GANEX

Newsletter No. 43

August 2016

III-N Technology

Coordinated by CRHEA-CNRS research laboratory, this monthly newsletter is produced by Knowmade with collaboration from the managers of GANEX groups. The newsletter presents a selection of newest scientific publications, patent applications and press releases related to III-Nitride semiconductor materials (GaN, AlN, InN and alloys)

All issues on www.ganex.fr in *Veille* section.
Free subscription http://www.knowmade.com/ganex

GANEX

Cluster of Excellence (Labex, 2012-2019)
GANEX is a cluster gathering French research teams involved in GaN technology. The objective of **GANEX** is to strengthen the position of French academic players in terms of knowledge and visibility, and reinforce the French industrials in terms of know-how and market share.
www.ganex.fr

We Know Technology, We Know Patents
Knowmade is a Technology Intelligence and IP Strategy consulting company specialized in analysis of patents and scientific information. The company supports R&D organizations, industrial companies and investors in their business development by helping them to understand their IP environment and follow technology trends. **Knowmade** is involved in Microelectronics & Optoelectronics, Compound Semiconductors, IC Manufacturing & Advanced Packaging, Power & RF Devices, MEMS & Sensors, Photonics, Micro & Nanotechnology, Biotech/Pharma, MedTech & Medical Devices. **Knowmade** provides Prior art search, Patent Landscape Analysis, Patent Valuation, Freedom-to-Operate Analysis, Litigation/Licensing support, Scientific Literature Landscape, Technology Scouting and Technology Tracking. **Knowmade** combines information search services, technology expertise, powerful analytics tools and proprietary methodologies for analyzing patents and scientific information. **Knowmade**'s analysts have an in-depth knowledge of scientific & patent databases and Intellectual Property.
www.knowmade.com

METHODOLOGY

Sources
10+ scientific journal editors
Elsevier, IOP, IEEE, Wiley, Springer,
APS, AIP, AVS, ECS, Nature, Science …
10+ specialist magazines
Semiconductor Today, ElectoIQ, i-micronews,
Compound Semiconductor, Solid State Technology …
5+ open access database: *FreeFulPDF, DOAJ …*
Patent database: *Questel-Orbit*

Each month
250+ new scientific publications
120+ new patent applications
20+ new press releases

Selection by III-N French experts

GANEX
monthly newsletter

TABLE OF CONTENTS

(clickable links to chapters)

SCIENTIFIC PUBLICATION **4**

GROUP 1 - LEDs and Lighting 4

GROUP 2 - Laser and Coherent Light 10

GROUP 3 - Power Electronics 12

GROUP 4 - Advanced Electronics and RF 15

GROUP 5 – MEMS and Sensors 18

GROUP 6 - Photovoltaics and Energy harvesting 22

GROUP 7 - Materials, Technology and Fundamental 25

PRESS RELEASE **39**

PATENT APPLICATION **64**

SCIENTIFIC PUBLICATION

Selection of new scientific articles

GROUP 1 - LEDs and Lighting

Group leader: Benjamin Damilano (CRHEA-CNRS)

Information selected by Benjamin Damilano (CRHEA-CNRS)

Reduced efficiency droop of nonpolar a-plane (11-20) GaN-based light-emitting diodes by vertical injection geometry

Department of Printed Electronics Engineering, Sunchon National University, Jeonnam 540-742, South Korea

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4958720

Vertical nonpolar a-plane (11-20) InGaN/GaN light-emitting diodes (LEDs) have been demonstrated by using laser lift-off technique. The forward voltage of the a-plane vertical LEDs was 4.3 V at 350 mA, which was reduced by 0.8 V compared to that of the a-plane lateral LEDs. The vertical geometry of the a-plane LEDs produced the higher quantum efficiency with a low efficiency droop and also enhanced the output power by more than 40%, when compared to those of a-plane lateral LEDs. These results can be attributed to the high thermal dissipation as well as uniform current spreading of the vertical geometry of the a-plane LEDs. Furthermore, elimination of the highly defected GaN nucleation layer after removing the sapphire substrates during the fabrication process can also enhance current injection efficiency, followed by the increase in the output power.

Using band engineering to tailor the emission spectra of trichromatic semipolar InGaN light-emitting diodes for phosphor-free polarized white light emission

Materials Department, University of California, Santa Barbara, California 93106, USA

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4958308

We report a polarized white light-emitting device that monolithically integrates an electrically injected blue light-emitting diode grown on the (202¯1¯)(202¯1¯) face of a bulk GaN substrate and optically pumped InGaN quantum wells (QWs) with green and red light emission grown on the (202¯1)(202¯1) face. To overcome the challenges associated with growing high indium content InGaN QWs for long wavelength emission, a p-i-n doping profile was used to red-shift the emission wavelength of one of the optically pumped QWs by creating a built-in electric field in the same direction as the polarization-induced electric field. Emission peaks were observed at 450 nm from the electrically injected QW and at 520 nm and 590 nm from the optically pumped QWs, which were situated in n-i-n and p-i-n structures, respectively. The optically pumped QW in the p-i-n structure was grown at a growth temperature that was 10 °C colder compared to the QW in the n-i-n structure, so the emission from the QW in the p-i-n structure was red-shifted due to increased indium content as well as the built-in electric field. Modeling work confirmed that the built-in electric field made a greater contribution than the change in alloy composition to the red-shift in emission from the QW in the p-i-n structure. The combined emission from the red, green, and blue QWs resulted in white-light emission with Commission Internationale de l'Eclairage x- and y-chromaticity coordinates of (0.33, 0.35) and an optical polarization ratio of 0.30.

Combined electrical and resonant optical excitation characterization of multi-quantum well InGaN-based light-emitting diodes

Tyndall National Institute, University College Cork, Lee Maltings, Dyke Parade, Cork, Ireland
School of Engineering, University College Cork, Cork, Ireland

AIP Advances 6
http://dx.doi.org/10.1063/1.4959100

We present a comprehensive study of the emission spectra and electrical characteristics of

InGaN/GaN multi-quantum well light-emitting diode (LED) structures under resonant optical pumping and varying electrical bias. A 5 quantum well LED with a thin well (1.5 nm) and a relatively thick barrier (6.6 nm) shows strong bias-dependent properties in the emission spectra, poor photovoltaic carrier escape under forward bias and an increase in effective resistance when compared with a 10 quantum well LED with a thin (4 nm) barrier. These properties are due to a strong piezoelectric field in the well and associated reduced field in the thicker barrier. We compare the voltage ideality factors for the LEDs under electrical injection, light emission with current, photovoltaic mode (PV) and photoluminescence (PL) emission. The PV and PL methods provide similar values for the ideality which are lower than for the resistance-limited electrical method. Under optical pumping the presence of an n-type InGaN underlayer in a commercial LED sample is shown to act as a second photovoltaic source reducing the photovoltage and the extracted ideality factor to less than 1. The use of photovoltaic measurements together with bias-dependent spectrally resolved luminescence is a powerful method to provide valuable insights into the dynamics of GaN LEDs.

On the role of diluted magnetic cobalt-doped ZnO electrodes in efficiency improvement of InGaN light emitters

Department of Materials Science and Engineering, National Chung Hsing University, Taichung 40227, Taiwan

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4955488

The 120-nm-thick cobalt-doped ZnO (Co-doped ZnO, CZO) dilute magnetic films deposited by pulsed laser deposition were employed as the n-electrodes for both lateral-type blue (450 nm) and green (520 nm) InGaN light emitters. In comparison to the conventional blue and green emitters, there were 15.9% and 17.7% enhancements in the output power (@350 mA) after fabricating the CZO n-electrode on the n-GaN layer. Observations on the role of CZO n-electrodes in efficiency improvement of InGaN light emitters were performed. Based on the results of Hall measurements, the carrier mobilities were 176 and 141 cm2/V s when the electrons passed through the n-GaN and the patterned-CZO/n-GaN, respectively. By incorporating the CZO n-electrode into the InGaN light emitters, the electrons would be scattered because of the collisions between the magnetic atoms and the electrons as the device is driven, leading to the reduction of the electron mobility. Therefore, the excessively large mobility difference between electron and hole carriers occurred in the conventional InGaN light emitter can be efficiently decreased after preparing the CZO n-electrode on the n-GaN layer, resulting in the increment of carrier recombination rate and the improvement of light output power.

Unintentional indium incorporation into barriers of InGaN/GaN multiple quantum wells studied by photoreflectance and photoluminescence excitation spectroscopy

Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4955426

InxGa1– xN/GaN single and multi quantum well (MQW) structures with x ≈ 0.13 were investigated optically by photoreflectance, photoluminescence excitation spectroscopy, and luminescence. Clear evidence of unintentional indium incorporation into the nominal GaN barrier layers is found. The unintentional In content is found to be around 3%. Inhomogeneous distribution of In atoms occurs within the distinct quantum well (QW) layers, which is commonly described as statistical alloy fluctuation and leads to the characteristic S-shape temperature shift of emission energy. Furthermore, differences in emission energy between the first and the other QWs of a MQW stack are found experimentally. This effect is discussed with the help of model calculations and is assigned to differences in the confining potential due to unwanted indium incorporation for the upper QWs.

Comparative efficiency analysis of GaN-based light-emitting diodes and laser diodes

NUSOD Institute LLC, Newark, Delaware 19714-7204, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4958619

Nobel laureate Shuji Nakamura predicted in 2014 that GaN-based laser diodes are the future of solid state lighting. However, blue GaN-lasers still exhibit less than 40% wall-plug efficiency, while some GaN-based blue light-emitting diodes exceed 80%. This paper investigates non-thermal reasons behind this difference. The inherently poor hole conductivity of the Mg-doped waveguide cladding layer of laser diodes is identified as main reason for their low electrical-to-optical energy conversion efficiency.

Enhancement of optical polarization degree of AlGaN quantum wells by using staggered structure

State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, School of Physics, Peking University, Beijing 100871, China

Optics Express
http://dx.doi.org/10.1364/OE.24.018176

Staggered AlGaN quantum wells (QWs) are designed to enhance the transverse-electric (TE) polarized optical emission in deep ultraviolet (DUV) light- emitting diodes (LED). The optical polarization properties of the conventional and staggered AlGaN QWs are investigated by a theoretical model based on the k·p method as well as polarized photoluminescence (PL) measurements. Based on an analysis of the valence subbands and momentum matrix elements, it is found that AlGaN QWs with step-function-like Al content in QWs offers much stronger TE polarized emission in comparison to that from conventional AlGaN QWs. Experimental results show that the degree of the PL polarization at room temperature can be enhanced from 20.8% of conventional AlGaN QWs to 40.2% of staggered AlGaN QWs grown by MOCVD, which is in good agreement with the theoretical simulation. It suggests that polarization band engineering via staggered AlGaN QWs can be well applied in high efficiency AlGaN-based DUV LEDs.

High luminous efficacy green light-emitting diodes with AlGaN cap layer

Materials Department, University of California, Santa Barbara, California 93106, USA

Optics Express
http://dx.doi.org/10.1364/OE.24.017868

We demonstrate very high luminous efficacy green light-emitting diodes employing $Al_{0.30}Ga_{0.70}N$ cap layer grown on patterned sapphire substrates by metal organic chemical vapor deposition. The peak external quantum efficiency and luminous efficacies were 44.3% and 239 lm/w, respectively. At 20 mA (20 A/cm2) the light output power was 14.3 mW, the forward voltage was 3.5 V, the emission wavelength was 526.6 nm, and the external quantum efficiency was 30.2%. These results are among the highest reported luminous efficacy values for InGaN based green light-emitting diodes.

Nano-light-emitting-diodes based on InGaN mesoscopic structures for energy saving optoelectronics

Peter Grünberg Institute (PGI-9) Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany
Jülich Aachen Research Alliance, JARA, Fundamentals of Future Information Technology, D-52425 Jülich, Germany
Robert Bosch GmbH, D-72760 Reutlingen, Germany
Faculté des Sciences, de la Technologie et de la Communication, Université du Luxembourg, L-1359 Luxembourg, Luxembourg

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4960007

Vertically integrated III-nitride based nano-LEDs (light emitting diodes) were designed and fabricated for operation in the telecommunication wavelength range in the (p-GaN/InGaN/n-GaN/sapphire) material system. The band edge luminescence energy of the nano-LEDs could be engineered by tuning the composition and size of the InGaN mesoscopic structures. Narrow band edge photoluminescence and electroluminescence were observed. Our

mesoscopic InGaN structures (depending on diameter) feature a very low power consumption in the range between 2 nW and 30 nW. The suitability of the technological process for the long-term operation of LEDs is demonstrated by reliability measurements. The optical and electrical characterization presented show strong potential for future low energy consumption optoelectronics.

