests in the growth of nonpolar and semipolar gallium nitride based on epitaxial films, heterostructures, and devices. The polar properties of GaN make the behaviors of the different polar directions distinctly different, especially when there is impurity incorporatied. However, the influence of the polar direction on the impurity incorporation and luminescence properties is lacking. We have investigated the unintentional impurities oxygen and carbon in GaN films grown on c-plane, r-plane as well as m-plane sapphire by metal-organic chemical vapor deposition. The GaN layer was analyzed by secondary

ion mass spectroscopy. The different trend of the incorporation of oxygen and carbon have been explained in the polar（0001） nonpolar (11-20) and semipolar (11-22) GaN by combination of the atom bonding structure and the origin direction of the impurities. Furthermore, it is found there is stronger yellow luminescence (YL) in GaN with higher concentration of carbon, suggesting that C-involved defects are the origin responsible for the YL.

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Challenges for group III nitride semiconductors for solid state lighting and beyond

26 May 2014	**27 May 2014**	28 May 2014	29 May 2014

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start at	Subject	Num.
	Challenging aspects of III nitride: material characterisation, technology, new devices : M. Straßburg, A. Hangleiter and E. Monroy	
08:30	**Impact of defects on emission efficiency of polar, nonpolar, and semipolar nitride quantum wells** **Authors :** Andreas Hangleiter **Affiliations :** Institute of Applied Physics Technische Universität Braunschweig 38106 Braunschweig, Germany **Resume :** III-nitride-based light emitters are known to be surprisingly insensitive to the large dislocation density in typical heteroepitaxial device structures. For c-plane quantum wells, this has been shown to be related to thickness variations in the quantum well associated with the defects, leading to an anti-localization of carriers in defect-free areas. For longer wavelength light emitters, the "green-gap" problem still persists. While this can partly be explained by the quantum-confined Stark effect and the low oscillator strength of thick or high-indium-content quantum wells, even nonpolar nitride quantum wells exhibit a strong reduction of efficiency towards green emission. We demonstrate that this can be explained by strain-induced defects leading to stronger nonradiative recombination at larger lattice mismatch. Even though the radiative probability is higher in non- and semipolar quantum wells, the presence of lower energy slip planes in these orientations leads to strong nonradiative contributions.	K.II 1

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start at	Subject	Num.
09:00	**Growth and thermoelectric properties of In(Ga)N thin film heterostructures** **Authors :** B. Loitsch, J. (Zi-Jian) Ju, F. Schuster, M. Stutzmann, and G. Koblmüller* **Affiliations :** Walter Schottky Institut and Physik Department, TU München, Garching, 85748, Germany **Resume :** InN and related heterostructureshave been strongly considered for infrared photonics, solar cells,and high-speed devices. Recently alsoa very large thermopowerhas been identified in InN [1], making this materialfurther interesting for integrated thermoelectrics in nitride-based devices. Despite some progress which has been achieved in the fabrication of state-of-the-art InN films, these materials have been inhibitedhowever by two main limitations: (i) very high threading dislocation (TD) densities (> 10E10 cm-2),and (ii) highelectron concentrations (> 10E17 cm-3) mainly due to residualimpurities and TDs. Here, we presentnovelgrowth strategies using plasma-assisted molecular beam epitaxy (PAMBE) to further reduce the detrimental TD densities. Unconventional N-rich growth conditions are demonstrated toreduce TD densitiesmost effectively,leading to record low TD densities (low-10E9 cm-2) even for small film thicknesses [2]. Simultaneously, these conditionsenable much higher growth temperatures than metal-rich growth, minimizing the critical temperature gap between InN and GaN growth.Based on as-grownInN and In-rich InGaN films we further characterize the thermoelectric properties using temperature-dependent thermopower measurements.These data are compared with calculations of the Boltzmann transport equation to identify the carrier-concentration and temperature-dependent scattering factors (ionized impurities and TDs vs. phonons) in the Seebeck coefficient. Additional experiments are presented forfurther control ofthe Seebeck coefficient and the thermal conductivity viagrowth of InN/InGaNsuperlattices. [1] N. Miller, J. W. Ager, H. M. Smith, M. A. Mayer, K. M. Yu, E. E. Haller, W.Walukiewicz, W.	K.II 2

J.Schaff, C.Gallinat, G.Koblmuller, and J. S. Speck, J. Appl. Phys. 107, 113712 (2010). [2] B. Loitsch, F. Schuster, M. Stutzmann, and G. Koblmüller, Appl. Phys. Lett. 102, 051916 (2013).

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09:30 **Separating the effects of strain and variations in quantum well thickness and In content on the emission of InGaN/GaN nano-LEDs** K.II 3

Authors : G. Sarau, M. Heilmann, M. Latzel, S. Christiansen
Affiliations : Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, 91058 Erlangen, Germany

Resume : The scattering in the emission wavelength of InGaN/GaN MQW heterostructures is generally attributed to local variations in strain, thickness and In content. Here, we employed a combination of nanosphere lithography and reactive ion etching to produce tightly size-controlled nano-LEDs with a mean top diameter of 188.11±16.92 nm demonstrated to result in a high efficient and collimated light emission towards the surface normal. A statistically relevant study of the strain state in individual nano-LEDs was performed using non-resonant micro-Raman spectroscopy based on a clear splitting (nanorod and substrate) of the E2(high) phonon mode of GaN. We found a consistent strain relaxation with regard to the strain in the initial film and the nanostructuring procedure that was also confirmed by the blue shift of the CL emission. Complementary micro-Raman–CL spectroscopic measurements on the same, isolated nanorods covering the entire range of stress states showed that the same strain level does not necessarily result in the same QW emission wavelength for all nanorods. Band profile calculations agreed well with the optical transitions observed in the CL experiments, namely a mean emission at 441.09±5.82 nm, when fluctuations in the well thickness of 2–2.4 nm and in the In composition of 0.18 – 0.22 were considered with respect to the nominal values of 2.2 nm and 0.2, respectively. Our work establishes a powerful methodology for basic understanding of light emission from nano-emitters.

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09:45 **Localization of bound states in strained nitride superlattice heterostructures** K.II 4

Authors : Pawel Strak, Pawel Kempisty, Agnieszka Jamroz, Konrad Sakowski, Stanislaw Krukowski
Affiliations : Institute of High Pressure Physics of the Polish Academy of Sciences

Resume : We have studied the bound electron and hole states in nitride superlattice heterostructures using a density functional theory. The systems are assumed to be differently strained in lateral directions, with a lattice vector changing evenly from one to the second a lattice constants of two compounds forming structure. The c lattice vector is allowed to relax fully. When considering heterostructures composed of a ternary compound, the a and c lattice vectors are taken from Vegard's law. The effects of these external influences as well as of changes in the geometry of the heterostructures on the localization of bound states are discussed in detail. Direct inspection of the obtained energy band profiles suggest that the localization of bound states differs significantly, due to differences in band offsets of valence and conduction bands, which are related not only to differences in strain conditions. When passing from binary to ternary compounds we have found unexpected almost zero valence band offset between well and a barrier, which could be easily changed from positive to negative values by small changes in strain conditions. These had strong influence on localization of bound valence states and accordingly strong influence on reduction of optical transition rates.

add to my program (close full abstract)

10:00 **Coffee break**

10:30 **GaN/Al(Ga)N nanostructures for intersubband optoelectronics** K.II 5

Authors : E. Monroy 1, M. Beeler 1, Bellet-Amalric 1, C. Bougerol 1, P. Hillev 2, J. Schörmann 2, M. Eickhoff 2, M. Tchernycheva 3, F. H. Julien 3, A. Vardi 4, G. Vahir 4.
Affiliations : 1. CEA-CNRS Group Nanophysics and Semiconductors, CEA/INAC/SP2M and CNRS-Institute Néel, 17 rue des Martyrs, 38054 Grenoble cedex 9, France; 2. I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany; 3. Photis Dept., Institut d’Electronique Fondamentale, Université Paris-Sud, 91405 Orsay cedex, France; 4. Solid State Institute and Department of Electrical Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel.

Resume : III-nitrides have recently emerged as promising materials for new intersubband (ISB) technologies with potential applications for fiber-optic communications and throughout the THz spectral range. ISB transitions in

GaN/AlGaN quantum wells (QWs) can be tuned from 1.0 µm to 10 µm, and ISB absorption in the THz range (> 20 µm) has also been reported. For certain devices, it is interesting to replace QWs by laterally confined systems like quantum dots (QDs) to increase the intraband recovery times. In the case of GaN/AlN QDs, near-infrared TM-polarized intraband absorption has been observed, and is attributed to transitions from the ground state of the conduction band to the first excited electronic state confined along the growth axis. Furthermore, the lateral confinement in the QDs gives rise to additional mid-infrared transitions reacting to TE-polarized excitation. However, in the QD system the material choice and the nanostructure dimensions, which determine the operational wavelength, are limited by the elastic requirements for Stranski-Krastanov growth. In the case of nanowires (NWs), their large surface-to-volume ratio allows misfit strain to be elastically released, extending the viable active region size and composition beyond the limits of planar systems or QDs. In this work we present and discuss the intraband performance of these three kinds of nanostructures (QWs, QDs, NWs), studying the effect of their geometries and strain distribution on their optical properties.

add to my program **(close full abstract)**

11:00 **Selective-area growth of GaN Nanowires by MOVPE** K.II 6

Authors : P. M. Coulon, B. Alloing, V. Brändli, S. Chenot, M. Teisseire, P. Vennéguès, M. Leroux, J. Zuniga-Pérez

Affiliations : CRHEA-CNRS, Rue Bernard Grégory, F-06560 Valbonne, FRANCE

Resume : The lack of native GaN substrates at a reasonable prize and large sizes has prompted the use of alternative substrates for the development of GaN -based optoelectronics, in particular sapphire, silicon carbide and lately silicon. Unfortunately, due to differences between substrate and layer in terms of chemical nature, lattice parameters and thermal expansion coefficients, a number of defects appear in the GaN layers including threading dislocations and cracks. In this context, GaN nanowires (NWs) have been proposed as an alternative approach for integrating GaN on almost any kind of substrate due to their outstanding structural and optical properties. In this work, we present the selective-area growth of GaN NWs on patterned GaN-on-sapphire templates using metalorganic vapor phase epitaxy (MOVPE). It will be shown that low III/V ratios are necessary to promote the NW growth on Ga-polar substrates; otherwise pyramidal-shape nanostructures are formed. Furthermore, we will demonstrate that the NWs aspect ratio can be successfully tuned modifying the growth temperature and the H2/N2 ratio, which enable to control (and limit) the lateral growth rate perpendicular to {10-10} facets. Besides, the influence of the pattern geometry on the NWs aspect ratio and size homogeneity will be addressed. Finally, structural and optical properties of single GaN NWs will be described based on transmission electron microscopy and cathodoluminescence experiments.

add to my program **(close full abstract)**

11:15 **Single photon emission from InGaN quantum dots in GaN nanowires grown in ordered arrays** K.II 7

Authors : Ž. Gačević 1, S. Lazić 2, N. García-Lepetit 1, E. Chernysheva 2, S.Albert 1, A. Bengochea-Encabo 1, S. Metzner 3, M. Müller 3, F. Bertram 3, J. Christen 1, J.M. Calleja 2, and E. Calleja 1

Affiliations : 1. ISOM-DIE, Universidad Politécnica de Madrid Spain; 2. Departamento de Física de Materiales, Universidad Autónoma de Madrid, E-28049 Madrid, Spain; 3. Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany

Resume : An InGaN quantum dot (QD) embedded into a GaN nanowire (NW) is a promising system for realization of efficient quantum light emitters. Among those, single photon sources (SPSs) based on self-assembled (SA) GaN QDs and InGaN disks embedded into SA GaN NWs have been recently reported. We demonstrate here the emission of single photons from the QD-like states observed in the 20 nm thick InGaN disks embedded into GaN NWs ordered in a two-dimensional array. The structure was fabricated on (0001)GaN-on-sapphire templates using nanohole masks prepared by colloidal lithography. Scanning electron microscopy confirms the formation of NWs with pyramidal tops and highly uniform diameters and heights (200 and 500 nm, respectively), ordered in hexagonal matrices (with 270 nm pitch). Photoluminescence (PL) and transmission electron microscopy combined with cathodoluminescence reveal an intense emission band around 500 nm, originating from the apices of the InGaN sections. They further confirm that the luminescence originates from excitons confined in a strong electric field, with their initial lifetimes (~1 ns) nearly constant up to the room temperature. Micro-PL measurements reveal intense and narrow (< 500 µeV) QD-like emission lines. Photon correlation

measurements performed on these emission centers using a Hanbury Brown and Twiss interferometer show pronounced antibunching. We find the g(2)(0) < 0.3, which is a clear signature of single photon emission.

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11:30 **The impact of trench defects on the efficiency of InGaN/GaN LEDs and implications for the green gap** K.II 8

Authors : F. C-P. Massabuau, F. Oehler, A. Kovacs, M.J. Kappers, C.J. Humphreys, R.E. Dunin-Borkowski, R.A. Oliver

Affiliations : Department of Materials Science and Metallurgy, University of Cambridge, Cambridge CB2 3QZ, UK; Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany.

Resume : Trench defects are a commonly occurring flaw in InGaN/GaN quantum well (QWs) structures, where a region of material is enclosed by a V-shaped trench. Nevertheless their impact on light emitting diodes (LEDs) has been largely overlooked. Here we provide evidence of the negative impact of trench defects on LED emission. Two five-period blue InGaN/GaN QW structures were grown by metal-organic vapour phase epitaxy, with different Trimethylindium fluxes yielding different trench defect densities. A p-doped GaN layer was deposited on top of the QWs, forming an LED. A second set of samples was grown with five QWs grown with a temperature ranging from 690oC to 780oC, and no p-GaN deposited. In the first set of samples, we show by transmission electron microscopy that during the growth and anneal of the p-doped GaN layer partial or complete desorption of the QWs enclosed by the trench defects occurs. Active region degradation is also demonstrated by room temperature photoluminescence data revealing a 40% loss of intensity for the LED with higher trench defect density. In the second set of samples we show a two order of magnitude increase in trench defect density between blue- and green-emitting QW structures, implying that the loss of active material in green LEDs would be even more severe. In conclusion we show that trench defects have a negative impact on GaN LEDs. Our data strongly support the hypothesis that trench defects could more severely degrade the efficiency of green LED.

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11:45 **The effect of alkali earth metal doping in GaN** K.II 9

Authors : John Buckeridge, C. Richard A. Catlow, A. Walsh, D. O. Scanlon, A. A. Sokol

Affiliations : University College London, Kathleen Lonsdale Materials Chemistry, Department of Chemistry, 20 Gordon Street, London WC1H 0AJ, United Kingdom

Resume : The effects of doping on the minority charge carrier concentration in GaN remains a controversial issue, with many theoretical studies producing contradicting results. The standard method to model defects in crystals is the plane-wave supercell approach, which has disadvantages related to unwanted interaction between periodic images of defects. We present results of calculations based on a hybrid quantum mechanical/molecular mechanical embedded cluster approach to modelling defect formation associated with Group 2 dopants in GaN. As our approach does not employ periodic boundary conditions, provides access to the vacuum level, and allows the use of high level quantum chemistry approximations, accurate and unambiguous defect levels can be determined. From our calculations we find that a substantial amount of experimentally determined optical data can be attributed to the N vacancy in GaN, which is a charge-compensating defect for Group 2 dopant incorporation. Our calculated defect levels associated with the dopants are in excellent agreement with experiment where available. Furthermore, we definitively show that standard hybrid density functionals are inadequate for treating these defects and that double exchange is necessary for an accurate description.

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12:00 **Lunch break**

13:30 **Nucleation and growth mechanisms of spontaneously formed GaN nanowires in molecular beam epitaxy** K.II 10

Authors : S. Fernández-Garrido 1, V. Kaganer 1, X. Kong 1, K. K. Sabelfeld 1 2, J. K. Zettler 1, T. Gotschke 1, R. Calarco 1, J. Grandal 1 3, E. Calleja 3, A. Trampert 1, L. Geelhaar 1 and O. Brandt1

Affiliations : 1 Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany; 2 Institute of Computational Mathematics and Mathematical Geophysics, Russian Academy of Sciences, Lavrentiev Prosp. 6, 630090 Novosibirsk, Russia; 3 ISOM and Dpt. de Ingeniería Electrónica, ETSI Telecomunicación Universidad Politécnica de Madrid, 28040 Madrid, Spain

Resume : In contrast to epitaxial films, single crystalline GaN nanowires (NWs) can be grown on dissimilar substrates because their high aspect ratio inhibits the propagation of dislocations along the NW axis. Consequently, GaN nanowires have attracted great interest for the monolithic integration of optoelectronic devices on silicon. However, the physical mechanisms governing the spontaneous nucleation and growth of NWs are not completely understood yet. In this work, we show that, in the absence of structural or morphological defects of the substrate, GaN NWs form spontaneously along the [000 1] direction. The in-situ investigation by line-of-sight quadrupole mass spectrometry of the desorbing Ga flux during NW formation allows us to elucidate the role of the growth parameters on both the nucleation and subsequent growth of GaN NWs. We demonstrate that a self-regulated process, which depends on the effective III/V flux ratio, determines the final NW radius. We also introduce an empirical model that provides a quantitative comprehensive description of the time evolution of the entire NW ensemble, where collective effects (shadowing and exchange of Ga atoms between adjacent NWs) must be taken into account. Furthermore, the present model also makes it possible to extract, from the time evolution of the desorbing Ga flux, relevant growth parameters such as the nucleation rate or the average incubation time that precedes the formation of GaN NWs.

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14:00 **low-temperature p-type doping for high-efficiency green light emitters** K.II 11

Authors : M. Malinverni 1, N. Grandjean 1, J.-M. Lamy 1, N. Kaufmann 1, L. Lahourcade 1, D. Martin 1, J.-F. Carlin 1, M. Rossetti 2, A. Castiglia2, M. Duelk 2, C. Velez 2
Affiliations : 1. Institute of Condensed Matter Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland; 2. Exalos AG, CH-8952 Schlieren, Switerland

Resume : The technology of III-V nitride based light emitting diodes (LEDs) is nowadays well established in the blue wavelength range with impressive performance, i.e. a maximum wall plug efficiency exceeding 50%. However, LED efficiency goes down at high current density and for longer wavelength range. There is therefore still a room for research to get rid of the efficiency droop, or at least to limit it, and to extend the operation wavelength toward longer wavelength, beyond the green, while keeping a reasonable efficiency. Long-wavelength InGaN quantum wells require high indium content, which in turn leads to materials degradation and strain issues. In addition, high In content InGaN alloys are subject to thermal degradation, which may occur during the growth of p-type layers. In this presentation, we will present the growth of Mg doped GaN layers at low-temperature (750°C) by molecular beam epitaxy (MBE). The electrical properties compare well with those obtained on state of the art metal organic vapour phase epitaxy grown layers. Successful implementation of MBE grown GaN p-type cladding layers in lasers and long-wavelength LEDs will be reported. In addition, we will show that the use of low temperatures limits the diffusion of doping species across the p-n junction interface allowing us to achieve tunnel junction with excellent characteristics.