Growth of monolithic full-color GaN-based LED with intermediate carrier blocking layers

EPI Lab, Ostendo Technologies, Inc., 679 Brea Canyon Rd, Walnut, CA 91789, USA

AIP Advances
http://dx.doi.org/10.1063/1.4959897

Specially designed intermediate carrier blocking layers (ICBLs) in multi-active regions of III-nitride LEDs were shown to be effective in controlling the carrier injection distribution across the active regions. In principle, the majority of carriers, both holes and electrons, can be guided into targeted quantum wells and recombine to generate light of specific wavelengths at controlled current-densities. Accordingly we proposed and demonstrated a novel monolithic InGaN-based LED to achieve three primary colors of light from one device at selected current densities. This LED structure, which has three different sets of quantum wells separated with ICBLs for three primary red-green-blue (RGB) colors, was grown by metal-organic chemical vapor deposition (MOCVD). Results show that this LED can emit light ranging from 460 to 650 nm to cover the entire visible spectrum. The emission wavelength starts at 650 nm and then decreases to 460 nm or lower as the injection current increases. In addition to three primary colors, many other colors can be obtained by color mixing techniques. To the best of our knowledge, this is the first demonstration of monolithic full-color LED grown by a simple growth technique without using re-growth process.

Carrier dynamics and Coulomb-enhanced capture in III-nitride quantum heterostructures

Soraa, Inc., 6500 Kaiser Dr., Fremont, California 94555, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959143

A detailed study of the small-signal response of III-Nitride quantum well (QW) light-emitting diodes is presented, in which the electrical and optical responses are simultaneously measured. A complete transport-recombination model is introduced to account for measurements. This allows for a proper evaluation of the recombination lifetime and for the accurate quantification of thermionic carrier escape from the QW. Further, a yet-unreported carrier capture mechanism is identified and quantified; it increases with the carrier density in the QW and bears the signature of a Coulomb in-scattering process.

High-Output-Power Ultraviolet Light Source from Quasi-2D GaN Quantum Structure

State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, School of Physics, Peking University, Beijing, P. R. China
Collaborative Innovation Center of Quantum Matter, Beijing, P. R. China
Ioffe Institute, St. Petersburg, Russia

Advanced Materials
http://dx.doi.org/10.1002/adma.201600990

Quasi-2D GaN layers inserted in AlGaN matrix are proposed as a novel active region to develop high-output-power UV light source. Such structure is successfully achieved by precise control in molecular beam epitaxy and shows an amazing output power of ≈160 mW at 285 nm with a pulsed electron-beam excitation. This device is promising and competitive in the non-line-of-sight communications or sterilization field.

On the internal quantum efficiency for InGaN/GaN light-emitting diodes grown on insulating substrates

Key Laboratory of Electronic Materials and Devices of Tianjin, School of Electronics and Information Engineering, Hebei University of Technology, Tianjin, P.R. China

Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600281

The internal quantum efficiency (IQE) for InGaN/GaN light-emitting diodes (LEDs) grown on [0001] sapphire substrates is strongly affected by various factors including polarization effect in the InGaN/GaN multiple quantum wells (MQWs), insufficient electron and hole injections, low p-type GaN doping efficiency, carrier loss due to the Auger recombination, and current crowding effect especially for the hole current in the p-GaN region. In this work, the remedies taken by the scientific community to enhance the IQE are reviewed, compared and summarized. Meanwhile, this review also discusses alternative ways including polarization self-screening effect, polarization cooling, hole accelerator, and hole modulator. The structural solutions we propose in this work can better improve the device performance without increasing the processing difficulty significantly, and their effectiveness in improving the IQE is further supported by the numerical and experimental studies. For example, on the contrary to common belief, the polarizations in the [0001] oriented InGaN/GaN LEDs can be advantageously used to improve the device performance based on our designs.

Flexible GaN Light-Emitting Diodes Using GaN Microdisks Epitaxial Laterally Overgrown on Graphene Dots

Department of Physics and Astronomy, Institute of Applied Physics, and Research Institute of Advanced Materials, Seoul National University, Seoul, Korea
Department of Materials Science and Engineering, Research Institute of Advanced Materials, Seoul National University, Seoul, Korea
Department of Chemistry and Nano Science, Ewha Womans University, Seoul, Korea

Advanced Materials
http://dx.doi.org/10.1002/adma.201601894

The epitaxial lateral overgrowth (ELOG) of GaN microdisks on graphene microdots and the fabrication of flexible light-emitting diodes (LEDs) using these microdisks is reported. An ELOG technique with only patterned graphene microdots is used, without any growth mask. The discrete micro-LED arrays are transferred onto Cu foil by a simple lift-off technique, which works reliably under various bending conditions.

InGaN/GaN multiple quantum wells on selectively grown GaN microfacets and the applications for phosphor-free white light-emitting diodes

School of Science, Jiangsu Provincial Research Center of Light Industrial Optoelectronic Engineering and Technology, Jiangnan University, No. 1800 Lihu Road, Wuxi 214122, China
School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China

Reviews in Physics
http://dx.doi.org/10.1016/j.revip.2016.06.001

Phosphor-free InGaN/GaN multiple quantum well (MQW) white light-emitting diodes (LEDs) have the advantages of simpler device process and potentially higher efficiency, and have attracted much attention in recent years. A host of technologies are emerging for implementing such white-light LEDs. Among them, the key issue is the color tuning of different emission wavelengths from InGaN/GaN MQWs with different indium (In) content. However, owing to the limited growth technology for long-wavelength InGaN/GaN MQWs with high In content, it is very attractive to study selective area epitaxy (SAE) of InGaN/GaN MQWs on GaN microstructures with non- or semipolar microfacets combined with (0001) c-plane. In this paper, we briefly review the previous developments of InGaN/GaN MQW based phosphor-free white light LEDs, then the particular technology for the growth of InGaN/GaN MQWs on the regrown GaN microfacets using SAE has been introduced, and related mechanisms for the formation of different non- or semipolar GaN microfacets fabricated by various mask patterns are discussed in detail. Furthermore, sophisticated approaches made use of the InGaN/GaN MQWs on GaN microfacets to

fabricated phosphor-free white light LEDs with polychromatic emissions are reviewed.

InGaN Light-Emitting Diodes with an Embedded Nanoporous GaN Distributed Bragg Reflectors

Department of Materials Science and Engineering, National Chung Hsing University, Taichung, 402, Taiwan

Scientific Reports
http://dx.doi.org/10.1038/srep29138

InGaN light emitting diodes (LED) structure with an embedded 1/4λ-stack nanoporous-GaN/undoped-GaN distributed Bragg reflectors (DBR) structure have been demonstrated. Si-heavily doped GaN epitaxial layers (n+-GaN) in the 12-period n+-GaN/u-GaN stack structure are transformed into low refractive index nanoporous GaN structure through the doping-selective electrochemical wet etching process. The central wavelength of the nanoporous DBR structure was located at 442.3 nm with a 57 nm linewidth and a 97.1% peak reflectivity. The effective cavity length (6.0λ), the effective penetration depth (278 nm) in the nanoporous DBR structure, and InGaN active layer matching to Fabry-Pérot mode order 12 were observed in the far-field photoluminescence radiative spectra. High electroluminescence emission intensity and line-width narrowing effect were measured in the DBR-LED compared with the non-treated LED structure. Non-linear emission intensity and line-width reducing effect, from 11.8 nm to 0.73 nm, were observed by increasing the laser excited power. Resonant cavity effect was observed in the InGaN LED with bottom nanoporous-DBR and top GaN/air interface.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowmade

Low threshold continuous-wave lasing of yellow-green InGaN-QD vertical-cavity surface-emitting lasers

Department of Electronic Engineering, Xiamen University, Xiamen 361005, China
Department of Electronic Engineering, East China Normal University, Shanghai 200241, China

Optics Express
http://dx.doi.org/10.1364/OE.24.015546

Low threshold continuous-wave (CW) lasing of current injected InGaN quantum dot (QD) vertical-cavity surface-emitting lasers (VCSELs) was achieved at room temperature. The VCSEL was fabricated by metal bonding technique on a copper substrate to improve the heat dissipation ability of the device. For the first time, lasing was obtained at yellow-green wavelength of 560.4 nm with a low threshold of 0.61 mA, corresponding to a current density of 0.78 kA/cm2. A high degree of polarization of 94% were measured. Despite the operation in the range of "green gap" of GaN-based devices, single longitudinal mode laser emission was clearly achieved due to the high quality of active region based on InGaN QDs and the excellent thermal design of the VCSELs.

Fabrication and structural properties of AlN submicron periodic lateral polar structures and waveguides for UV-C applications

Department of Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina 27695, USA
Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4955033

Periodically poled AlN thin films with submicron domain widths were fabricated for nonlinear applications in the UV-VIS region. A procedure utilizing metalorganic chemical vapor deposition growth of AlN in combination with laser interference lithography was developed for making a nanoscale lateral polarity structure (LPS) with domain size down to 600 nm. The Al-polar and N-polar domains were identified by wet etching the periodic LPS in a potassium hydroxide solution and subsequent scanning electron microscopy (SEM) characterization. Fully coalesced and well-defined vertical interfaces between the adjacent domains were established by cross-sectional SEM. AlN LPSs were mechanically polished and surface roughness with a root mean square value of ~10 nm over a 90 µm × 90 µm area was achieved. 3.8 µm wide and 650 nm thick AlN LPS waveguides were fabricated. The achieved domain sizes, surface roughness, and waveguides are suitable for second harmonic generation in the UVC spectrum.

Comparative efficiency analysis of GaN-based light-emitting diodes and laser diodes

NUSOD Institute LLC, Newark, Delaware 19714-7204, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4958619

Nobel laureate Shuji Nakamura predicted in 2014 that GaN-based laser diodes are the future of solid state lighting. However, blue GaN-lasers still exhibit less than 40% wall-plug efficiency, while some GaN-based blue light-emitting diodes exceed 80%. This paper investigates non-thermal reasons behind this difference. The inherently poor hole conductivity of the Mg-doped waveguide cladding layer of laser diodes is identified as main reason for their low electrical-to-optical energy conversion efficiency.

Broadband tunable microwave photonic phase shifter with low RF power variation in a high-Q AlN microring

Tsinghua National Laboratory for Information Science and Technology, State Key Lab on Integrated Optoelectronics, Department of Electronic Engineering, Tsinghua University, Beijing 100084, China

Optics Letters
http://dx.doi.org/10.1364/OL.41.003599

An all-optically tunable microwave photonic phase shifter is demonstrated based on an epitaxial aluminum nitride (AlN) microring with an intrinsic quality factor of 3.2×106. The microring adopts a pedestal structure, which allows overcoupling with 700 nm gap size and facilitates the fabrication process. A phase shift for broadband signals from 4 to 25 GHz is demonstrated by employing the thermo-optic effect and the separate carrier tuning technique. A phase tuning range of 0°–332° is recorded with a 3 dB radio frequency (RF) power variation and 48 mW optical power consumption. In addition, AlN exhibits intrinsic second-order optical nonlinearity. Thus, our work presents a novel platform with a low propagation loss and the capability of electro-optic modulation for applications in integrated microwave photonics.

Room-Temperature Observation of Trapped Exciton-Polariton Emission in GaN/AlGaN Microcavities with Air-Gap/III-Nitride Distributed Bragg Reflectors

Institute of Industrial Science and ‡Institute for Nano Quantum Information Electronics, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo, 153-8505, Japan

ACS Photonics
http://dx.doi.org/10.1021/acsphotonics.6b00003

We demonstrate trapped exciton-polariton emission at room temperature from nonpolar GaN/AlGaN cavities sandwiched between air/AlGaN distributed Bragg reflectors. Nanoscale thickness fluctuations characteristic to the nonpolar AlGaN cavity layer create deep potential traps, giving rise to a strong (in-plane) localization of exciton-polaritons. The observed quantized exciton-polariton states exhibit a large quantized energy of up to 6 meV, which benefits from the wide bandgap of III-nitrides. The experimental results are well explained by numerical simulations. III-Nitride exciton-polaritons in such deep traps will be useful for practical exciton-polariton lasers with high degrees of coherence and high-repetition rate Josephson oscillators with multicomponent condensates.