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14:30 **High quality GaN on Si for solid state lighting – challenges and solutions** K.II 12

Authors : Alois Krost 1, Armin Dadgar 1, and André Strittmatter 1 2
Affiliations : 1.Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany; 2. Technische Universität Berlin Institut für Festkörperphysik Sekretariat EW 5-2 Hardenbergstraße 36 D-10623 Berlin Germany

Resume : Nowadays GaN light emitters are predominantly grown by MOVPE on sapphire substrates although LEDs on SiC, Si and even GaN show competitive performances. As the LED market is driven mostly by cost reduction GaN-on-silicon technology is perhaps the only current alternative to GaN-on-sapphire because of available substrate size and price. In the last decade the development of GaN on Si LEDs led to steadily increasing performances by solving numerous difficulties for the growth of GaN on Si. Of these difficulties cracking is the most severe which can be solved by several methods. AlGaN buffers, AlN/GaN superlattices, Al(Ga)N interlayers as well as selective growth are all viable pathways to control strain in LED structures and thereby prevent cracking during cooling after growth. However, these methods cannot be applied straightforward. For example, AlN/GaN superlattices and AlGaN interlayers for strain engineering introduce misfit dislocations but may also lead to additional threading dislocations. It has been observed that such interlayers have different impact on the following GaN layer in dependence of their specific position in the layer stack. We will demonstrate that the function of these layers depends on the strain state of the previous layer. Because of the high absorption coefficient

of Si, LEDs have to be processed as thin film devices to achieve maximum light output. Here, high n-type doping is advised to enable efficient n-contact metallization and low operation voltage. We developed germanium doping for GaN layers with ND>10^20 cm-3 for this purpose. Ge doping has also the advantage over Si doping in avoiding edge type dislocation related tensile stress generation during growth. Our investigations show that Ge-doping behaves quite different to Si enabling much higher doping concentrations while maintaining a smooth GaN surface.

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15:00 **Investigation of cubic GaN quantum dots grown by the Stranski-Krastanov process**

Authors : M. Bürger, D. Reuter, and D.J. As
Affiliations : University of Paderborn, Department of Physics, Warburger Str. 100, D-33098 Paderborn, Germany

Resume : Recently GaN quantum dots (QDs) have attracted large interest for future applications in the quantum information technology like single photon sources or low threshold lasers. The main research focuses on the naturally stable hexagonal GaN (h-GaN) phase. However, in h-GaN QDs a Quantum Confined Stark Effect arises by internal piezoelectric and spontaneous polarization fields along the polar (0001) c-direction. This leads to performance limitations of optoelectronic devices containing h-GaN QDs. In the last decade important steps towards the growth and characterization of metastable cubic GaN (c-GaN) QDs in (001) direction have been mastered to avoid these undesirable internal fields. In this work, the investigation of c-GaN QDs created on cubic AlN (c-AlN) barriers by the Stranski-Krastanov growth mode is presented. We grow our samples by plasma assisted molecular beam epitaxy on (001) 3C-SiC substrates in-situ controlled by reflection high energy diffraction. We correlate the QD density of uncapped samples, investigated by atomic force microscopy, with photoluminescence experiments of similar but capped samples. The QD density can be varied by the amount of deposited GaN over one order of magnitude. Our results evidence the Stranski-Krastanov growth mode as the driving formation mechanism of the QDs. The critical layer thickness of c-GaN on pseudo morphological strained c-AlN on 3C-SiC was experimentally determined to 1.95 monolayers.

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15:15 **Effect of Random Alloy Fluctuations on Emission Strength in InGaN/GaN LEDs**

Authors : M. Auf der Maur, A. Pecchia, D. Barettin, G. Penazzi, F. Sacconi, A. Di Carlo
Affiliations : University of Rome Tor Vergata; CNR-ISMN; University of Rome Tor Vergata; Bremen Center for Computational Materials Science; Tiberlab S.r.l.; University of Rome Tor Vergata

Resume : In this work we present a theoretical study of the effect of random alloy fluctuations in the quantum well (QW) of an InGaN/GaN LED on the spontaneous emission properties. The calculations are based on an empirical tight-binding (ETB) model, using an sp3d5s* parametrization. Strain is calculated with a valence force field (VFF), preconditioned with a continuous linear elasticity calculation. The devices we consider consist of a single 3 nm QW with varying In content, undoped GaN barriers and AlGaN EBL. We first seek a selfconsistent solution of the Schroedinger/drift-diffusion model at a realistic operating current, using a kp model. Then we calculate the first few electron and hole states using ETB, and from this the optical matrix elements. These calculations are repeated for a statistical ensemble of structures with uniform random In distributions in the QW for each mean In concentration. For a reasonable representation of the random alloy and the induced fluctuations of the particles' orbitals we use a periodic supercell in the plane of the QW of 6x6 nm^2. As a result we obtain statistical distributions of the transition energies and oscillator strengths for different In concentrations. We find on the one hand that the oscillator strength is correlated with the transition energy, and on the other hand that the mean oscillator strength of the random alloy calculations shows a stronger decrease with In concentration than that obtained using virtual crystal approximation.

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15:30 **QCSE and Excited States in thick InGaN/GaN QWs**

Authors : Felix Nippert 1, Steffen Westerkamp 1, Anna Nirschl 2, Ines Pietzonka 2, Tobias Schulz 3, Martin Albrecht 3, Alexander Franke 1, Thomas Kure 1, Christian Nenstiel 1, Gordon Callsen 1, Martin Strassburg 2, Axel Hoffmann 1
Affiliations : 1. Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany; 2. OSRAM Opto Semiconductors GmbH,

K.II 15

Leibnizstraße 4, 93055 Regensburg, Germany; 3. Leibniz-Institut für Kristallzüchtung, Max-Born-Straße 2, 12489 Berlin, Germany.

Resume : We study MOCVD-grown green-emitting c-plane InGaN/GaN QW - structures of very high quality. They show no structural defects such as thickness fluctuations, phase separation or Indium clustering. TEM analyses confirm the excellent quality of our samples. Using temperature-dependent PL, we observe a drastically reduced internal quantum efficiency (IQE) with increasing thickness. Using photoluminescence and exciting only the QWs, we show that this the result of three effects: Firstly, the increasing internal electric fields due to the quantum-confined Stark effect (QCSE) separate electrons and holes along the growth direction reducing the radiative rates. Secondly, we see a loss of in-plane localization which combined with the longer carrier lifetime enhances carrier diffusion to non-radiative recombination centers in the thickest QWs (4.3~nm). Thidly, when using a high excitation power density, we observe excited states in the QWs, which emit in the blue to UV region and have very short lifetimes of less than 30ps. 8-band k.p calculations support our interpretation. These states comprise an additional non-radiative loss channel competing with Auger processes.

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15:45 **Influence of growth area reduction on cubic GaN**

Authors : R.M. Kemper 1 2, A. Kovács 3, T. Riedl 1 2, D. Meertens 3, K. Tillmann 3, D.J. As 1 2 and J. K. N. Lindner 1 2

Affiliations : 1. University of Paderborn, Department of Physics, Warburger Str. 100, 33098 Paderborn, Germany 2. Center for Optoelectronics and Photonics, Warburger Str. 100, 33098 Paderborn, Germany 3. Ernst-Ruska Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany

Resume : Up to date there is a huge interest in nitride technologies to fabricate dislocation free epilayers for high-quality GaN-based devices. So far hexagonal GaN is the mostly used material among all group III-nitrides. But due to the absence of internal electrical fields in the cubic phase of GaN this system has also attracted growing interest. One way for the elimination of misfit dislocations is the reduction of the growth area. Defect reduction in mismatched systems is also predicted by the theory of nanoheteroepitaxy (NHE), which describes the selective growth on nano-patterned (10 -100 nm) substrates. In order to investigate the influence of growth area reduction in the cubic GaN/3C-SiC (001) system, 3C-SiC mesa structures with scaled-down (001) growth area lengths from ~500 nm to ~20 nm are fabricated by electron beam lithography and reactive ion etching. High-resolution TEM measurements demonstrate that the cubic phase nucleates epitaxially on top of all analyzed 3C-SiC structures. The influence of growth area reduction is indicated by a drastical reduction of the {111} stacking fault (SF) density with scaled down growth area. While on top of the larger posts with top edge lengths of ~500 nm and ~240 nm SFs occur in bunches, almost defect-free c-GaN growth on the ~20 nm mesas is observed. This structural improvement gives evidence that growth area reduction significantly influences the growth of c-GaN as predicted by theoretical calculations according to the theory of NHE.

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16:00 **Coffee break**

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PROGRAM VIEW : 2014 Spring
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Symposium : K

Challenges for group III nitride semiconductors for solid state lighting and beyond

26 May 2014	27 May 2014	**28 May 2014**	29 May 2014

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start at	Subject	Num.
	Nitride devices and their application : E. Calleja, M. Kuball and H. Fujioka	
08:30	**Performance and reliability of GaN power electronic devices** **Authors :** Martin Kuball **Affiliations :** H. H. Wills Physics Department University of Bristol Tyndall Avenue BS8 1TL U.K. **Resume :** GaN is presently being explored as new material for power electronic devices, aiming at achieving superior performances to Si based technology. Although good to excellent performances have been demonstrated, current GaN devices still do not exploit the full performance potential of this material system, neither the reliability of the devices is fully adequate. I will review the latest developments in this field, including the role of Carbon doped GaN buffer layers for the working of the devices, in the addition the integration of GaN with diamond material systems to enable even higher power densities than presently possible.	K.III 1

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start at	Subject	Num.
09:00	**Nitride based lasers in visualization and lighting** **Authors :** B. Stojetz, S. Tautz, C. Vierheilig, A. Loeffler, J. Ristic, S. Gerhard, C. Eichler, A. Lell, T. Wurm, J. Mueller, G. Bruederl, A. Somers, A. Avramescu, H. Koenig, U. Strauss **Affiliations :** OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany **Resume :** Recently, blue emitting lasers based on nitride semiconductors achieved impressive high power levels of several Watt. This power level has opened a wide field of possible applications like automotive headlamps and business projectors. Blue lasers with a power level of 1.4-1.6W are already state of the art. Mostly arrays of TO metal cans are used to get total light output of the order tens of Watt. Present development focuses on achieving even higher output power for a single emitter that would reduce the number of diodes needed. We present R&D laser diodes with thermal roll-over above 5W. Since thermal properties are crucial, we show details on the temperature dependence of the laser parameters. Pico projectors and head-up displays are examples for applications using red, blue and green single mode lasers up to 100mW. Direct green laser diodes >> 100mW are an interesting opportunity for high resolution high power cinema projection. However, high power levels for the green spectral range are very challenging. We investigate loss mechanism of R&D structures for green lasers in detail. R&D samples up to 1W at >515nm emission wavelength are demonstrated.	K.III 2

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start at	Subject	Num.
09:30	**Linear and nonlinear optical characterisation of polarity controlled AlGaN waveguides for integrated optics** **Authors :** M. Rigler 1, J. Buh 2, M. P. Hoffman 3, R. Kirste 3, M. Bobea 3, Michael Gerhold 4, R. Collazo 3, Z. Sitar 3, M. Zgonik 1 2 **Affiliations :** 1. Faculty of Mathematics and Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia; 2. J. Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia; 3. Department of Materials Science and Engineering, North Carolina State University, Campus Box 7919, Raleigh, NC 27695-7919, USA; 4. Engineering Science Directorate, Army Research Office, P.O. BOX 12211, Research Triangle Park, NC 27703, USA **Resume :** Fabrication of UV laser diodes faces a number of challenges such as doping, high threshold, and increased sensitivity to defects and surface	K.III 3

roughness. Recent research on polar characteristics of III-nitride semiconductors showed great potential of using AlGaN for laser sources in the UV region through nonlinear light conversion. Unfortunately, conventional phase matching techniques cannot be used in AlGaN thin films, however, quasi phase matching (QPM) is possible if periodic modification of the nonlinear crystal is produced to correct the relative phase mismatch at regular intervals. The AlGaN periodic structures used in these experiments are fabricated in such a way that the orientation of the crystalline c-axis is periodically inverted as a function of position, leading to a periodically poled structure of 180° N- and III-metal-polar domains with sharp interfaces. As a precursor to second harmonic generation, detailed refractive index measurements AlGaN thin films of both polarities were performed via spectroscopic ellipsometry and prism coupling. Mode propagation losses in AlGaN waveguides with varying cross-sections and Al contents were measured at several wavelengths and compared. Finally, second harmonic generation in visible and UV region was demonstrated in GaN and AlN waveguides by use of the modal-dispersion phase matching technique. Knowledge of the presented optical properties of AlGaN waveguides is crucial in developing an integrated UV laser source.

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09:45

Designing InGaN/GaN nano-LED arrays for etendue-limited applications

Authors : S.M. Lis, S.E.J. O?Kane, S.A. Fox, C.J. Lewins, Y.D. Zhuang, J. Sarma, P.A. Shields, D.W.E Allsopp
Affiliations : Dept. of Electronic and Electrical Engineering, University of Bath, Bath, BA2 7AY, UK

Resume : Light-emitting diodes (LEDs) based on arrays of nanorod (NR) emitters have been widely re-searched in recent years. Advantages of such LEDs include increased internal quantum efficiency due to strain relaxation, low defect densities and increased light extraction efficiency. Another ad-vantage of NR-LEDs is the potential for highly directional light emission, a desirable attribute for etendue limited applications. Factors that affect this directionality include light waveguiding in the NRs and in any underlying GaN buffer layer from which light can be diffracted by highly ordered NR arrays. This paper presents the results of a study by simulation and measurement of the direc-tionality of light emission from NR-LEDs ICP etched from epitaxy containing either a single InGaN/GaN quantum well or a MQW oriented in the c-plane. It is shown how the diameter, height and sidewall angle of an NR, the thickness of any ITO contact layer and location of the dipoles in-fluence the far-field radiation pattern, notably the directionality of the emitted light. The emissive properties of single NRs were simulated by a modal expansion technique that accounts for reflection and diffraction at the nanorod ends, while those of nanorod arrays were studied using the finite-difference time-domain (FDTD) method. The predictions of both models were compared with detailed measured far-field angular emission patterns from green and blue light emitting NRs over a wide range of wavelengths, with excellent agreement achieved. The comparisons with results obtained by modal expansion reveal the dominant waveguide modes, which in turn depend on the wavelength of the emission and its radial and axial location within the NRs. The FDTD study revealed the diffractive behaviour.

K.III 4

add to my program **(close full abstract)**

10:00 **Coffee break**

10:30

Pulsed Sputtering Technique for Fabrication of Future Nitride Devices

Authors : Hiroshi Fujioka
Affiliations : Institute of Industrial Science , The University of Tokyo; JST-CREST

Resume : It is well known that nitride devices show very high performance, but their applications are limited because of the high fabrication cost with sophisticated methods such as MBE or MOCVD. To solve this problem and fabricate low-cost GaN devices, we have to utilize a pulsed sputtering crystal growth technique. PSD (pulsed sputtering deposition) has already attracted much attention of industry engineers because its productivity is much higher than that of conventional MOCVD. In this technique, surface migration of the film precursors is enhanced and, therefore, the temperature for epitaxial growth is dramatically reduced. This reduction allows us to utilize various large area low cost substrates that have never been used for growth of semiconductors so far due to their chemical vulnerability. As low-cost large area substrates, we have investigated feasibility of metal foils, mica sheets, and highly oriented graphite/grapheme sheets. We can expect fabrication of low-cost flexible GaN

K.III 5

devices with the use of these substrates. The other advantage with the use of PSD lies in the fact that low substrate temperature allows us to grow high quality InGaN and InAlN with high In concentrations. This nature is quite important for the fabrication of long wavelength LEDs and solar cells. In this presentation, we will demonstrate successful epitaxial growth of group III nitride semiconductors and operation of various nitride devices such as AlGaN/GaN HEMTs, RGB LEDs, and solar cells. We will also demonstrate devices prepared on low-cost flexible substrates such as metal foils, graphite/graphene sheets, and mica sheets.

add to my program **(close full abstract)**

11:00

High quality thick InGaN nanostructures grown by nanoselective area growth for new generation photovoltaic devices.

Authors : S. Suresh 2, P. Renaud 1 2, X. Li 1 2, Y. El. Gmili 2, K. Panztas 1 2, G. Orsal 2 3, G. Patriache 4, J. P. Salvestrini 2 3, A. Ougazzaden 1 2.
Affiliations : 1. Georgia Institute of Technology/GTL, UMI 2958 GT/CNRS, 57070 Metz, France; 2. CNRS UMI 2958 Georgia Tech-CNRS, 57070 Metz, France; 3. Université de Lorraine, LMOPS, EA4423, 57070 Metz, France; 4. LPN CNRS, UPR, Route de Nozay, F-91460 Marcoussis, France.

Resume : There is a tremendous need for developing novel approaches to realize good quality thick InGaN epilayers to significantly improve the efficiency of concentrating photovoltaic systems. One possible solution for obtaining thicker and better InGaN is Nano Selective Area Growth (NSAG). Applying NSAG technology, we have grown successfully, 120 nm thick, perfectly selective InGaN nanorod and nanowire arrays over the dielectric mask using metal organic chemical vapor deposition. Uniform stripes and dots nanopatterns of SiO2 with 100 nm openings were realized using E-beam lithography. In the unmasked area InGaN is stymied with 3D growth, clusters of In and defects whereas the InGaN nanostructures in the patterened area are perfectly hexagonal, monocrystalline and homogenous in size, shape and composition exposing the smooth semipolar facets, which is sign of high quality nanostructures. The approximate indium composition and the strain state in the field were determined by the HRXRD analysis and the photoluminescence near band emission peak. Further structural properties were studied using cross sectional transmission electron microscope. The optical properties of these nanostructures were studied using the depth resolved cathodoluminescence spectroscopy, which showed considerable redshift in emission peaks confirming increase of In incorporation in the nanostructures. The interesting results of the structural and optical characterizations and possible growth mechanism of these InGaN

K.III 6

add to my program **(close full abstract)**

11:15

Polarization matching design of InGaN-based semi-polar quantum wells for color stability and improved wave function overlap

Authors : G. Kozlowski, S. Schulz and B. Corbett
Affiliations : Photonics Theory Group, Tyndall National Institute, Lee Maltings, Cork, Ireland

Resume : Quantum wells (QWs) based on InGaN alloys received much attention for the design of optoelectronic devices. However, with increasing In content, the performance of devices grown along the polar c-axis suffer significantly from electrostatic built-in fields [1,2]. Several different approaches have been discussed in the literature to circumvent problems originating from these built-in polarization fields [3,4]. Here, we present a theoretical study of the polarization engineering in semi-polar InGaN heterostructures. We study the influence of GaN, AlGaN, and AlInN barrier material on the performance of semi-polar (11-22) InGaN QWs for blue and yellow emission. We show that the magnitude of the built-in electric field across the QW can be controlled by the barrier material. Our results indicate that AlInN is a promising candidate to achieve i) reduced wavelength shifts with increasing currents and ii) strongly increased spatial overlap of electron and hole wave functions, important for reduced optical recombination times. [1] Appl. Phys. Lett. 73, 1691 (1998) [2] Appl. Phys. Lett. 89, 041121 (2006) [3] Appl. Phys. Lett. 91, 183507 (2007) [4] Semicond. Sci. Technol. 27, 024002 (2012)

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add to my program **(close full abstract)**

11:30

Significant improvement of the device characteristics of light-emitting diodes based on GaN nanowires

Authors : M. Musolino, F. Limbach, A. Tahraoui, O. Brandt, L. Geelhaar, and H. Riechert
Affiliations : Paul-Drude-Institut für Festkörperelektronik

K.III 8

Resume : III-N nanowires (NWs) are an attractive alternative to conventional planar layers as the basis for light-emitting diodes (LEDs), since the NW geometry enables the growth of (In,Ga)N/GaN heterostructures with high In

content on cost-effective Si substrates in high crystal quality. However, the processing of such structures is necessarily more complex. Specifically, the planarization of the NW ensemble and the formation of the top p-type contact are challenging, with detrimental consequences for device performance. Here, we show that the optimization of the p-type contact drastically improves the optical and electrical characteristics of NW-LEDs. In particular, after planarization we directly deposit indium tin oxide (ITO) without any layer of elemental metals. Since ITO has a high optical transmittance, it is possible to deposit thick layers that provide a good contact to many NWs without strongly reducing the extraction of light. We fabricated two different LED samples with either ITO or Ni/Au top contact from the same (In,Ga)N/GaN NW ensemble grown on Si substrate by molecular beam epitaxy. The device fabricated with ITO exhibits lower turn-on voltage (about 2.5 V), lower series resistance, higher relative external quantum efficiency, and a ten times higher number density of NWs emitting electroluminescence. This result is an important step towards the fabrication of highly efficient LEDs based on NWs.