GROUP 3 - Power Electronics

Group leader: Frédéric Morancho (LAAS-CNRS)

Information selected by Frédéric Morancho (LAAS-CNRS) and Yvon Cordier (CRHEA-CNRS)

Thermally stable device isolation by inert gas heavy ion implantation in AlGaN/GaN HEMTs on Si

Temasek Laboratories@NTU, Nanyang Technological University, 50 Nanyang Drive, Singapore 637553

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4955152

Multiple energies of heavy ion implantation with inert-gas ion (84Kr+) were carried out on AlGaN/GaN high-electron-mobility transistors (HEMTs) for planar device isolation. Thermal stability of the implantated samples were also investigated by isochronal annealing at 500, 600, 700, and 800 °C (each temperature for 1 h.). Due to the damages created by heavy ions (84Kr+) in the GaN lattice, the implant-isolated Al0.27Ga0.73N/GaN HEMT samples exhibited better thermal stability than 40Ar+-implant-isolation. This was also confirmed by Rutherford backscattering spectrometry in channeling condition and ultraviolet micro-Raman spectroscopy measurements. With reference to mesa-isolated AlGaN/GaN HEMTs, the buffer breakdown voltage is also stable in the implant-isolated AlGaN/GaN HEMTs. An enhanced OFF-state breakdown voltage was also realized in the implant-isolated AlGaN/GaN HEMTs. The inert gas heavy ion implantation (84Kr+) is a viable solution for the fabrication of thermally stable planar AlGaN/GaN HEMTs even up to 800 °C under long-term isochronal annealing.

Investigation of kink effect in normally-off AlGaN/GaN recessed-gate MOS-heterostructure FETs

School of Electronic and Electrical Engineering, Hongik University, Seoul 121-791, South Korea

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4959842

Kink effects, anomalous increase of the output current, were observed at room temperature in normally-off AlGaN/GaN metal-oxide-semiconductor (MOS)-heterostructure field effect transistors with recessed gate. The kink phenomenon occurred only at certain bias-sweeping conditions and is suggested to result from electron trapping and subsequent detrapping process which gave rise to temporary shift of the threshold voltage. The magnitude of the kink is related to the positive gate bias and the temperature. Positive bias applied on the gate induced the negative charge build-up at the MOS interface and hot electrons released trapped electrons by impact ionization.

Impact of recess etching and surface treatments on ohmic contacts regrown by molecular-beam epitaxy for AlGaN/GaN high electron mobility transistors

Microsystems Technology Laboratories, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA
Université Grenoble-Alpes, 38000 Grenoble, France
CEA Grenoble, INAC-PHELIQS, 38000 Grenoble, France

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959831

Ohmic contacts fabricated by regrowth of n+ GaN are favorable alternatives to metal-stack-based alloyed contacts in GaN-based high electron mobility transistors. In this paper, the influence of reactive ion dry etching prior to regrowth on the contact resistance in AlGaN/GaN devices is discussed. We demonstrate that the dry etch conditions modify the surface band bending, dangling bond density, and the sidewall depletion width, which influences the contact resistance of regrown contacts. The impact of chemical surface treatments performed prior to regrowth is also investigated. The sensitivity of the contact resistance to the surface treatments is found to depend upon the dangling bond density of the sidewall facets exposed after dry etching. A theoretical model has been developed in order to explain the observed trends.

An AlN/Al0.85Ga0.15N high electron mobility transistor

Sandia National Laboratories, PO Box 5800, Albuquerque, New Mexico 87185-1085, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959179

An AlN barrier high electron mobility transistor (HEMT) based on the AlN/Al0.85Ga0.15N heterostructure was grown, fabricated, and electrically characterized, thereby extending the range of Al composition and bandgap for AlGaN channel HEMTs. An etch and regrowth procedure was implemented for source and drain contact formation. A breakdown voltage of 810 V was achieved without a gate insulator or field plate. Excellent gate leakage characteristics enabled a high Ion/Ioff current ratio greater than 107 and an excellent subthreshold slope of 75 mV/decade. A large Schottky barrier height of 1.74 eV contributed to these results. The room temperature voltage-dependent 3-terminal off-state drain current was adequately modeled with Frenkel-Poole emission.

Time-dependent threshold voltage drift induced by interface traps in normally-off GaN MOSFET with different gate recess technique

Institute of Microelectronics, Peking University, Beijing 100871, China

Applied Physics Express
http://dx.doi.org/10.7567/APEX.9.091001

The time-dependent threshold voltage drift induced by fast interface traps in a fully gate-recessed normally-off GaN MOSFET is studied. It is found that the degree and time scale of the shift in threshold voltage are consistent with the density and time constant of interface traps at the MOS interface. The device based on wet etching delivers higher interface quality and threshold voltage stability than that based on dry etching. Nitrogen deficiency and high oxygen coverage are considered to be the origins of the high interface trap density in the MOSFET fabricated by dry etching.

Oxide Charge Engineering of Atomic Layer Deposited AlOxNy/Al2O3 Gate Dielectrics: A Path to Enhancement Mode GaN Devices

Department of Materials Science and Engineering, Stanford University, Stanford, California 94305, United States

ACS Appl. Mater. Interfaces
http://dx.doi.org/10.1021/acsami.6b03862

Nitrogen incorporation to produce negative fixed charge in Al2O3 gate insulator layers is investigated as a path to achieve enhancement mode GaN device operation. A uniform distribution of nitrogen across the resulting AlOxNy films is obtained using N2 plasma enhanced atomic layer deposition (ALD). The flat band voltage (Vfb) increases to a significantly more positive value with increasing nitrogen concentration. Insertion of a 2 nm thick Al2O3 interlayer greatly decreases the trap density of the insulator/GaN interface, and reduces the voltage hysteresis and frequency dispersion of gate capacitance compared to single-layer AlOxNy gate insulators in GaN MOSCAPs.

Selective Area Growth: a Promising Way for Recessed Gate GaN MOSFET with High Quality MOS Interface

State Key Lab of Optoelectronics Materials & Technologies, School of Physics & Engineering, Sun Yat-Sen University, Guangzhou 510275, P. R. China

IEEE Electron Device Letters
http://dx.doi.org/10.1109/LED.2016.2590821

Based on the selective area growth (SAG) technique, an enhancement mode GaN recessed gate MOSFET was fabricated successfully with negligible gate trapping effect, presenting an extremely small threshold voltage (Vth) hysteresis of 50 mV at a gate bias swing up to +10 V. Compared with the larger Vth hysteresis of a recessed gate GaN MOSFET fabricated by dry-etching, the correlation between the Vth hysteresis and the lattice damage related traps caused by plasma dry etching process has been confirmed. Furthermore, the SAG recessed MOSFET shows a lower turn-on resistance due to the higher MOS channel mobility. We believe that all of these superior performance of SAG MOSFET

are attributed to the damage free high quality GaN surface at the Al2O3/GaN MOS interface, which indicates that the SAG is a promising alternative technique towards stable GaN MOSFET for the power switching applications.

GROUP 4 - Advanced Electronics and RF

Group leader: Jean-Claude Dejaeger (IEMN)

Information selected by Jean-Claude Dejaeger (IEMN) and Yvon Cordier (CRHEA-CNRS)

Low frequency noise in two-dimensional lateral GaN/AlGaN Schottky diodes

Institute of High Pressure Physics, Polish Academy of Sciences, ul. Sokołowska 29/37, 01-142 Warsaw, Poland
Top-GaN Ltd., ul. Sokołowska 29/37, 01-142 Warsaw, Poland

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4958857

Schottky diodes with Ni/Au contact to the side of the two dimensional channel in GaN/AlGaN system were fabricated and studied. This kind of lateral heterodimensional diodes demonstrated the ideality factor n = 1.2–1.25 and apparent barrier height ϕb = (0.59–0.63) eV. The noise measurements within the frequencies range from 1 Hz to 50 kHz showed that the diodes demonstrated the superposition of 1/f and generation recombination noise. In spite of extremely small area of lateral Schottky diodes, the amplitude of noise was similar or even smaller than that for AlGaN and GaN Schottky diodes with the regular contact. This makes GaN-based lateral Schottky diodes to be very promising devices for RF and terahertz applications.

Degradation and annealing effects caused by oxygen in AlGaN/GaN high electron mobility transistors

Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, Tennesse 37235, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4958706

Hot-carrier degradation and room-temperature annealing effects are investigated in unpassivated ammonia-rich AlGaN/GaN high electron mobility transistors. Devices exhibit a fast recovery when annealed after hot carrier stress with all pins grounded. The recovered peak transconductance can exceed the original value, an effect that is not observed in control passivated samples. Density functional theory calculations suggest that dehydrogenation of pre-existing ON-H defects in AlGaN plays a significant role in the observed hot carrier degradation, and the resulting bare ON can naturally account for the "super-recovery" in the peak transconductance.

InN thin-film transistors fabricated on polymer sheets using pulsed sputtering deposition at room temperature

Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959777

Indium nitride (InN) is potentially suitable for the fabrication of high performance thin-film transistors (TFTs) because of its high electron mobility and peak electron velocity. However, InN is usually grown using a high temperature growth process, which is incompatible with large-area and lightweight TFT substrates. In this study, we report on the room temperature growth of InN films on flexible polyimide sheets using pulsed sputtering deposition. In addition, we report on the fabrication of InN-based TFTs on flexible polyimide sheets and the operation of these devices.

Effects of proton irradiation and thermal annealing on off-state step-stressed AlGaN/GaN high electron mobility transistors

Department of Chemical Engineering, University of Florida, Gainesville, Florida 32611

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4959028

The effects of proton irradiation doses on dc characteristics of reference, electrically stressed under off-state conditions and stressed/annealed AlGaN/GaN high electron mobility transistors (HEMTs) were investigated. The HEMTs were irradiated with protons at a fixed energy of 5 MeV and doses ranging from 1013 to 1015 cm−2. As

expected, in all three types of HEMTs, more degradation of the device dc characteristics was observed for higher doses due to the larger displacement damage in two-dimensional electron gas channel of the HEMTs. The electrically stressed HEMTs after proton irradiation showed more degradation compared with reference and stressed/annealed HEMTs. After proton irradiation at a dose of 1015 cm−2, the drain saturation current and maximum transconductance of stressed HEMTs were decreased by 28.5% and 15%, respectively, compared to 24% and 11.5%–12%, respectively, for reference and stressed/annealed devices. The dc characteristics of stressed/annealed HEMTs after proton irradiation showed similar degradation trends compared with those of reference HEMTs, confirming that annealing is effective in removing defects created by the off-state stressing. In some cases, the authors also annealed stressed/irradiated HEMTs after the proton irradiation step. The drain current and transconductance of stressed/irradiated HEMTs were slightly increased after subsequent thermal annealing at 450 °C for 10 min, while reverse gate leakage current after annealing was decreased more than an order of magnitude. The interface trap density of stressed HEMTs after proton irradiation at a dose of 1015 cm−2 increased from 3.05 × 1012 to 1.37 × 1013/cm2 V and were reduced to 6.01 × 1012/cm2 V following thermal annealing. Our results are consistent with the notion that off-state stressing creates defects that have a common origin with those created by proton irradiation, and thus, irradiation of off-state stressed devices leads to more defects than in unstressed devices that are subsequently irradiated. Annealing the stressed devices prior to irradiation makes them behave the same as unstressed HEMTs when both are irradiated with protons.

Effect of proton irradiation dose on InAlN/GaN metal-oxide semiconductor high electron mobility transistors with Al2O3 gate oxide

Department of Chemical Engineering, University of Florida, Gainesville, Florida 32611

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4959786

The effects of proton irradiation on the dc performance of InAlN/GaN metal-oxide-semiconductor high electron mobility transistors (MOSHEMTs) with Al2O3 as the gate oxide were investigated. The InAlN/GaN MOSHEMTs were irradiated with doses ranging from 1 × 1013 to 1 × 1015 cm−2 at a fixed energy of 5 MeV. There was minimal damage induced in the two dimensional electron gas at the lowest irradiation dose with no measurable increase in sheet resistance, whereas a 9.7% increase of the sheet resistance was observed at the highest irradiation dose. By sharp contrast, all irradiation doses created more severe degradation in the Ohmic metal contacts, with increases of specific contact resistance from 54% to 114% over the range of doses investigated. These resulted in source-drain current–voltage decreases ranging from 96 to 242 mA/mm over this dose range. The trap density determined from temperature dependent drain current subthreshold swing measurements increased from 1.6 × 1013 cm−2 V−1 for the reference MOSHEMTs to 6.7 × 1013 cm−2 V−1 for devices irradiated with the highest dose. The carrier removal rate was 1287 ± 64 cm−1, higher than the authors previously observed in AlGaN/GaN MOSHEMTs for the same proton energy and consistent with the lower average bond energy of the InAlN.