add to my program **(close full abstract)**

11:45 **Design and Fabrication of Uni-Travelling Carrier (UTC) Photodiode based on InxGa1-xN semiconductors**

Authors : B. Alshehri 1, K. Dogheche 1, P.I. Seetoh 3, J.H. Teng 2, S.J. Chua 3, D. Decoster 1, E. Dogheche 1
Affiliations : 1 Institute of Electronics, Microelectronics and Nanotechnology, Optoelectronics Group (IEMN CNRS) Villeneuve d'Ascq, France 2 Institute of Materials Research and Engineering (IMRE), Singapore 117602, Singapore, 3 Department of Electrical and Computer Engineering, National University of Singapore (NUS), Singapore 117576

Resume : This work is focused both on InxGa1-xN single-layer and InxGa1-xN/GaN multilayered structures, with high Indium content (x>35%). In this study, InGaN/GaN films are epitaxially grown on sapphire substrates by metalorganic chemical vapor deposition (MOCVD). The microstructure of GaN and InxGa1-xN thin films are characterized by SEM/AFM/TEM [1] and optically by prism coupling/ ellipsometry for the refractive indices [2]. We focus here on the design and the fabrication of ultra-fast photodiodes operating in visible wavelength range. Different configurations for UTC photodiodes have been fabricated (sizes ranging from 2.5 to 50µm) and the technological processes optimized including dry etching processes for patterning GaN/InGaN layers. Ti/Al/Ni/Au and ITO materials for p and n type contacts are also investigated. [1] A. Gokarna, A. Gauthier-Brun, W. Liu, Y. Androussi, E. Dumont, E. Dogheche, J. H. Teng, S.J. Chua, D. Decoster, Applied Physics Letters ,Vol.96 , Issue: 19, May 2010. [2] A. Gauthier- Brun, J.H. Teng, E. Dogheche, Wei Liu, M Tonouchi A. Gokarna, S.J. Chua, D. Decoster, Properties of InxGa1-xN films in Terahertz range, Applied Physics Letter, 100, 071913 (2012)

K.III 9

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12:00 **Lunch break**

13:30 **Confinement and transport characteristics of high-density two dimensional electron gas in novel GaN-based heterostructures**

Authors : Jincheng Zhang*, Fanna Meng, Junshuai Xue, Juncai Ma, Linyu Shi, Zhongfen Zhang, Huijuan Wen, Zhiyu Lin, Hao Zhou, Yue Hao
Affiliations : Key Lab of Wide Band Gap Semiconductor Technology, School of Microelectronics, Xidian University, Xi'an 710071, China

Resume : Due to strong polarization properties of III-nitrides, GaN-based heterostructures, such as AlGaN/GaN heterostructure, InAlN/GaN heterostructure, etc, have a special two dimensional electron gas (2DEG) with high density and high mobility. However, since the 2DEG density is very high, a large quantity of electron can overflow from the triangle potential well of 2DEG interface under higher temperature. This overflow of 2DEG will lead to reduction of the total electron mobility [1], and the HEMT device cannot be pinched off. In this report, to confine the overflow of high-density 2DEG, many novel heterostructures, such as high Al-content AlGaN/GaN with deeper potential well [2], AlGaN/GaN/AlGaN and InAlN/GaN/AlGaN double heterostructures with a back-barrier[3,4], AlGaN/GaN/AlGaN/GaN and InAlN/GaN/InAlN/GaN hetero - structure with double channels[5], were studied. GaN-based devices with these structures exhibit excellent transport characteristics under high temperature, so they are more suitable for the applications in high temperature electronic devices. References: [1] Zhang Jinfeng, Wang Chong, Zhang Jincheng, Hao Yue. Chinses Physics, 15(5):1060, 2006. [2] Zhang ZhongFen, Zhang JinCheng, et

K.III 10

al, Science in China-Series G: Physics Mechanics and Astronomy, 52(12):1879-1884, 2009. [3] Meng, Fanna, Zhang, Jincheng, Zhou, Hao, et al, Journal of Applied Physics, 112(2), 2012. [4] Juncai Ma, Jincheng Zhang, Junshuai Xue, Chinese Journal of Semiconductors, 33(1), 2012. [5] Xue, JunShuai, Zhang, JinCheng, et al, Journal of Applied Physics, 111(11), 2012.

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14:00 **GaN-based devices for new gas sensor technologies**

Authors : Martin W. G. Hoffmann 1 2 3, Jordi Sama 1, Olga Casals 1, Francisco Hernandez-Ramirez 1 3, Andreas Waag 2, Hao Shen 2, J. Daniel Prades 1
Affiliations : 1. Department of Electronics, University of Barcelona, Barcelona, Spain; 2. Institut fur Halbleitertechnik, Technische Universitaet Braunschweig, Braunschweig, Germany; 3. Department of Advanced Materials for Energy Applications, Catalonia Institute for Energy Research (IREC), Barcelona, Spain.

Resume : Low power consumption, long-term stability and high specificity are some of the most sought after requirements for future gas sensors technologies. In this contribution, the potential of GaN-based devices to contribute to this field will be discussed. First, new optically-driven sensor device concepts featuring zero power consumption have shown that this is an open field for optically active materials[1]. Light emitters and absorbers active in the visible range, such as InGaN, are required to operate these new technologies in ambient light. Second, the traditional strategy to maximize the sensor response by choosing chemically and thermally unstable materials leads to well know long-term stability issues. Additionally, this choice produces vigorous and highly unspecific responses to gases. Following recent finding[2], an alternative strategy could be relying on highly stable gas-immune materials to build up the fundamental elements of the sensor platform in combination with highly specific functionalizations. The well-established microelectronic GaN processes would provide the necessary fine control over the electrical and optical properties of the device platform. The flexibility of molecular chemistry would deliver sufficient flexibility to tailor the specific response of the sensor almost at will. Finally, the first attempts to implement this strategy in new devices will be presented. [1]NanoEnergy 2013, 2, 514–522. [2]Adv.Funct.Mater. 2013, DOI: 10.1002/adfm.201301478

K.III 11

add to my program **(close full abstract)**

14:30 **A continuous composition spread approach towards monolithic, wavelength-selective multichannel UV-photo-detector arrays**

Authors : Holger von Wenckstern
Affiliations : Universität Leipzig, Institut für Experimentelle Physik II, Halbleiterphysik

Resume : The detection of ultraviolet irradiation is important in environmental research and monitoring, flame detection and monitoring of industrial processes as UV curing of glues, adhesives or disinfection of drinking water by UV irradiation. Besides (Al,Ga)N semiconducting oxides present a material class that is very suited for realization of detectors operating in the UV-A, UV-B and even the UV-C spectral range. For most applications the determination of spectrally integrated UV radiation is not sufficient and a spectrally resolved detection of UV radiation is desired. Here, we demonstrate an approach towards monolithic wavelength-selective UV-A photo-detectors by using a continuous composition spread approach.

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add to my program **(close full abstract)**

15:00 **Optimization of the emission properties of cerium-doped nanophosphors**

Authors : Lucie Devys Géraldine Dantelle Jean-Pierre Boilot Thierry Gacoin
Affiliations : Laboratoire de Physique de la Matière Condensée, UMR CNRS 7643 – Ecole Polytechnique – 91128 PALAISEAU Cedex, France

Resume : Ce-doped $Y_3Al_5O_{12}$ (YAG:Ce) phosphors are commercially used for white LEDs. Their excitation indeed overlaps the emission of the GaN and the combination of their yellow emission with the blue of the GaN provides a good color rendering. At the microscale they have a perfect photostability and luminescent quantum yield (QY) exceeding 90%. YAG nanoparticles, which can be appropriate to prepare transparent films can also be synthesized; however, their photostability is altered and the QY divided by 2. Furthermore, the YAG matrix allows the incorporation of only 3% percent of Ce. The absorption is thus weak, which is limiting for thin films applications. In this work, we investigated the reasons of this decrease of performances at nanoscale and proposed ways to improve them. XPS measurements highlighted the role of the oxidation of the cerium of the surface in the photobleaching. A protected annealing was thus developed. A first heating in air at 1000°C improves the crystallinity, and a second at 600°C under reductive atmosphere allows to regenerate the Ce^{3+} ions. Such treatment allows to reduce the photobleaching (from 80% to 20%) and increases their QY. In parallel, a microwave synthesis of the Ce-doped

K.III 13

matrix Gd3Sc2Al5O12 (GSAG:Ce) was developed. It has the same garnet geometry as the YAG and similar excitation and emission bands. Although the QY of the GSAG:Ce (52%) is lower, it is compensated by its large cell parameter which allows the incorporation of up to 13% of cerium.

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15:15 **BAlN thin layers for deep UV applications**

Authors : X. Li 1 2, S. Suresh 2, Y. El Gmili 2, F. Genty 3, P. Voss1, J-P. Salvestrini 2 3, A. Ougazzaden 1 2.
Affiliations : 1. Georgia Institute of Technology / GTL, UMI 2958, Georgia;Tech-CNRS, 57070 Metz, France; 2. CNRS UMI 2958, Georgia Tech-CNRS, 57070 Metz, France; 3. Université de Lorraine, LMOPS, EA4423, 57070 Metz, France

Resume : Boron containing III-nitrides are attractive system for deep-UV LEDs and LDs because of their wide bandgaps and flexible lattice. However the crystallinity and boron content have been limited due to large mismatch between BN and other nitrides. In this work, BAlN layers with boron composition from 1% to 5% were successfully grown on AlN template substrates by low-pressure organometallic vapor phase epitaxy. The samples were grown at 650˚C and then annealed at 1020˚C for recrystallization. Growth techniques such as temperature, growth time and TEB/III ratio in the gas phase were investigated. High quality BAlN layers were grown using flow-modulate epitaxy method that allows to enhance surface migration of boron atoms. 70 nm-thick layers show a good surface morphology. For the first time, clear XRD peak relating to 5% boron for this new material was observed, which suggests the formation of single-phase solid solution. Adding more boron to the AlN produced a shift in the peak positions to greater angles. Further results by TEM and optical characterizations will be presented. This new material is promising for deep-UV applications and gives more freedom for bandgap engineering of multi-structure devices.