A 1.8/2.6 GHz high efficiency dual-band harmonic controlled, 50W GAN power amplifier with wide bandwidth characteristics

Department of Wireless Communications Engineering, Kwangwoon University, Seoul, Korea

Microwave and Optical Technology Letters
http://dx.doi.org/10.1002/mop.30078

A high efficiency dual band 50W GaN HEMT power amplifier is presented at 1.8 GHz and 2.6 GHz. An impedance matching network of the dual band amplifier at the fundamental and second harmonic frequencies is constructed to obtain wide bandwidth characteristics with reduction of sensitivity to impedance variation with frequency fluctuations. The matching network is composed of a three-stage transmission line and an open-ended stub with low Q-factors. A T-type DC bias line is performed to control impedances at second

harmonic frequencies. From the measured results, the proposed dual band GaN HEMT amplifier achieved a minimum of 55% efficiency at 1.8 GHz and 2.6 GHz with a 300 MHz bandwidth for a maximum output power of 47 dBm.

Fabrication of InGaN thin-film transistors using pulsed sputtering deposition

Institute of Industrial Science, The University of Tokyo, Tokyo 153-8505, Japan

Scientific Reports
http://dx.doi.org/10.1038/srep29500

We report the first demonstration of operational InGaN-based thin-film transistors (TFTs) on glass substrates. The key to our success was coating the glass substrate with a thin amorphous layer of HfO2, which enabled a highly c-axis-oriented growth of InGaN films using pulsed sputtering deposition. The electrical characteristics of the thin films were controlled easily by varying their In content. The optimized InGaN-TFTs exhibited a high on/off ratio of ~108, a field-effect mobility of ~22 cm2 V−1 s−1, and a maximum current density of ~30 mA/mm. These results lay the foundation for developing high-performance electronic devices on glass substrates using group III nitride semiconductors.

On the Radiation Tolerance of AlGaN/GaN HEMTs

Naval Research Laboratory, Washington, DC 20375, USA

ECS J. Solid State Sci. Technol.
http://dx.doi.org/10.1149/2.0281607jss

The radiation tolerance of AlGaN/GaN high electron mobility transistors (HEMTs) fabricated on high quality, low threading dislocation density (TDD) ammonothermal GaN and hydride vapor phase epitaxy GaN substrates was studied and compared to the radiation response of devices on SiC substrates where the TDD is 104 times higher. Hall and transport measurements were performed as a function of 2 MeV proton fluence. The threading dislocation density had no effect on the radiation response. Comparing the results with published data reveals that almost all irradiated GaN-based HEMTs respond to radiation damage similarly regardless of differences in initial film quality, device structure, aluminum mole fraction, etc. AlGaAs/GaAs HEMTs are also shown to behave similarly but are around ten times more sensitive to radiation damage than GaN-based HEMTs. Known values of the displacement energy thresholds in GaN and GaAs are used to calculate that 36% fewer defects are created in GaN than in GaAs, which is too small to cause a 1000% difference in radiation sensitivity between GaN- and GaAs-based HEMTs. An alternative explanation is proposed in which the piezoelectric field at the AlGaN/GaN interface causes scattered carriers to be reinjected into the 2DEG channel, thereby mitigating some of the harmful radiation effects.

GROUP 5 – MEMS and Sensors

Group leader: Marc Faucher (IEMN)

Information selected by Knowmade

Depletion-mediated piezoelectric AlGaN/GaN resonators

Department of Electrical Engineering and Computer Science, University of Michigan, MI, USA

Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201532746

The electromechanical properties of an acoustic wave propagating in a piezoelectric media can be tuned by modulation of the resistivity of the piezoelectric material. This is readily available in piezoelectric semiconductor materials, wherein acoustic phonons and charge carriers can interact. In this work, we employ epitaxially grown AlGaN/GaN heterostructures in bulk acoustic wave resonators with Schottky interdigitated transducers biased in the depletion region to study the interaction between piezoelectric strain and depletion charges. By modulating the impedance of the depletion layer upon application of DC voltages, we tune the acoustic properties of bulk-mode resonators and show significant Q enhancement as the result of a depletion force added to the piezoelectric actuation force. Furthermore, we compare the performance of such resonators with pure GaN piezoelectric resonators that have the same geometry but with the AlGaN layer removed. When integrated with AlGaN/GaN HEMTs (located on the acoustic cavity or next to the resonator), such resonators can be used as frequency references in oscillator circuits in radio frequency (RF) blocks or utilized in harsh environment sensing applications.

AlN-on-SOI platform-based micro-machined hydrophone

Institute of Microelectronics, Agency for Science, Technology and Research (A*STAR), 2 Fusionopolis Way, #08-02 Innovis Tower, 138634 Singapore

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959078

This paper reports a piezoelectric aluminum nitride (AlN) based micro-machined infrasonic hydrophone. We have conducted a systematic design study for the hydrophone sensor to meet the stringent requirements of underwater applications. The hydrophone sensor was fabricated on a cavity silicon-on-insulator (SOI) substrate using an in-house CMOS-compatible AlN-on-SOI process platform. A 5 × 5 arrayed hydrophone sensor was characterized thoroughly using an industry-standard hydrophone calibration instrument. The results show that the hydrophone achieved a sound sensitivity of −182.5 dB ± 0.3 dB (ref. to 1 V rms/μPa) and an eligible acceleration sensitivity of only −196.5 dB (ref. to 1 V rms/μg), respectively, a non-linearity of 0.11%, a noise resolution of 57.5 dB referenced to 1 μPa/√Hz within an ultra-low operation bandwidth of 10 Hz~100 Hz, the highest noise resolution of micro-machined hydrophones reported to date, and better than traditional bulky hydrophones in terms of the same application. The size of the 5 × 5 arrayed hydrophone sensor is about 2 mm × 2 mm.

Ultra-high frequency, high Q/volume micromechanical resonators in a planar AlN phononic crystal

Department of Mechanical and Nuclear Engineering, Kansas State University, Manhattan, Kansas 66506, USA

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4958671

This paper presents the first design and experimental demonstration of an ultrahigh frequency complete phononic crystal (PnC) bandgap aluminum nitride (AlN)/air structure operating in the GHz range. A complete phononic bandgap of this design is used to efficiently and simultaneously confine elastic vibrations in a resonator. The PnC structure is fabricated by etching a square array of air holes in an AlN slab. The fabricated PnC resonator resonates at

1.117 GHz, which corresponds to an out-of-plane mode. The measured bandgap and resonance frequencies are in very good agreement with the eigen-frequency and frequency-domain finite element analyses. As a result, a quality factor/volume of 7.6 × 1017/m3 for the confined resonance mode was obtained that is the largest value reported for this type of PnC resonator to date. These results are an important step forward in achieving possible applications of PnCs for RF communication and signal processing with smaller dimensions.

GHz spurious mode free AlN lamb wave resonator with high figure of merit using one dimensional phononic crystal tethers

Institute of Microelectronics, Agency for Science, Technology and Research (A*STAR), 2 Fusionopolis Way, #08-02, Innovis, Singapore 138634

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4955410

This letter reports a spurious mode free GHz aluminum nitride (AlN) lamb wave resonator (LWR) towards high figure of merit (FOM). One dimensional gourd-shape phononic crystal (PnC) tether with large phononic bandgaps is employed to reduce the acoustic energy dissipation into the substrate. The periodic PnC tethers are based on a 1 µm-thick AlN layer with 0.26 µm-thick Mo layer on top. A clean spectrum over a wide frequency range is obtained from the measurement, which indicates a wide-band suppression of spurious modes. Experimental results demonstrate that the fabricated AlN LWR has an insertion loss of 5.2 dB and a loaded quality factor (Q) of 1893 at 1.02 GHz measured in air. An impressive ratio of the resistance at parallel resonance (Rp) to the resistance at series resonance (Rs) of 49.8 dB is obtained, which is an indication of high FOM for LWR. The high Rp to Rs ratio is one of the most important parameters to design a radio frequency filter with steep roll-off.

Low temperature aluminum nitride thin films for sensory applications

Institute for Materials Science, Chair for Inorganic Functional Materials, Kiel University, D-24143 Kiel, Germany

Institute for Materials Science, Chair for Synthesis and Real Structure, Kiel University, D-24143 Kiel, Germany

AIP Advances
http://dx.doi.org/10.1063/1.4959895

A low-temperature sputter deposition process for the synthesis of aluminum nitride (AlN) thin films that is attractive for applications with a limited temperature budget is presented. Influence of the reactive gas concentration, plasma treatment of the nucleation surface and film thickness on the microstructural, piezoelectric and dielectric properties of AlN is investigated. An improved crystal quality with respect to the increased film thickness was observed; where full width at half maximum (FWHM) of the AlN films decreased from 2.88 ± 0.16° down to 1.25 ± 0.07° and the effective longitudinal piezoelectric coefficient (d33,f) increased from 2.30 ± 0.32 pm/V up to 5.57 ± 0.34 pm/V for film thicknesses in the range of 30 nm to 2 µm. Dielectric loss angle (tan δ) decreased from 0.626% ± 0.005% to 0.025% ± 0.011% for the same thickness range. The average relative permittivity (εr) was calculated as 10.4 ± 0.05. An almost constant transversal piezoelectric coefficient (|e31,f|) of 1.39 ± 0.01 C/m2 was measured for samples in the range of 0.5 µm to 2 µm. Transmission electron microscopy (TEM) investigations performed on thin (100 nm) and thick (1.6 µm) films revealed an (002) oriented AlN nucleation and growth starting directly from the AlN-Pt interface independent of the film thickness and exhibit comparable quality with the state-of-the-art AlN thin films sputtered at much higher substrate temperatures.

Epitaxial InN/InGaN quantum dots on Si: Cl– anion selectivity and pseudocapacitor behavior

Instituto de Sistemas Optoelectrónicos y Microtecnología (ISOM), Universidad Politécnica de Madrid, Ciudad Universitaria s/n, 28040 Madrid, Spain

Applied Physics Express
http://dx.doi.org/10.7567/APEX.9.081004

Epitaxial InN quantum dots (QDs) on In-rich InGaN, applied as an electrochemical electrode, activate Cl−-anion-selective surface attachment, bringing forth faradaic/pseudocapacitor-like behavior. In contrast to traditional

pseudocapacitance, here, no chemical reaction of the electrode material occurs. The anion attachment is explained by the unique combination of the surface and quantum properties of the InN QDs. A high areal capacitance is obtained for this planar electrode together with rapid and reversible charge/discharge cycles. With the growth on cheap Si substrates, the InN/InGaN QD electrochemical electrode has great potential, opening up new application fields for III–nitride semiconductors.

Polymer bonding of GaN crystal layer on silicon substrate for micro mechanical resonator applications

Department of Finemechanics, Tohoku University, Sendai, 980-8579, Japan

Microsystem Technologies
http://dx.doi.org/10.1007/s00542-016-3075-0

A polymer bonding method of GaN crystal layer on silicon substrate is proposed for the integration of GaN micro electromechanical devices on silicon substrate. A GaN crystal layer is grown on a silicon wafer epitaxially with a buffer layer. Avoiding the influence of residual stress of the buffer layer on the GaN micro electromechanical devices, the GaN layer is transferred onto another silicon wafer by the polymer bonding method and the buffer layer is removed. The bonding method consists of two-step polymer process to prevent from breaking the bonded GaN thin layer by air bubbles. The polymer is patterned to generate air channels in the first polymer process so that the air bubbles are not remained after bonding the GaN/silicon wafer. The air channels are filled with another polymer in the second polymer process. Then, the silicon substrate of the GaN/silicon wafer is removed by silicon deep reactive ion etching, and the buffer layer for GaN crystal growth is also etched by fast atom beam of SF6 plasma and Cl2 reactive ion plasma. The bonded GaN layer is used for fabricating GaN micro mechanical resonators on silicon substrate by etching the polymers as sacrificial layer. The deformation of the freestanding resonator was minimized by removing the buffer layer. A cantilever resonator fabricated from GaN layer is excited by optical means and the basic characteristics are discussed.

Solar-blind Al x Ga1–x N (x > 0.45) p–i–n photodiodes with a polarization-p-doped emitter

Ioffe Physical Technical Institute, Russian Academy of Sciences, St. Petersburg, 194021, Russia

Technical Physics Letters
http://dx.doi.org/10.1134/S1063785016060250

Polarization-induced p-type doping of AlGaN layers with high aluminum content during plasmaassisted MBE growth has been studied. It is shown that a gradient of the AlN molar fraction in AlGaN (composition gradient) on a level of 0.005 nm–1 must be set in order to obtain a hole concentration of ~1018 cm–3 (measured by the C–V method) in Al x Ga1–x N:Mg (x = 0.52–0.32) layers with dopant concentration [Mg] = 1.3 × 1018 cm–3. p–i–n photodiodes based on AlGaN heterostructures with such layers as p-emitters showed maximum photoresponsitivity in the solar-blind wavelength range (λ = 281 nm) about 35 and 48 mA/W at reverse bias voltage U = 0 and–5 V, respectively, and exhibited a dark current density of 3.9 × 10–8 A/cm2 at U =–5 V.