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add to my program **(close full abstract)**

15:30 **High critical temperature ultra-thin NbN films for broadband single photon detection**

Authors : Diane Sam-Giao, Eva Monroy, Stéphanie Pouget, Max Hofheinz, Val Zwiller
Affiliations : CEA Grenoble / INAC / SPSMS / LATEQS | CEA Grenoble / INAC / SP2M / NPSC | CEA Grenoble / INAC / SP2M / SGX | CEA Grenoble / INAC / SPSMS / LATEQS | TU Delft / Quantum transport group and CEA Grenoble / INAC / SP2M / NPSC

Resume : Single photon detection is crucial in applications such as quantum cryptography, Lidar, and medical imaging. A promising solution consists in using ultra-thin superconducting (i.e. NbN) nanowires as active media: growing an ultra-thin NbN film with excellent superconducting properties is thus a challenging prerequisite. Today system detection efficiencies up to 40% are obtained on SOI at 1.3 µm. On-chip detection efficiencies up to 90% in the IR region were measured by mounting the nanowire on a Si waveguide. Our target is to achieve high detection efficiency and extend the spectral range of operation towards visible and UV. Therefore, the waveguiding material must be transparent in a broad spectral range. GaN/AlN is an interesting material combination, thanks to its transparent band from 400 to 6000 nm, its mechanical and thermal robustness and the maturity of its technology for waveguide fabrication. The waveguide structure under study consist of 600 nm GaN grown on 1 µm AlN on sapphire by MBE. On top of such structure, thin (< 10 nm) NbN films were deposited by DC magnetron sputtering. The thickness of the layers was measured by x-ray reflectivity and x-ray diffraction showed that the NbN layer is monocristalline. A critical temperature of 13.5 K was obtained on 8.5 nm thick NbN layers, to be compared to 16 K for bulk material. These promising results pave the way for single photon detectors made of NbN nanowires on GaN waveguides with high efficiency from UV to IR.

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15:45 **Rectifying porous GaN p-n junctions fabricated by Chemical Vapor Deposition**

Authors : J.J. Carvajal 1, O.V. Bilousov 1, O. Martínez 2, J. Jiménez 2, H. Geaney 3 4, C. O'Dwyer 3 4, F. Díaz 1, M. Aguiló 1
Affiliations : 1. Física i Cristal•lografia de Materials i Nanomaterials (FiCMA-FiCNA) and EMaS, Universitat Rovira i Virgili (URV), Marcellí Domingo s/n, E-43007 Spain; 2. GdS-Optronlab, Departamento Física Materia Condensada, Univ. de Valladolid, Edificio I+D, Paseo de Belén, 11, 47011, Valladolid, Spain; 3. Department of Chemistry, University College Cork, Cork, Ireland; 4. Tyndall National Institute, Lee Maltings, Cork, Ireland

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Resume : GaN is an important wide band-gap semiconductor in electronics and optoelectronics. In its porous form is particularly interesting for developing optoelectronic devices with improved efficiency, such as LEDs with enhanced efficiency and sensors with enhanced sensitivity. Through chemical vapour

deposition [1], we have shown that it was possible to produce nanoporous GaN without any etching or chemical post-growth treatment, with the porosity being present only on the (0001) face of the material. Low resistivity ohmic Pt and Au metallic contacts were demonstrated on porous n-type GaN by the formation of intermetallic seed layers through the vapour-solid-solid (VSS) mechanism [2]. Also, we have been able to develop p-type porous GaN by doping with Mg, with a charge carrier concentration of the order of 1018 cm-3 [3]. Now, we go one step further, and present the fabrication of high quality partially and totally porous GaN rectifying p-n junctions for the first time, through a 2 step CVD process on non-porous GaN films grown on sapphire substrates, and show their behaviour as diodes with effective uniform conduction. These porous junctions have potential applications in high brightness unencapsulated LEDs with enhanced light emitting properties and high surface area sensors with improved sensitivity. [1] Carvajal & Rojo, Crystal Growth Des., 9 (2009) 320 [2] Bilousov et al., ACS Appl. Mater. Interfaces 4 (2012) 6927 [3] Bilousov et al., Appl. Phys. Lett. 103 (2013) 112103

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16:00 **PLENARY SESSION**

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PROGRAM VIEW : 2014 Spring
MY PROGRAM : 2014 Spring

Symposium : K

Challenges for group III nitride semiconductors for solid state lighting and beyond

26 May 2014	27 May 2014	28 May 2014	29 May 2014

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start at	Subject	Num.
	Characterization and III nitride technicology : D. Cherns, R. Martin and D. Prades	
08:30	**Spatial Mapping of Gallium Nitride light emitters** **Authors :** Robert W. Martin **Affiliations :** Department of Physics, SUPA, University of Strathclyde, G4 0NG, UK **Resume :** A number of routes to improved Gallium Nitride light emitters will be explored using high resolution spatial mapping techniques, performed within the "Lighting the Future" U.K. research programme (Cambridge, Bath, Manchester and Strathclyde Universities). Notable differences in performance resulting from changes in the growth parameters of the InGaN/GaN quantum well region and underlayer in blue LEDs will be described using a mapping tool combining electroluminescence (EL) and cathodoluminescence (CL) spectroscopy with electron beam induced current (EBIC). Micron scale spatial variations in emission spectra and induced current will be related to changes in the active region and the efficiency of the devices. In addition sub-micron resolution CL studies of nanorods, both isolated and in arrays, will be presented to demonstrate the potential for increased light emission from such structures. Novel macromolecules based on the bodipy structure are being developed to colour convert the blue emission into the yellow spectral region and the use of these materials in combination with blue LEDs for white light generation will be reported.	K.IV 1
add to my program	(close full abstract)	
09:00	**Cathodoluminescence imaging and spectroscopy of nitride nano-structures with nm-scale spatial resolution** **Authors :** Frank Bertram, Juergen Christen **Affiliations :** Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany **Resume :** For a detailed understanding of complex semiconductor heterostructures a systematic determination of the structural, chemical, and optical properties on a nanometer scale is essential. The combination of luminescence spectroscopy – in particular at liquid He temperatures - with the high spatial resolution of a scanning transmission electron microscope (STEM) (dx<1 nm at RT,dx <5 nm at 10K), as realized by the technique of low temperature scanning transmission electron microscopy cathodoluminescence spectroscopy (STEM-CL), provides a unique, extremely powerful tool for the optical nano-characterization. In this study we will present our STEM-CL results from an ordered array of InGaN/GaN nano rods (NR) grown in top-down fabrication on GaN/sapphire template: the GaN template was structured using standard photolithography and reactive ion etching. Subsequently, the NRs were overgrown by MBE with a GaN buffer followed by a thick InGaN layer. We observe the highest CL intensity in the upper part of each NR. Spectrally resolved CL measurements at 15 K reveal distinct luminescence contributions originating from the different InGaN sections. Highly resolved linescans of individual NRs exhibit a characteristic luminescence from the bottom InGaN followed by a middle InGaN region. In addition, the upper part of the NR layer shows a broad, strongly red-shifted luminescence giving a detailed understanding of the In composition with distinct In gradients in vertical and radial directions.	K.IV 2
add to my program	(close full abstract)	

09:30 **Revisiting non-radiative processes in InGaN quantum wells by combining photoluminescence and structural analyses**

Authors : T. Schulz 1, T. Remmele 1, T. Markurt 1, M. Albrecht 1, F. Nippert 2, A. Hoffmann 2, A. Nirschl 3, I. Pietzonka 3, H. Lugauer 3, M. Straßburg 3.
Affiliations : 1. Leibniz-Institute for Crystal Growth, Max-Born-Str. 2, 12489 Berlin, Germany; 2. Technical University Berlin, Hardenbergstr. Straße des 17. Juni 135, 10623 Berlin, Germany; 3. OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany;

Resume : There is an ongoing debate about the nature of the non-radiative recombination processes in InGaN quantum wells, causing in the efficiency "droop" or the "green gap". We have combined structural characterization by transmission electron microscopy imaging with an analysis of the recombination dynamics studies by means of time delayed photoluminescence. These studies were carried out for various InGaN quantum well structures exhibiting different designs (conventional/staggerd), different thicknesses and varying mean InGaN compositions. Our structural analyses unequivocally revealed that state of the art and highly effective quantum wells emitting in the blue spectral range exhibit (i) a random In distribution (ii) thickness fluctuations of the quantum well not larger than a single monolayer (iii) no extended defects in the active zone. Thus, we conclude that highly efficient devices do not necessitate additional lateral charge carrier localization except the one promoted by the quantum well and the random InxGa1-xN alloy itself. Concerning the recombination dynamics, we have found two different recombination processes: (i) A slow component on the order of a few µs which is continuously red shifting with increasing delay time and (ii) a fast component on the order of a few ns. We attribute the slow (fast) component to the recombination of the ground state (excited state) of the electron and/or the hole. We draw two major conclusions from these observations: First, older lifetime measurements in InGaN were dominated by the non-radiative instead of the radiative lifetime. Second, the excited state transition acts as a major carrier loss mechanism in the quantum well due to its smaller electronic confinement. This may cause a charge carrier "overflow" relevant for both the droop, as well as in thick quantum wells emitting in the green spectral range.

K.IV 3

add to my program **(close full abstract)**

09:45 **Interface morphology and strain relaxation in axial (In,Ga)N/GaN nanowire heterostructures investigated by transmission electron microscopy**

Authors : X. Kong 1, S. Albert 2, A. Bengoechea-Encabo 2, M. Hanke 1, M.A. Sanchez-Garcia 2, E. Calleja 2, A. Trampert 1
Affiliations : 1. Paul-Drude-Institut fur Festkorperelektronik, Hausvogteiplatz 5–7, D-10117 Berlin, Germany; 2. ISOM and Dpto. Ingenieria Electronica, ETSI Telecomunicacion, Universidad Politecnica, Ciudad Universitaria, 28040 Madrid, Spain.

Resume : Axial (In,Ga)N/GaN nanowire (NW) heterostructures are considered as promising building blocks for the realization of novel high performance light-emitting diodes. Here we will report on the interplay between interface morphology, epitaxial strain and local chemical composition distribution in axial (In,Ga)/GaN NW heterostructures investigated by transmission electron microscopy (TEM). Two sets of NW samples are grown by plasma-assisted molecular beam epitaxy on Si(111) in a self-assembled way and on patterned GaN templates in an ordered way, respectively. Local electron energy-loss spectroscopy measurements show that both sets of NWs have a similar final indium concentration of 35%, but remarkably different interface profiles. The difference of interface profile is strongly linked to the interface morphology: i) In self-assembled NWs showing a large chemical interface width (~40 nm), the interface geometry exhibits a pencil-like shape, where 60°-type misfit dislocations are formed (i.e., with Burgers vector b=a/3[11-20]). ii) On the other hand, the ordered NWs containing flat boundaries and a small interface width of ~10 nm, are plastically relaxed by the formation of partial dislocations associated with stacking faults. Additionally, the residual strain distribution along the (In,Ga)N NWs is studied by high-resolution TEM and geometric phase analysis. The influence of interface morphology and chemical composition profile on local strain distribution and strain relaxation mechanism is further discussed by calculations based on finite-element method.

K.IV 4

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10:00 **Coffee break**

10:30 **Femtosecond-laser surface structuring of nitrides and related materials**

Authors : Tobias Voss
Affiliations : Institute of Solid State Physics, University of Bremen, Germany and Department of Fiber Optical Sensor Systems, Fraunhofer Heinrich Hertz Institute, Goslar, Germany

Resume : The fabrication of micro- and nanostructured functionalized semiconductor surfaces for modern device applications is a very important topic of present research. By focusing intense ultrashort (<100fs) laser pulses onto the surface of semiconductor crystals or epilayers, transient states of matter under extreme excitation conditions can be generated. Nonlinear multi-photon absorption processes result in complex interactions of the laser pulses with the semiconductor surface and allow for surface structuring with high precision, the formation of self-organized periodic surface structures, and doping due to the incorporation of atoms or molecules from the surrounding atmosphere. Here, we will analyse the interaction of intense ultrashort laser pulses with the surface of c-oriented GaN crystals (and some related materials) which leads to the formation of laser-induced periodic surface structures. We will discuss the origin of these surface structures and their evolution as the number of laser pulses applied per surface area is increased. We will further demonstrate the possibility of optically hyperdoping the surface layer of binary compound semiconductors by exploiting the ultrafast melting and ablation processes occurring during the interaction of ultrashort laser pulses with the material's surface layer. Applications of femtosecond-laser surface structuring of nitrides and related materials in light- and heat-management of LEDs and solar cells will also be discussed.

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11:00 **Electro-optical characterization of single InGaN/GaN core-shell LEDs with respect to current density**

Authors : Johannes Ledig, Xue Wang, Jana Hartmann, Markus Bähr, Andreas Fahl, Frederik Steib, Hergo–H. Wehmann, Andreas Waag
Affiliations : Institut für Halbleitertechnik, Technische Universität Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany.

Resume : Three dimensional light emitting diodes (LEDs) with a shell geometry around a columnar GaN core are supposed to have substantial advantages over conventional planar LEDs. The active area along the sidewalls of the GaN pillars can substantially be increased by high aspect ratios. Due to the 3-dimensional shape, the electrical and optical characterization of such device structures is a substantial problem. Here we demonstrate that a nano-manipulator setup inside a scanning electron microscope can be used in combination with a cathodoluminescence (CL) system to characterize the electro-optical properties by directly contacting single facets of the 3D structure. Electron beam induced current (EBIC) images clearly prove that the pn-junction is completely wrapped around the core. By comparing spatially resolved CL and EBIC, the rate of charge carrier generation, trapping and separation in different regions is discussed. We will present electroluminescence (EL) spectra from single core-shell LEDs obtained at different injection currents, in both the region of MQW as well as defect related emission. A wavelength shift of the MQW emission by 60 nm is observed along the structure height for both excitation methods (CL and EL), indicating a gradient of the indium incorporation. In addition, metal contacts have been fabricated in order to get a defined contact area By evaluating the contact area and the EL spectra we gain an insight to the internal efficiency versus current density.

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11:15 **Ultrafast optical spectroscopy of Eu-doped GaN layers**

Authors : E. M. L. D. de Jong 1, W. D. A. M. de Boer 1, T. Gregorkiewicz 1, A. Koizumi 2, D. Timmerman 2, and Y. Fujiwara 2
Affiliations : 1. Van der Waals-Zeeman Institute, University of Amsterdam, The Netherlands; 2. Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University, Japan.

Resume : The rare-earth doped gallium nitride (GaN) materials have shown to be a promising candidate for LEDs, lasers and full-colour displays due to their ability to emit sharp and stable spectral lines. Based on these materials, efficient green and blue LEDs have been successfully developed. For realization of red emission Eu doping is considered. Here, we report on ultrafast optical spectroscopy investigations of state-of-the-art red-emitting GaN doped with trivalent europium (Eu3+) fabricated by organometallic vapor phase epitaxy. We employ experimental techniques of transient induced absorption (IA), using a conventional femtosecond pump-probe setup, and photoluminescence (PL)

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emission and excitation spectroscopy. In that way, carrier decay dynamics measured by IA is cross-correlated with photon generation responsible for PL. The spectrally and temporally resolved data allow for unique insights into the complex energy transfers in this system and their dynamics. In particular, we managed to separate carrier trapping from the build-up of the excited state population of Eu3+ ions, responsible for the red emission band. On this basis, an energy transfer model including dynamics of individual steps can be proposed for the first time. These findings provide fundamental information on the excitation and de-excitation mechanisms of Eu3+ ions in GaN and will serve for further optimization of this material towards lighting applications.

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11:30 **Nanometer-scale optical and structural properties of an AlInN/GaN based microcavity**

Authors : Gordon Schmidt, Marcus Müller, Anja Dempewolf, Silke Petzold, Peter Veit, Frank Bertram, Christoph Berger, Armin Dadgar, Alois Krost, Jürgen Christen
Affiliations : Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany

Resume : III-Nitride based microcavities (MC) are one of the most promising candidates for the realization of polariton lasers operating at room temperature since they exhibit highly stable excitons and large oscillator strength. These lasers operate without inversion in the strong coupling regime (SCR) where the squared strength of the light-matter coupling g has to overcome the mean value of the squared line widths of exciton and cavity mode. Since g is proportional to the square root of the number of quantum wells (QWs), the SCR can be reached by embedding a large number of QWs.We present the optical and the structural properties at the nanometer scale of a MOVPE grown MC structure comprising a large number of embedded InGaN QWs by cathodoluminescence in a scanning transmission electron microscope (STEM-CL). The sample consists of a 28-fold InGaN/GaN QWs embedded in a GaN λ cavity on top of an AlInN/GaN distributed Bragg reflector (DBR) grown on sapphire substrate. Direct comparison of the STEM images with simultaneously recorded CL mappings resolve the complete layer sequence. In particular, the DBR layer stack is proven to be laterally and vertically homogeneous with sharp GaN/AlInN interfaces. A dominant emission with a broad spectral range of the InGaN MQW can be observed. Spectrally resolved linescans across the active region exhibit a redshift from the bottom (425 nm) to the top (465 nm) visualizing strain relaxation, higher In incorporation, and/or increasing QW thickness.

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11:45 **Optical and Microstructural properties into nanoporous GaN films grown on sapphire by metal organic chemical vapor deposition**

Authors : B. Alshehri 1, S-M Lee 2, J-H Kang 2, K. Dogheche, S-H Gong 3, S-W Ryu2, E. Dumont 4, Y-H Cho 3, E. Dogheche 1
Affiliations : 1. Institute of Electronics, Microelectronics and Nanotechnology, Optoelectronics Group (IEMN CNRS UMR 8520) Villeneuve d?Ascq, France; 2, Department of Physics, Chonnam National University, Gwangju 500-757, Republic of Korea; 3. Advanced Institute of Science Technology (KAIST), Daejeon 305-701, Republic of Korea; 4. Energy Research Centre, University of Mons, 7000 Mons, Belgium.

Resume : Gallium Nitride (GaN) thin films have been prepared on sapphire by metal organic chemical vapor deposition (MOCVD) technique and a chemical etching method using KOH is used to develop nanoporous structures [1]. We present comparative investigations of porous and nonporous GaN layers. While the pores density is determined, we have investigated the microstructures in GaN films by using transmission electron microscopy (TEM). The refractive index dispersion has been evaluated through different techniques, ellipsometry and guided-wave prism coupling [2]. We have correlated the microstructure with the refractive index of the material. The aim of this research is to demonstrate that optical properties of GaN can be tuned by controlling the pores size and spacing. For a pores density of 20%, we report an index variation Δn= -12*10-3. The control of the refractive index into GaN is therefore fundamental for the design of active and passive optical devices [1] S-H Gong, A. Stolz,G-H Myeong, E. Dogheche, A. Gokarna, S-W Ryu, D. Decoster, Y-H Cho, Optics letters, vol 36 no.21, pp4272-4274, nov 2011. [2] Y-H Lee, J-H Kang, S-W Ryu, Thin Solid Films, vol.540 150 (2013).

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12:00 **Lunch break**

13:30 **Materials properties and electron dynamics in GaN-based LEDs by electron emission spectroscopy**

Authors : Lucio Martinelli 1, Justin Iveland 2, Marco Piccardo 2, Jacques Peretti 1, James S. Speck 2, and Claude Weisbuch 1 2.
Affiliations : 1. Laboratoire de Physique de la Matie`re Condense´e, CNRS-Ecole Polytechnique, 91128 Palaiseau Cedex, France ; 2. Materials Department, University of California, Santa Barbara, California 93106, USA.

Resume : The non-thermal rollover of the internal quantum efficiency in GaN based LEDs at high current density, known as 'efficiency droop' is one of the key limitations in making ultimate efficiency, solid-state light sources. We report on the study of the physical processes occurring inside LEDs by energy analysis of electrons emitted in vacuum under electrical injections. We observed a hot-electron emission peak, linearly correlated with the droop current. As confirmed by complementary near-UV, low energy photoemission spectroscopy we assigned this peak to Auger electrons thermalized in higher valleys in GaN conduction band.