THz Acoustic Spectroscopy by using Double Quantum Wells and Ultrafast Optical Spectroscopy

Institute of Physics, Academia Sinica, Taipei 11529, Taiwan

Scientific Reports
http://dx.doi.org/10.1038/srep28577

GaN is a pivotal material for acoustic transducers and acoustic spectroscopy in the THz regime, but its THz phonon properties have not been experimentally and comprehensively studied. In this report, we demonstrate how to use double quantum wells as a THz acoustic transducer for measuring generated acoustic phonons and deriving a broadband acoustic spectrum with continuous frequencies. We experimentally investigated the sub-THz frequency dependence of acoustic attenuation (i.e., phonon mean-free paths) in GaN, in addition to its physical origins such as anharmonic scattering, defect scattering, and boundary scattering. A new upper limit of

attenuation caused by anharmonic scattering, which is lower than previously reported values, was obtained. Our results should be noteworthy for THz acoustic spectroscopy and for gaining a fundamental understanding of heat conduction.

Dual-channel microcantilever heaters for volatile organic compound detection and mixture analysis

Department of Electrical Engineering, University of South Carolina, Columbia, SC 29208, USA

Scientific Reports
http://dx.doi.org/10.1038/srep28735

We report on novel microcantilever heater sensors with separate AlGaN/GaN heterostructure based heater and sensor channels to perform advanced volatile organic compound (VOC) detection and mixture analysis. Operating without any surface functionalization or treatment, these microcantilevers utilize the strong surface polarization of AlGaN, as well as the unique heater and sensor channel geometries, to perform selective detection of analytes based on their latent heat of evaporation and molecular dipole moment over a wide concentration range with sub-ppm detection limit. The dual-channel microcantilevers have demonstrated much superior sensing behavior compared to the single-channel ones, with the capability to not only identify individual VOCs with much higher specificity, but also uniquely detect them in a generic multi-component mixture of VOCs. In addition, utilizing two different dual channel configurations and sensing modalities, we have been able to quantitatively determine individual analyte concentration in a VOC mixture. An algorithm for complete mixture analysis, with unique identification of components and accurate determination of their concentration, has been presented based on simultaneous operation of an array of these microcantilever heaters in multiple sensing modalities.

GROUP 6 - Photovoltaics and Energy harvesting

Group leader: Eva Monroy (INAC-CEA)

Information selected by Knowmade

Ag nanoparticles-embedded surface plasmonic InGaN-based solar cells via scattering and localized field enhancement

Center for Spintronics, Korea Institute of Science and Technology (KIST), 5, Hwarang-ro 14 gil,
Seongbuk-gu, Seoul 02792, South Korea

Optics Express
http://dx.doi.org/10.1364/OE.24.0A1176

Ag nanoparticles are embedded in intentionally etched micro-circle p-GaN holes by means of a thermal agglomeration process to enhance the light absorption efficiency in InGaN/GaN multi-quantum-well (MQW) solar cells. The Ag nanoparticles are theoretically and experimentally verified to generate the plasmon light scattering and the localized field enhancement near the MQW absorption layer. The external quantum efficiency enhancement at a target wavelength region is demonstrated by matching the plasmon resonance of Ag nanoparticles, resulting in a Jsc improvement of 9.1%. Furthermore, the Ag-nanoparticle-embedded InGaN solar cell is effectively fabricated considering the carrier extraction that more than 70% of F.F. and 2.2 V of high Voc are simultaneously attained.

An In0.5Ga0.5N nanowire photoanode for harvesting deep visible light photons

Department of Electrical and Computer Engineering, McGill University, 3480 University Street, Montreal, Québec H3A 0E9, Canada
Department of Materials Science and Engineering, Canadian Centre for Electron Microscopy, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4M1, Canada

APL Mater.
http://dx.doi.org/10.1063/1.4958964

III-nitride semiconductors hold tremendous promise for realizing high efficiency photoelectrodes. However, previously reported InGaN photoelectrodes generally exhibit very low photocurrent densities, due to the presence of extensive defects, dislocations, and indium phase separation. Here, we show that In0.5Ga0.5N nanowires with nearly homogeneous indium distribution can be achieved by plasma-assisted molecular beam epitaxy. Under AM1.5G one sun illumination, the InGaN nanowire photoanode exhibits a photocurrent density of 7.3 mA/cm2 at 1.2 V (vs. NHE) in 1M HBr. The incident-photon-to-current efficiency is above 10% at 650 nm, which is significantly higher than previously reported values of metal oxide photoelectrodes.

Atomic-Scale Origin of Long-Term Stability and High Performance of p-GaN Nanowire Arrays for Photocatalytic Overall Pure Water Splitting

Department of Electrical & Computer Engineering, McGill University, Montreal, QC, Canada
Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Advanced Materials
http://dx.doi.org/10.1002/adma.201602274

Atomic-scale origin of the unusually high performance and long-term stability of wurtzite p-GaN oriented nanowire arrays is revealed. Nitrogen termination of both the polar inline image top face and the nonpolar inline image side faces of the nanowires is essential for long-term stability and high efficiency. Such a distinct atomic configuration ensures not only stability against (photo) oxidation in air and in water/electrolyte but as importantly provides the necessary overall reverse crystal polarization needed for efficient hole extraction in p-GaN.

Highly mismatched GaN1−x Sb x alloys: synthesis, structure and electronic properties

Department of Physics and Materials Science, City University of Hong Kong, Kowloon, Hong Kong
Materials Sciences Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA

Semiconductor Science and Technology
http://dx.doi.org/10.1088/0268-1242/31/8/083001

Highly mismatched alloys (HMAs) is a class of semiconductor alloys whose constituents are distinctly different in terms of size, ionicity and/or electronegativity. Electronic properties of the alloys deviate significantly from an interpolation scheme based on small deviations from the virtual crystal approximation. Most of the HMAs were only studied in a dilute composition limit. Recent advances in understanding of the semiconductor synthesis processes allowed growth of thin films of HMAs under non-equilibrium conditions. Thus reducing the growth temperature allowed synthesis of group III-N–V HMAs over almost the entire composition range. This paper focuses on the $GaN_{x}Sb_{1-x}$ HMA which has been suggested as a potential material for solar water dissociation devices. Here we review our recent work on the synthesis, structural and optical characterization of $GaN_{1-x}Sb_{x}$ HMA. Theoretical modeling studies on its electronic structure based on the band anticrossing (BAC) model are also reviewed. In particular we discuss the effects of growth temperature, Ga flux and Sb flux on the incorporation of Sb, film microstructure and optical properties of the alloys. Results obtained from two separate MBE growths are directly compared. Our work demonstrates that a large range of direct bandgap energies from 3.4 eV to below 1.0 eV can be achieved for this alloy grown at low temperature. We show that the electronic band structure of $GaN_{1-x}Sb_{x}$ HMA over the entire composition range is well described by a modified BAC model which includes the dependence of the host matrix band edges as well as the BAC model coupling parameters on composition. We emphasize that the modified BAC model of the electronic band structure developed for the full composition of $GaN_{x}Sb_{1-x}$ is general and is applicable to any HMA.

A study on the effects of amphoteric defect concentration on the characteristics parameters of $In_{x}Ga_{1-x}N$ thin-film solar cells

Azar Aytash Co., Technology Incubator, University of Tabriz, Tabriz, Iran

Applied Physics A
http://dx.doi.org/10.1007/s00339-016-0183-8

Group III nitride semiconductors can partly cover the solar spectrum from ultraviolet to infrared spectra due to their ability to vary their band gap. These semiconductors have a substantial potential to develop ultra-high efficiency solar cells. However, defects have a profound effect on their power conversion efficiency. Since defects lead to dramatic changes in electronic and optoelectronic properties, controlling process to get acceptable defects density in solar cells is a noteworthy parameter in technological and device applications. This paper indicates a numerical simulation study to optimize the p–i–n InGaN homojunction solar cells by investigation of defect density in the whole cell structure. In this study, we assumed that the p-region and n-region thicknesses are 100 and 150 nm, respectively, and the optimized value of cell thickness is 1.3 µm. Similarly, we chose amphoteric defect density from 1015 to 1019 cm−3, and then the effects of defects density on characteristic parameters of cell have been studied. Based on our results, when the amphoteric defect concentration is below the 1015 cm−3, constant value for FF values in all layers was obtained. Therefore, cell efficiency remains the same in lower amphoteric defect density where all FF, V_{OC} and J_{SC} are constant. By increasing the amphoteric defect density from 1015 cm−3, the cell efficiency falls down dramatically from 20 to about 1 % at 1019 cm−3. In our simulated structure, the cell efficiency parameter decreases with increasing the defects density until it reaches the 1015 cm−3. Above this value, no change in the parameters was observed. Our results revealed that the high defect density range 1015–1019 cm−3 may be an equally significant cause of performance loss.

Fabrication and characterization of GaN/InGaN MQW solar cells

Pramila Mahala , Sumitra Singh, Suchandan Pal, Kuldip Singh, Ashok Chauh
Solar Energy, Pandit Deendayal Petroleum University (SSE-PDPU), Gandhinagar, Gujarat, 382007, India

Applied Physics A
http://dx.doi.org/10.1007/s00339-016-0146-0

In this paper, the p-GaN/i-GaN–InGaN (5MQW)/n-GaN solar cell with 33 % indium composition is

grown, fabricated and characterized. The X-ray diffraction, atomic force microscopy and photoluminance are performed for the solar cell. The photovoltaic parameters are short-circuit current (0.30 mA/cm2), open-circuit voltage (1.69 V), fill factor (41.3 %) and efficiency (0.21 %) under AM 1.5G illumination. The crystallite size of 379 Å and strain of 0.335 % is calculated with the help of Williamson–Hall analysis. Series resistance and shunt resistance are 62 kΩ and 0.10 MΩ, respectively.

Enhanced performances of vertical-structured green-band InGaN/GaN multiple-quantum-well solar cells with aluminum reflectors

Department of Electronic Engineering, Xiamen University, Xiamen, 361005, China

Journal of the Korean Physical Society
http://dx.doi.org/10.3938/jkps.68.1291

We demonstrated vertical-structured InGaN/GaN multiple-quantum-well (MQW) solar cells with enhanced performances at a wavelength of 510 nm. The enhancement was achieved by using a ptype ohmic mirror with a combined indium-tin-oxide film and an aluminum (Al) reflector inserted beneath the MQW absorption region. In addition, both good ohmic contact and high reflection were observed. The vertical-structured MQW solar cell with an Al reflector exhibited significant improvements in device performances as compared to that without the Al reflector, including a 49% increase in the short-circuit current density and a 56% increase in the power conversion efficiency.

Analysis of Products from Photoelectrochemical Reduction of 13CO2 by GaN-Si Based Tandem Photoelectrode

Advanced Research Division, Panasonic Corporation, Seika, Kyoto 619-0237, Japan

J. Phys. Chem. C
http://dx.doi.org/10.1021/acs.jpcc.6b03840

Gallium nitride (GaN) has been shown to be a good photocatalyst for not only water splitting but also carbon dioxide (CO2) reduction. To verify the catalytic reaction involved in CO2 reduction, it is essential to confirm that the reaction products only come from dissolved CO2. Here, we report the results of 13CO2-labeling experiments on a GaN-Si based photoelectrochemical system for each reduction product. It was found that the 13C-based CO2 was almost completely converted to formic acid (HCOOH), methane, and ethylene when KCl was used as the electrolyte. In contrast, HCOOH from 12C was observed when KHCO3 electrolyte was used, meaning that HCO3– in the electrolyte partly contributed to CO2 reduction. The energy conversion efficiency and Faradaic efficiency of the respective reduction processes in the present system are also discussed.

An InGaN based solar cell including dual InGaN/GaN multiple quantum wells

School of Physics and Optoelectronic Engineering and the State Key Discipline Laboratory of Wide Band Gap Semiconductor Technology, Xidian University, Xian, 710071, China

IEEE Photonics Technology Letters
http://dx.doi.org/10.1109/LPT.2016.2575058

An InGaN/GaN solar cell including a dual multiple quantum wells (MQWs) structure is investigated. It shows an obvious advantage over the conventional InGaN/GaN cell, which only contains a single MQWs structure. Because the short current density (Jsc) increases, the 1 sun power conversion efficiency significantly improves from 0.62% (single MQWs cell) to 1.02% (dual MQWs cell). From the measurement of EQE and PL spectra, the enhancement of effective photoelectric response within the solar spectrum mainly contributes to the high device performance, due to the introduced upper MQWs of higher In content.

NANO
Information selected by
Jesús Zúñiga Pérez (CRHEA-CNRS)

Nano-light-emitting-diodes based on InGaN mesoscopic structures for energy saving optoelectronics

Peter Grünberg Institute (PGI-9) Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany
Jülich Aachen Research Alliance, JARA, Fundamentals of Future Information Technology, D-52425 Jülich, Germany
Robert Bosch GmbH, D-72760 Reutlingen, Germany
Faculté des Sciences, de la Technologie et de la Communication, Université du Luxembourg, L-1359 Luxembourg, Luxembourg

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4960007

Vertically integrated III-nitride based nano-LEDs (light emitting diodes) were designed and fabricated for operation in the telecommunication wavelength range in the (p-GaN/InGaN/n-GaN/sapphire) material system. The band edge luminescence energy of the nano-LEDs could be engineered by tuning the composition and size of the InGaN mesoscopic structures. Narrow band edge photoluminescence and electroluminescence were observed. Our mesoscopic InGaN structures (depending on diameter) feature a very low power consumption in the range between 2 nW and 30 nW. The suitability of the technological process for the long-term operation of LEDs is demonstrated by reliability measurements. The optical and electrical characterization presented show strong potential for future low energy consumption optoelectronics.

Bandgap measurements and the peculiar splitting of E2H phonon modes of InxAl1-xN nanowires grown by plasma assisted molecular beam epitaxy

Photonics Laboratory, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4959260

The dislocation free Inx Al 1-xN nanowires (NWs) are grown on Si(111) by nitrogen plasma assisted molecular beam epitaxy in the temperature regime of 490 °C–610 °C yielding In composition ranges over 0.50 ≤ x ≤ 0.17. We study the optical properties of these NWs by spectroscopic ellipsometry (SE), photoluminescence, and Raman spectroscopies since they possesses minimal strain with reduced defects comparative to the planar films. The optical bandgap measurements of Inx Al 1-xN NWs are demonstrated by SE where the absorption edges of the NW samples are evaluated irrespective of substrate transparency. A systematic Stoke shift of 0.04–0.27 eV with increasing x was observed when comparing the micro-photoluminescence spectra with the Tauc plot derived from SE. The micro-Raman spectra in the NWs with x = 0.5 showed two-mode behavior for A1(LO) phonons and single mode behavior for E2 H phonons. As for x = 0.17, i.e., high Al content, we observed a peculiar E2 H phonon mode splitting. Further, we observe composition dependent frequency shifts. The 77 to 600 K micro-Raman spectroscopy measurements show that both AlN- and InN-like modes of A1(LO) and E2 H phonons in Inx Al 1-xN NWs are redshifted with increasing temperature, similar to that of the binary III group nitride semiconductors. These studies of the optical properties of the technologically important Inx Al 1-xN nanowires will path the way towards lasers and light-emitting diodes in the wavelength of the ultra-violet and visible range.

Superluminescent light emitting diodes on naturally survived InGaN/GaN lateral nanowires

Applied Quantum Mechanics Laboratory, Centre of Excellence in Nanoelectronics, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959562

We demonstrate a method for nanowire formation by natural selection during wet anisotropic chemical etching in boiling phosphoric acid. Nanowires of sub-10 nm lateral dimensions and lengths of 700 nm or more are naturally formed during the wet etching due to the convergence of the nearby crystallographic hexagonal etch pits. These nanowires are site controlled when formed in augmentation with dry etching. Temperature and power dependent photoluminescence characterizations confirm excitonic transitions up to room temperature. The exciton confinement is enhanced by using two-dimensional confinement whereby enforcing greater overlap of the electron-hole wave-functions. The surviving nanowires have less defects and a small temperature variation of the output electroluminescent light. We have observed superluminescent behaviour of the light emitting diodes formed on these nanowires. There is no observable efficiency roll off for current densities up to 400 A/cm2.

An In0.5Ga0.5N nanowire photoanode for harvesting deep visible light photons

Department of Electrical and Computer Engineering, McGill University, 3480 University Street, Montreal, Québec H3A 0E9, Canada
Department of Materials Science and Engineering, Canadian Centre for Electron Microscopy, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4M1, Canada

APL Mater.
http://dx.doi.org/10.1063/1.4958964

III-nitride semiconductors hold tremendous promise for realizing high efficiency photoelectrodes. However, previously reported InGaN photoelectrodes generally exhibit very low photocurrent densities, due to the presence of extensive defects, dislocations, and indium phase separation. Here, we show that In0.5Ga0.5N nanowires with nearly homogeneous indium distribution can be achieved by plasma-assisted molecular beam epitaxy. Under AM1.5G one sun illumination, the InGaN nanowire photoanode exhibits a photocurrent density of 7.3 mA/cm2 at 1.2 V (vs. NHE) in 1M HBr. The incident-photon-to-current efficiency is above 10% at 650 nm, which is significantly higher than previously reported values of metal oxide photoelectrodes.

Controlled Coalescence of AlGaN Nanowire Arrays: An Architecture for Nearly Dislocation-Free Planar Ultraviolet Photonic Device Applications

Department of Electrical and Computer Engineering, McGill University, Montreal, QC, Canada

Advanced Materials
http://dx.doi.org/10.1002/adma.201602645

Nearly dislocation-free semipolar AlGaN templates are achieved on c-plane sapphire substrate through controlled nanowire coalescence by selective-area epitaxy. The coalesced Mg-doped AlGaN layers exhibit superior charge carrier transport properties. The semipolar AlGaN ultraviolet light-emitting diodes demonstrate excellent performance. This work establishes the use of engineered nanowire structures as a viable architecture to achieve large-area, dislocation-free planar photonic and electronic devices.

The effects of nanocavity and photonic crystal in InGaN/GaN nanorod LED arrays

State Key Laboratory for Artificial Microstructure and Mesoscopic Physics, School of PhysicsPeking University

Nanoscale Research Letters
http://dx.doi.org/10.1186/s11671-016-1548-9

InGaN/GaN nanorod light-emitting diode (LED) arrays were fabricated using nanoimprint and reactive ion etching. The diameters of the nanorods range from 120 to 300 nm. The integral photoluminescence (PL) intensity for 120 nm nanorod LED array is enhanced as 13 times compared to that of the planar one. In angular-resolved PL (ARPL) measurements, there are some strong lobes as resonant regime appeared in the far-field radiation patterns of small size nanorod array, in which the PL spectra are sharp and intense. The PL lifetime for resonant regime is 0.088 ns, which is 40 % lower than that of non-resonant regime for 120 nm nanorod LED array. At last, three dimension finite difference time domain (FDTD) simulation is performed. The

effects of guided modes coupling in nanocavity and extraction by photonic crystals are explored.

Exceptionally long GaN sub-micrometer rods grown by HVPE on a MOCVD-GaN rod template

Research Center for Wide-Gap Semiconductors, State Key Laboratory for Artificial Microstructures and Mesoscopic Physics, School of Physics, Peking University, Beijing 100871, PR China
Sino Nitride Semiconductor CO., LTD, Dongguan 523500, PR China

Journal of Alloys and Compounds
http://dx.doi.org/10.1016/j.jallcom.2016.07.115

The growth mechanism of exceptionally long N-polar GaN sub-micrometer (sub-µm) rods has not been revealed to date. In this work, we investigated the effects of the V/III molar ratio and HCl (diluted in carrier gas) on the lengthening of a MOCVD-GaN rod template by HVPE. It is found that a low V/III molar ratio and HCl (diluted in carrier gas) help form vertical sidewalls and suppress the lateral growth on the top part of exceptionally long GaN sub-µm rods. Simulation results revealed that the low V/III molar ratio leads to reactive species distributing almost exclusively on the top part of GaN rods, which can effectively prevent crystal growth on the bottom of GaN rods. Chlorine ions support the growth by etching the sidewalls. After growth, the diameter and length of each GaN rod are more than 1.5 µm and 70–80 µm, respectively. Finally, an empirical growth model was developed to account for the exceptionally long GaN sub-µm rods under HVPE growth.

Epitaxy of GaN Nanowires on Graphene

Laboratoire de Photonique et de Nanostructures (LPN), CNRS, Université Paris-Saclay, Route de Nozay, F-91460 Marcoussis, France

Nano Lett.
http://dx.doi.org/10.1021/acs.nanolett.6b01453

Epitaxial growth of GaN nanowires on graphene is demonstrated using molecular beam epitaxy without any catalyst or intermediate layer. Growth is highly selective with respect to silica on which the graphene flakes, grown by chemical vapor deposition, are transferred. The nanowires grow vertically along their c-axis and we observe a unique epitaxial relationship with the ⟨2$\bar{1}\bar{1}$0⟩ directions of the wurtzite GaN lattice parallel to the directions of the carbon zigzag chains. Remarkably, the nanowire density and height decrease with increasing number of graphene layers underneath. We attribute this effect to strain and we propose a model for the nanowire density variation. The GaN nanowires are defect-free and they present good optical properties. This demonstrates that graphene layers transferred on amorphous carrier substrates is a promising alternative to bulk crystalline substrates for the epitaxial growth of high quality GaN nanostructures.

Instability and Spontaneous Reconstruction of Few-Monolayer Thick GaN Graphitic Structures

Nanoelectronics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba 305-8565, Japan

Nano Lett.
http://dx.doi.org/10.1021/acs.nanolett.6b01225

Two-dimensional (2D) semiconductors are a very hot topic in solid state science and technology. In addition to van der Waals solids that can be easily formed into 2D layers, it was argued that single layers of nominally 3D tetrahedrally bonded semiconductors, such as GaN or ZnO, also become flat in the monolayer limit; the planar structure was also proposed for few-layers of such materials. In this work, using first-principles calculations, we demonstrate that contrary to the existing consensus the graphitic structure of few-layer GaN is unstable and spontaneously reconstructs into a structure that remains hexagonal in plane but with covalent interlayer bonds that form alternating octagonal and square (8|4 Haeckelite) rings with pronounced in-plane anisotropy. Of special interest is the transformation of the band gap from indirect in planar GaN toward direct in the Haeckelite phase, making Haeckelite few-layer GaN an appealing material for flexible nano-optoelectronics

Droop-Free, Reliable, and High-Power InGaN/GaN Nanowire Light-Emitting Diodes for Monolithic Metal-Optoelectronics

Photonics Laboratory, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia

Nano Lett.
http://dx.doi.org/10.1021/acs.nanolett.6b01945

A droop-free nitride light-emitting diode (LED) with the capacity to operate beyond the "green gap" has been a subject of intense scientific and engineering interest. While several properties of nanowires on silicon make them promising for use in LED development, the high aspect ratio of individual nanowires and their laterally discontinuous features limit phonon transport and device performance. Here, we report on the monolithic integration of metal heat-sink and droop-free InGaN/GaN quantum-disks-in-nanowire LEDs emitting at ~710 nm. The reliable operation of our uncooled nanowire-LEDs (NW-LEDs) epitaxially grown on molybdenum was evident in the constant-current soft burn-in performed on a 380 µm × 380 µm LED. The square LED sustained 600 mA electrical stress over an 8 h period, providing stable light output at maturity without catastrophic failure. The absence of carrier and phonon transport barriers in NW-LEDs was further inferred from current-dependent Raman measurements (up to 700 mA), which revealed the low self-heating. The radiative recombination rates of NW-LEDs between room temperature and 40 °C was not limited by Shockley–Read–Hall recombination, Auger recombination, or carrier leakage mechanisms, thus realizing droop-free operation. The discovery of reliable, droop-free devices constitutes significant progress toward the development of nanowires for practical applications. Our monolithic approach realized a high-performance device that will revolutionize the way high power, low-junction-temperature LED lamps are manufactured for solid-state lighting and for applications in high-temperature harsh environment.