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14:00 **Ion beam doping of gallium nitride and related nanostructures**

Authors : C. Ronning
Affiliations : Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena

Resume : Gallium nitride (GaN) and related nanostructures are dominating today the solid state lighting technology for LED devices operating above the green gap. However, further improvements in efficiencies and functionality are mandatory in order to keep this lead over other systems such as organic LEDs. This is only feasible, if one optimizes, combines and takes advantage of all possible processing technologies, which also includes ion implantation – an industrial standard technique. However, ion beam doping of GaN is an extremely difficult task, as subsequent annealing procedures typically lead to degradation of the GaN material before all implantation defects are annealed out and the implanted species are activated [1]. Therefore, sophisticated annealing techniques and procedures are desirable, which I will discuss in my presentation. Furthermore, I will give a review on past and current research performed on ion beam doping of GaN and related nanostructures. For the latter issue, I will focus on nanowires and optical doping using rare earth or transition metals. [1] C. Ronning, E. Carlson, R.F. Davis, Physics Reports 351 (2001) 349.

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14:30 **Plasmonic interaction, Indium and Silicon inclusion in Nitrides investigated by tip-enhanced Raman scattering**

Authors : E. Poliani 1, M. R. Wagner 1 2, J. S. Reparaz 1 2, M. Mandl 3, M. Strassburg 3, X. Kong 4, A. Trampert 4, C. Nenstiel 1, S. Fritze 5, A. Dadgar 5, A. Krost 5, A. Hoffmann 1 and J. Maultzsch 1.
Affiliations : 1. Institutür Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany; 2. ICN2 - Institut Catala de Nanociencia i Nanotecnologia, Campus UAB, 08193 Bellaterra (Barcelona), Spain; 3. OSRAM Opto Semiconductors GmbH, 93055 Regensburg, Germany; 4. Paul Drude Institute, 10117 Berlin, Germany; 5. Institut für Experimentelle Physik, Fakultät für Naturwissenschaften, Otto-von-Guericke-Universität Magdeburg, Universitätplatz 2, 39016 Magdeburg, Germany;

Resume : Tip-enhanced Raman spectroscopy (TERS) is a powerful tool for the characterization of semiconductor nanostructures like GaN nanorods with InGaN/GaN quantum wells, where chemical composition, strain, different polymorphs, and Indium clusters can be visualized with high spatial resolution and sensitivity [1]. More useful information is obtained through deeper understanding of this near-field light-matter interaction. For example, the presence of the evanescent field and localized surface plasmons modifies the standard selection rules. Here we demonstrate the surface sensitivity of TERS and the effect of electronic charge-density fluctuations. Two sets of GaN layers highly doped with Si and Ge with different carrier concentrations are studied. For highest Si doping, we report for the first time phonon-plasmon coupling for non-polar Raman modes, which allows sub-wavelength mapping of carrier concentration inhomogeneities. [1] Poliani, E.; Wagner, M. R.; Reparaz, J. S.; Mandl, M.; Strassburg, M.; Kong, X.; Trampert, A.; Sotomayor Torres, C. M.; Hoffmann, A.; Maultzsch, J. Nano Lett. 2013, 13, 3205–3212.

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15:00 **InGaN quantum dots: Potential sources for efficient recombination in the green spectral region**

Authors : S. Schulz, E. P. O'Reilly

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Affiliations : Tyndall National Institute; Tyndall National Institute, Department of Physics, University College Cork

Resume : The emission efficiency of c-plane InGaN quantum wells (QWs) drops significantly when going to thicker QWs and/or higher indium content and thus to longer wavelength. This behavior is related to the strong electrostatic built-in field in nitride-based heterostructures grown along the c-axis. Here we will show, using surface integral techniques, that the built-in fields in c-plane InGaN QDs is strongly reduced compared to c-plane InGaN QWs with the same In content. This reduction of the built-in field originates from two effects (i) a reduction of the [0001] surface area and (ii) strain redistributions in the QD system [1]. Thus, because of the reduction of the built-in field in a QD compared to a QW of the same composition, the In content in the QD can be increased considerably for a fixed field value. Consequently, InGaN QDs offer the possibility to achieve efficient emission at longer wavelength and ideally could provide a potential route to circumvent the green gap problem. Our analysis will be extended to non-identical InGaN QDs stacked along the c-axis. Our study reveals that the built-in field in these stacked QDs can be further reduced by a careful variation of the distance between the QDs leading to an increased spatial overlap of electron and hole wave functions [2]. Finally we will discuss the situation of an InGaN QD embedded in an InGaN QW and how this changes the built-in fields. [1] Phys. Rev. B 82, 033411 (2010) [2] Appl. Phys. Lett. 99, 223106 (2011)

add to my program **(close full abstract)**

15:15 **Microstructural and optical properties of defects in GaN films grown on chemically vapor-deposited graphene layers**

Authors : Hyobin Yoo, Kunook Chung, Suk In Park, Miyoung Kim*, Gyu-Chul Yi*
Affiliations : Seoul National University

Resume : Hybrid systems of inorganic semiconductor with graphene are emerging as novel materials for fabricating various kinds of devices with additional functionalities [1]. Particularly, GaN thin films grown on chemically vapor-deposited (CVD) graphene, which is transferable and scalable, are expected to resolve the problems of substrate limitations for the growth of GaN [2]. In order to further utilize the GaN thin films grown on CVD graphene in the field of optoelectronics, the microstructural defect analysis is essential since the defects are reported to deteriorate the device performances. However, the microstructural defects in the GaN films grown on polycrystalline CVD graphene and their effects on the macroscopic properties have rarely been studied yet. In this report, we examined the microstructural and optical properties of defects present in the GaN thin films grown on CVD graphene. First of all, we note that high-angle grain boundaries originated from polycrystallinity of CVD graphene were observed in GaN thin films which have rarely been reported. Optical properties of the high-angle grain boundaries were investigated by combination of electron backscatter diffraction and cathodoluminescence. Moreover, using aberration corrected scanning transmission electron microscopy, we examined atomic arrangement and core structures in the grain boundaries. [1] H. Yoo et al., Adv. Mater. 24 (2012) p. 515. [2] H. Yoo et al., Appl. Phys. Lett. 102 (2013) p. 051908.

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15:30 **The structure and composition of InxAl1-xN alloys grown by metal-organic vapour phase epitaxy**

Authors : A. Vilalta-Clemente1, M.P. Chauvat1, P. Gamarra2, M. Morales1, M. Tordjman2, J. F. Carlin3, M. A. di Forte-Poisson2, N. Grandjean3, and P. Ruterana1
Affiliations : 1 CIMAP UMR 6252 CNRS-ENSICAEN-CEA-UCBN, 6, Boulevard du Maréchal Juin, 14050 Caen Cedex, France, 2 Alcatel-Thales, III-V Lab. Route de Nozay, 91460 Marcoussis, France, 3 Institute of Condensed Matter Physics (ICMP), Ecole Polytechnique de Lausanne (EPFL) 1015 Lausanne, Switzerland, 4 LPN, Route de Nozay, 91460 Marcoussis, France

Resume : The nitride aluminium and indium alloy (InAlN), when lattice matched (LM) with GaN (i. e. In content at around 18%) is of great interest for opto- and micro-electronic applications. However, due to thermal mismatch between InN and AlN, the growth of good quality InAlN layers is still difficult and many workers have reported crystalline degradation versus thickness even at LM to GaN. The mechanisms governing this behaviour are not still clear, and many proposals are still under debate. In this work, we investigated InAlN layers, close to the LM composition, grown on GaN/Al2O3 by metal organic vapour phase epitaxy at different substrate temperatures and V/III ratios. Scanning transmission electron microscopy, X Ray diffraction, RBS and energy dispersive spectroscopies were used to determine the structure and composition. Our

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results show that the layers quality depends critically on the growth conditions. During our observations, structural disruption has been systematically observed versus thickness and depending on the growth conditions even completely polycrystalline layers were obtained. Therefore, it appears that obtaining good crystallinity and homogeneous composition layers probably needs a continuous layer evolution monitoring and corrections in the conditions during the growth. The influence and role of various parameters such as III/V ratios, growth temperature, sources control and overall pressure on the quality of the grown layers will be discussed.

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15:45 **Study of semipolar (11-22) GaN-based light-emitting diodes grown on epitaxial lateral overgrowth GaN by using hexagon shaped-SiO2 pattern**

Authors : Jae-Hwan Lee 1, Sang-Hyun Han 1, Jihoon Kim 2, Sung-Nam Lee 1*

Affiliations : 1. Optoelectronic Materials & Devices Laboratory, Department of Nano-Optical Engineering, Korea Polytechnic University, Korea; 2. Division of Advanced Materials Engineering, Kongju National University, Korea

Resume : GaN-based semiconductors have been used for the growth of high performance LD/LEDs, etc. Particularly, the epitaxial lateral overgrowth (ELO) technique has been used to reduce crystal defects in GaN film. In stripe ELO (SELO)-GaN, it is known that the direction of SiO2 pattern would determine lateral growth direction to planarize surface structure. However, there is a few report on growth of semipolar (11-22) hexagon ELO (HELO)-GaN film. In this study, we studied the effect of SiO2 hexagon pattern on growth and optical properties of semipolar SELO-GaN which was consisted of 4 ~12μm-width SiO2hexagon pattern. It found that HELO-GaN would more easily coalesce than conventional SELO-GaN due to the higher lateral growth from six directions, resulting in higher crystallographic tilts compared with conventional SELO-GaN film. In semipolar GaN template, FWHM variation of XRC azimuth scan represented W-shape while that of semipolar SELO-GaN film exhibited M-shape. It indicated that the distribution of crystal defect was modified by HELO process, which will be discussed in this presentation. Moreover, semipolar HELO-LED showed higher emission efficiency than conventional semipolar LED. Based on these results, we believed that SELO-GaN would be effective method to decrease crystal defect of semipolar GaN and to increase emission efficiency due to the increase of light extraction efficiency.

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16:00 **Coffee break**

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