Crystal structure and optical properties of a high-density InGaN nanoumbrella array as a white light source without phosphors

Department of Electronics and Material Science, Shizuoka University, Hamamatsu, Japan

NPG Asia Materials
http://dx.doi.org/10.1038/am.2016.99

We demonstrated the fabrication of a peculiar GaN/InGaN-based high-density nanocrystal array on a nitrogen polarity GaN layer using a simple self-assembly process for the first time. The nanocrystals consist of bending InGaN nanoplates and supporting GaN nanocolumns. The nanocrystals are umbrella shaped with diameters of ~200–700 nm; therefore, they are referred to as InGaN nanoumbrellas. Transmission electron microscopy revealed the crystal structures of the nanoumbrellas and provided information about their growth mechanism. The photoluminescence (PL) properties of the InGaN nanoumbrellas were also characterized, and an extremely wide range of optical emission wavelengths (~360–800 nm) was obtained from a small excitation diameter of ~10 µm. Multiple sharp peaks resembling lasing actions were also observed in the PL spectrum; the resonant mode was likely caused by the whispering gallery mode. These results indicate that the high-density GaN/InGaN-based nanoumbrella array can be used as a source of white light without phosphors.

NON/SEMI POLAR

Information selected by
Philippe De Mierry (CRHEA-CNRS)

Reduced efficiency droop of nonpolar a-plane (11-20) GaN-based light-emitting diodes by vertical injection geometry

Department of Printed Electronics Engineering, Sunchon National University, Jeonnam 540-742, South Korea

J. Vac. Sci. Technol. B
http://dx.doi.org/10.1116/1.4958720

Vertical nonpolar a-plane (11-20) InGaN/GaN light-emitting diodes (LEDs) have been demonstrated by using laser lift-off technique.

The forward voltage of the a-plane vertical LEDs was 4.3 V at 350 mA, which was reduced by 0.8 V compared to that of the a-plane lateral LEDs. The vertical geometry of the a-plane LEDs produced the higher quantum efficiency with a low efficiency droop and also enhanced the output power by more than 40%, when compared to those of a-plane lateral LEDs. These results can be attributed to the high thermal dissipation as well as uniform current spreading of the vertical geometry of the a-plane LEDs. Furthermore, elimination of the highly defected GaN nucleation layer after removing the sapphire substrates during the fabrication process can also enhance current injection efficiency, followed by the increase in the output power.

Using band engineering to tailor the emission spectra of trichromatic semipolar InGaN light-emitting diodes for phosphor-free polarized white light emission

Materials Department, University of California, Santa Barbara, California 93106, USA

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4958308

We report a polarized white light-emitting device that monolithically integrates an electrically injected blue light-emitting diode grown on the (202¯1¯)(202¯1¯) face of a bulk GaN substrate and optically pumped InGaN quantum wells (QWs) with green and red light emission grown on the (202¯1)(202¯1) face. To overcome the challenges associated with growing high indium content InGaN QWs for long wavelength emission, a p-i-n doping profile was used to red-shift the emission wavelength of one of the optically pumped QWs by creating a built-in electric field in the same direction as the polarization-induced electric field. Emission peaks were observed at 450 nm from the electrically injected QW and at 520 nm and 590 nm from the optically pumped QWs, which were situated in n-i-n and p-i-n structures, respectively. The optically pumped QW in the p-i-n structure was grown at a growth temperature that was 10 °C colder compared to the QW in the n-i-n structure, so the emission from the QW in the p-i-n structure was red-shifted due to increased indium content as well as the built-in electric field. Modeling work confirmed that the built-in electric field made a greater contribution than the change in alloy composition to the red-shift in emission from the QW in the p-i-n structure. The combined emission from the red, green, and blue QWs resulted in white-light emission with Commission Internationale de l'Eclairage x- and y-chromaticity coordinates of (0.33, 0.35) and an optical polarization ratio of 0.30.

Growth and coalescence control of inclined c-axis polar and semipolar GaN multilayer structures grown on Si(111), Si(112), and Si(115) by metalorganic vapor phase epitaxy

The Faculty of Microsystem Electronics and Photonics, Wroclaw University of Technology, Janiszewskiego 11/17, 50-372 Wroclaw, Poland

J. Vac. Sci. Technol. A
http://dx.doi.org/10.1116/1.4958805

Herein, silicon substrates in alternative orientations from the commonly used Si(111) were used to enable the growth of polar and semipolar GaN-based structures by the metalorganic vapor phase epitaxy method. Specifically, Si(112) and Si(115) substrates were used for the epitaxial growth of nitride multilayer structures, while the same layer schemes were also deposited on Si(111) for comparison purposes. Multiple approaches were studied to examine the influence of the seed layers and the growth process conditions upon the final properties of the GaN/Si(11x) templates. Scanning electron microscope images were acquired to examine the topography of the deposited samples. It was observed that the substrate orientation and the process conditions allow control to produce an isolated GaN block growth or a coalesced layer growth, resulting in inclined c-axis GaN structures under various forms. The angles of the GaN c-axis inclination were determined by x-ray diffraction measurements and compared with the results obtained from the analysis of the atomic force microscope (AFM) images. The AFM image analysis method to determine the structure tilt was found to be a viable method to estimate the c-axis inclination angles of the isolated blocks and the not-fully

coalesced layers. The quality of the grown samples was characterized by the photoluminescence method conducted at a wide range of temperatures from 77 to 297 K, and was correlated with the sample degree of coalescence. Using the free-excitation peak positions plotted as a function of temperature, analytical Bose-Einstein model parameters were fitted to obtain further information about the grown structures.

Green semipolar III-nitride light-emitting diodes grown by limited area epitaxy

Materials Department, University of California, Santa Barbara, California 93106, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4960001

The performance of multiple quantum well green and yellow semipolar light-emitting diodes (LEDs) is limited by relaxation of highly strained InGaN-based active regions and the subsequent formation of nonradiative defects. Limited area epitaxy was used to block glide of substrate threading dislocations and to reduce the density of misfit dislocations (MDs) directly beneath the active region of (202¯1)(202¯1) LEDs. Devices were grown and fabricated on a 1D array of narrow substrate mesas to limit the MD run length. Reducing the mesa width from 20 µm to 5 µm lowered the density of basal plane and non-basal plane MDs on the mesas and limited the number of defect-generating dislocation intersections. This improvement in material quality yielded a 73% enhancement in peak external quantum efficiency for the devices with the narrowest mesas compared to the devices with the widest mesas.

Efficiency studies on semipolar GaInN–GaN quantum well structures

Institute of Optoelectronics, Ulm University, Albert-Einstein-Allee 45, 89081 Ulm, Germany

Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600340

In order to clarify the reasons for the fairly poor electroluminescence (EL) performance of semipolar LED structures grown on patterned sapphire wafers, we have analyzed both, pure photoluminescence (PL) test structures without doping only containing 5 GaInN quantum wells and full EL test structures, all emitting at a wavelength of about 510 nm. Evaluating the PL intensity over a wide range of temperatures and excitation powers, we conclude that such quantum wells possess a fairly large internal quantum efficiency of about 20%. However, on EL test structures containing nominally the same quantum wells, we obtained an

Band-edge optical transitions in a nonpolar-plane GaN substrate: exciton–phonon coupling and temperature effects

Department of Physics, The University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China
Shenzhen Institute of Research and Innovation (SIRI), The University of Hong Kong, Pokfulam Road, Hong Kong, People's Republic of China

Semiconductor Science and Technology
http://dx.doi.org/10.1088/0268-1242/31/9/095004

We present a detailed investigation of the band-edge optical transitions involving the interacting exciton–phonon system, especially first-order longitudinal optical (LO) phonon-assisted luminescence of bound and free excitons in m- and c-plane GaN substrates in a low temperature range from 4 K to 40 K. The main luminescence features of all of the three kinds of excitons can be well described by the theoretical models that take exciton-LO-phonon coupling into account. The effective Bohr radii of the excitons play a key role in determining the Huang–Rhys factor characterizing the exciton-LO-phonon coupling strength in GaN. An interesting oscillatory structure is found to appear in the low-temperature luminescence spectra of the nonpolar-plane GaN substrate, which needs to be clarified by further investigations.

Highly sensitive nonpolar a-plane GaN based hydrogen diode sensor with textured active area using photo-chemical etching

School of Materials Science and Engineering, Hongik University, Jochiwon, Sejong 339-701, Republic of Korea

Sensors and Actuators B: Chemical
http://dx.doi.org/10.1016/j.snb.2016.07.091

In this work, a highly sensitive a- plane View the MathML source GaN (a-GaN) based hydrogen sensor with a large active surface area on the Schottky contact region was fabricated and characterized. By using a simple photochemical etching technique, a striated surface morphology with triangular prisms consisting of m-plane facets on the a-GaN surface was obtained. The maximum relative current change of the etched a-GaN diode was as high as 3.8 × 107%, and the reduction of the effective Schottky barrier height was 0.49 eV upon 4% hydrogen exposure. The photo-chemically etched a-GaN sensor showed a remarkably improved hydrogen response and good repeatability for cyclic exposure to hydrogen. The photo-chemically textured GaN surface with enlarged surface area increased the number of adsorption sites available for hydrogen molecules to catalytically-decompose into surface atoms, lowering the effective Schottky barrier height, thereby increasing the measured current. Furthermore, the hydrogen sensing properties of the etched a-GaN diodes at different values of humidity and temperature were investigated.

Room-Temperature Observation of Trapped Exciton-Polariton Emission in GaN/AlGaN Microcavities with Air-Gap/III-Nitride Distributed Bragg Reflectors

Institute of Industrial Science and ‡Institute for Nano Quantum Information Electronics, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo, 153-8505, Japan

ACS Photonics
http://dx.doi.org/10.1021/acsphotonics.6b00003

We demonstrate trapped exciton-polariton emission at room temperature from nonpolar GaN/AlGaN cavities sandwiched between air/AlGaN distributed Bragg reflectors. Nanoscale thickness fluctuations characteristic to the nonpolar AlGaN cavity layer create deep potential traps, giving rise to a strong (in-plane) localization of exciton-polaritons. The observed quantized exciton-polariton states exhibit a large quantized energy of up to 6 meV, which benefits from the wide bandgap of III-nitrides. The experimental results are well explained by numerical simulations. III-Nitride exciton-polaritons in such deep traps will be useful for practical exciton-polariton lasers with high degrees of coherence and high-repetition rate Josephson oscillators with multicomponent condensates.

Novel in situ self-separation of a 2 in. free-standing m-plane GaN wafer from an m-plane sapphire substrate by HCl chemical reaction etching in hydride vapor-phase epitaxy

Convergence Center for Advanced Nano Semiconductor (CANS), Department of Nano-Optical Engineering, Korea Polytechnic University (KPU), Siheun-si, Republic of Korea
Lumistal Co., Ltd., Business Incubation Center, KPU, Republic of Korea

CrystEngComm
http://dx.doi.org/10.1039/C6CE00642F

A 2 in.-diameter free-standing m-plane GaN wafer was fabricated through in situ self-separation using HCl chemical reaction etching (HCRE) in hydride vapor-phase epitaxy (HVPE). A 2 µm-thick m-plane GaN layer was directly grown on m-plane sapphire, followed by HCRE to form multiple voids at the interface between the m-plane sapphire and m-plane GaN. Void formation was attributed to preferential etching at high-defect regions (HDRs) such as stacking faults (SFs) and threading dislocations (TDs) in the m-plane GaN layer. After regrowth of an approximately 200 µm-thick m-plane GaN layer, self-separation was achieved during the cooling process. The free-standing m-plane GaN wafer was almost crack-free as a result of strain relief by the in situ self-separation process, which was confirmed by room-temperature Raman and photoluminescence measurements. It is supposed that the novel HCRE process can be applied to fabricate high-quality free-standing non-polar GaN wafers in the future.

OTHER
(fundamental, material, characterization, equipment)
Information selected by
Agnès Trassoudaine (Université d'Auvergne)
and Yvon Cordier (CRHEA-CNRS)

Elastic constants of GaN between 10 and 305 K

Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4955046

Using the antenna-transmission resonant ultrasound spectroscopy, we measured the elastic constants of GaN between 10 and 305 K using 72 resonance frequencies. The mode Grüneisen parameter is determined from temperature dependence of each elastic constant, which is larger along the c axis than along the a axis, showing anisotropy in lattice anharmonicity. The zero-temperature elastic constants, determined using the Einstein-oscillator model, yield the Debye characteristic temperature of 636 K. The ab-initio calculation is carried out for deducing the elastic constants, and comparison between calculations and measurements at 0 K reveals that the local-density-approximation potential is preferable for theoretically evaluating characteristics of GaN. The theoretical calculation also supports the anisotropy in lattice anharmonicity.

Curvature and bow of bulk GaN substrates

Materials Department, UCSB, Santa Barbara, California 93106, USA
Ioffe Physico-Technical Institute RAS, St. Petersburg 194021, Russia
ITMO University, St. Petersburg 197101, Russia

J. Appl. Phys.
http://dx.doi.org/10.1063/1.4959073

We investigate the bow of free standing (0001) oriented hydride vapor phase epitaxy grown GaN substrates and demonstrate that their curvature is consistent with a compressive to tensile stress gradient (bottom to top) present in the substrates. The origin of the stress gradient and the curvature is attributed to the correlated inclination of edge threading dislocation (TD) lines away from the [0001] direction. A model is proposed and a relation is derived for bulk GaN substrate curvature dependence on the inclination angle and the density of TDs. The model is used to analyze the curvature for commercially available GaN substrates as determined by high resolution x-ray diffraction. The results show a close correlation between the experimentally determined parameters and those predicted from theoretical model.

Time-resolved photoluminescence characterization of oxygen-related defect centers in AlN

Department of Chemistry, Graduate School of Science, Kobe University, Nada, Kobe 657-8501, Japan

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4958891

Time-resolved photoluminescence (PL) spectroscopy has been employed to investigate the emission characteristics of oxygen-related defects in AlN in the temperature region from 77 to 500 K. Two PL components with different decay constants are observed in the near-ultraviolet to visible regions. One is the PL component with decay time of <10 ns and its peak position shifts to longer wavelengths from ~350 to ~500 nm with increasing temperature up to 500 K. This PL component is attributed to the radiative relaxation of photoexcited electrons from the band-edge states to the ground state of the oxygen-related emission centers. In the time region from tens to hundreds of nanoseconds, the second PL component emerges in the wavelength region from 300 to 400 nm. The spectral shape and the decay profiles are hardly dependent on temperature. This temperature-independent PL component most likely results from the transfer of photoexcited electrons from the band-edge states to the localized excited state of the oxygen-related emission centers. These results provide a detailed insight into the radiative relaxation processes of the oxygen-related defect centers in AlN immediately after the photoexcitation process.

Growth and coalescence control of inclined c-axis polar and semipolar GaN multilayer structures grown on Si(111), Si(112), and Si(115) by metalorganic vapor phase epitaxy

The Faculty of Microsystem Electronics and Photonics, Wroclaw University of Technology, Janiszewskiego 11/17, 50-372 Wroclaw, Poland

J. Vac. Sci. Technol. A
http://dx.doi.org/10.1116/1.4958805

Herein, silicon substrates in alternative orientations from the commonly used Si(111) were used to enable the growth of polar and semipolar GaN-based structures by the metalorganic vapor phase epitaxy method. Specifically, Si(112) and Si(115) substrates were used for the epitaxial growth of nitride multilayer structures, while the same layer schemes were also deposited on Si(111) for comparison purposes. Multiple approaches were studied to examine the influence of the seed layers and the growth process conditions upon the final properties of the GaN/Si(11x) templates. Scanning electron microscope images were acquired to examine the topography of the deposited samples. It was observed that the substrate orientation and the process conditions allow control to produce an isolated GaN block growth or a coalesced layer growth, resulting in inclined c-axis GaN structures under various forms. The angles of the GaN c-axis inclination were determined by x-ray diffraction measurements and compared with the results obtained from the analysis of the atomic force microscope (AFM) images. The AFM image analysis method to determine the structure tilt was found to be a viable method to estimate the c-axis inclination angles of the isolated blocks and the not-fully coalesced layers. The quality of the grown samples was characterized by the photoluminescence method conducted at a wide range of temperatures from 77 to 297 K, and was correlated with the sample degree of coalescence. Using the free-excitation peak positions plotted as a function of temperature, analytical Bose-Einstein model parameters were fitted to obtain further information about the grown structures.

Structural and electronic properties of InN epitaxial layer grown on c-plane sapphire by chemical vapor deposition technique

Department of Physics, Indian Institute of Technology, Bombay, Mumbai 400076, India

J. Vac. Sci. Technol. A
http://dx.doi.org/10.1116/1.4955270

Growth of InN epilayers on c-plane sapphire substrate by chemical vapor deposition technique using pure indium metal and ammonia as precursors has been systematically explored. It has been found that [0001] oriented indium nitride epitaxial layers with smooth surface morphology can be grown on c-plane sapphire substrates by optimizing the growth conditions. Bandgap of the film is observed to be Burstein–Moss shifted likely to be due to high background electron concentration. It has been found that the concentration of this unintentional doping decreases with the increase in the growth temperature and the ammonia flux. Epitaxial quality on the other hand deteriorates as the growth temperature increases. Moreover, the morphology of the deposited layer has been found to change from flat top islands to faceted mounds as the flow rate of ammonia increases. This phenomenon is expected to be related to the difference in surface termination character at low and high ammonia flow rates.

Individual electron and hole localization in submonolayer InN quantum sheets embedded in GaN

Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e. V., Hausvogteiplatz 5–7, 10117 Berlin, Germany

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4960006

We investigate sub-monolayer InN quantum sheets embedded in GaN(0001) by temperature-dependent photoluminescence spectroscopy under both continuous-wave and pulsed excitation. Both the peak energy and the linewidth of the emission band associated with the quantum sheets exhibit an anomalous dependence on temperature indicative of carrier localization. Photoluminescence transients reveal

a power law decay at low temperatures reflecting that the recombining electrons and holes occupy spatially separate, individual potential minima reminiscent of conventional (In,Ga)N(0001) quantum wells exhibiting the characteristic disorder of a random alloy. At elevated temperatures, carrier delocalization sets in and is accompanied by a thermally activated quenching of the emission. We ascribe the strong nonradiative recombination to extended states in the GaN barriers and confirm our assumption by a simple rate-equation model.

Impact of recess etching and surface treatments on ohmic contacts regrown by molecular-beam epitaxy for AlGaN/GaN high electron mobility transistors

Microsystems Technology Laboratories, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA
Université Grenoble-Alpes, 38000 Grenoble, France
CEA Grenoble, INAC-PHELIQS, 38000 Grenoble, France

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959831

Ohmic contacts fabricated by regrowth of n+ GaN are favorable alternatives to metal-stack-based alloyed contacts in GaN-based high electron mobility transistors. In this paper, the influence of reactive ion dry etching prior to regrowth on the contact resistance in AlGaN/GaN devices is discussed. We demonstrate that the dry etch conditions modify the surface band bending, dangling bond density, and the sidewall depletion width, which influences the contact resistance of regrown contacts. The impact of chemical surface treatments performed prior to regrowth is also investigated. The sensitivity of the contact resistance to the surface treatments is found to depend upon the dangling bond density of the sidewall facets exposed after dry etching. A theoretical model has been developed in order to explain the observed trends.

Exciton dynamics at a single dislocation in GaN probed by picosecond time-resolved cathodoluminescence

Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Station3 CH-1015, Switzerland

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959832

We investigate the dynamics of donor bound excitons (D°XA) at T = 10 K around an isolated single edge dislocation in homoepitaxial GaN, using a picosecond time-resolved cathodoluminescence (TR-CL) setup with high temporal and spatial resolutions. An ~ 1.3 meV dipole-like energy shift of D°XA is observed around the dislocation, induced by the local strain fields. By simultaneously recording the variations of both the exciton lifetime and the CL intensity across the dislocation, we directly assess the dynamics of excitons around the defect. Our observations are well reproduced by a diffusion model. It allows us to deduce an exciton diffusion length of ~24 nm as well as an effective area of the dislocation with a radius of ~95 nm, where the recombination can be regarded as entirely non-radiative.

Determination of band offsets at GaN/single-layer MoS2 heterojunction

Photonics Laboratory, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4959254

We report the band alignment parameters of the GaN/single-layer (SL) MoS2 heterostructure where the GaN thin layer is grown by molecular beam epitaxy on CVD deposited SL-MoS2/c-sapphire. We confirm that the MoS2 is an SL by measuring the separation and position of room temperature micro-Raman E1 2g and A1 g modes, absorbance, and micro-photoluminescence bandgap studies. This is in good agreement with HRTEM cross-sectional analysis. The determination of band offset parameters at the GaN/SL-MoS2 heterojunction is carried out by high-resolution X-ray photoelectron spectroscopy accompanying with electronic bandgap values of SL-MoS2 and GaN. The valence band and conduction band offset values are, respectively, measured to be 1.86 ± 0.08 and 0.56 ± 0.1 eV with type II band alignment. The determination of these unprecedented band offset parameters opens up a way to integrate 3D group III nitride

materials with 2D transition metal dichalcogenide layers for designing and modeling of their heterojunction based electronic and photonic devices.

Successful Fabrication of GaN Epitaxial Layer on Non-Catalytically-grown Graphene

Department of Nano Science & Mechatronics Engineering, Interdisciplinary Research Center for Health and Nanotechnology Research Center, Konkuk University, Chungju-si 27478, Korea
Department of Applied Physics and Institute of Natural Sciences, Kyung Hee University, Yongin 446-701, Korea

Bulletin of the Korean Chemical Society
http://dx.doi.org/10.1002/bkcs.10809

Sapphire is widely used as a substrate for the growth of GaN epitaxial layer (EPI), but has several drawbacks such as high cost, large lattice mismatch, non-flexibility, and so on. Here, we first employ graphene directly grown on Si or sapphire substrate as a platform for the growth and lift-off of GaN-light-emitting diode (LED) EPI, useful for not only recycling the substrate but also transferring the GaN-LED EPI to other flexible substrates. Sequential standard processes of nucleation/recrystallization of GaN seeds and deposition of undoped (u-) GaN/AlN buffer layer were done on graphene/substrate before the growth of GaN-LED EPI, accompanied by taping and lift-off of u-GaN/AlN or GaN-LED EPI. This approach can overcome the limitations by the catalytic growth and transfer of graphene, and make the oxygen-plasma treatment of graphene for the growth of GaN EPI unnecessary.

AlN growth on nano-patterned sapphire: A route for cost efficient pseudo substrates for deep UV LEDs

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600218

C-plane-oriented sapphire substrates that were patterned on the nanoscale were overgrown by AlN using metal-organic vapor phase epitaxy. The occurrence of undesired misaligned AlN growth was detected. We found that this misaligned growth can be overcome by a proper choice of growth temperature and V/III ratio. Up to 8 µm thick c-plane-oriented AlN with a coalesced surface was obtained. An effective dislocation reduction was found due to bending of threading dislocation lines toward free surfaces during lateral growth. The distribution of crystal defects suggests that step bunching in AlN is accompanied by dislocation accumulation. Furthermore, nearly defect-free AlN crystallites with a hexagonal shape and a size of about 2 µm were observed.

Amplified spontaneous emission of phonons as a likely mechanism for density-dependent velocity saturation in GaN transistors

Department of Electrical and Computer Engineering, Johns Hopkins University, Baltimore, MD 21218, U.S.A.
Department of Electrical and Computer Engineering, The Ohio State University, Columbus, OH 43210, U.S.A.

Applied Physics Express
http://dx.doi.org/10.7567/APEX.9.094101

We show that density-dependent velocity saturation in a GaN high electron mobility transistor (HEMT) can be related to the stimulated emission of longitudinal optical (LO) phonons. As the drift velocity of electrons increases, the drift of the Fermi distribution in reciprocal space results in population inversion and gain for the LO phonons. Once this gain reaches a threshold value, the avalanche-like increase in LO phonon emission causes a rapid loss of electron energy and momentum and leads to drift velocity saturation. Our simple model correctly predicts both the general trend of decreasing saturation velocity with increasing electron density, and the measured experimental values of saturation.

Optical characteristics of wet-thermally oxidized bulk and nanoporous GaN

Department of Physics, Chonnam National University, Gwangju, 61186, Korea

Electronic Materials Letters
http://dx.doi.org/10.1007/s13391-016-6028-y

Gallium nitride (GaN) films deposited on sapphire substrates by metal organic chemical vapor deposition were successfully transformed into bulk and nanoporous gallium oxide (Ga_2O_3) using

a wet thermal oxidation technique. Oxidation depth measurements confirmed that the oxide growth appeared to be faster in the case of nanoporous GaN than that of bulk GaN. Spectroscopic ellipsometry was used to evaluate and compare the optical properties of nanoporous and bulk Ga2O3 films, such as refractive index and extinction coefficient, which revealed improved optical properties for nanoporous Ga2O3 compared to the bulk. The simulations conducted on the ellipsometric spectra for bulk and nanoporous Ga2O3 using the Forouhi-Bloomer model and the Bruggeman effective medium approximation revealed the best fit with a low mean square error value. In the case of nanoporous Ga2O3, zero absorption was observed in the wavelength range of 300 nm to 840 nm, supporting the use of this material as a transparent coating in optoelectronic devices.

Fabrication of GaN Microporous Structure at a GaN/Sapphire Interface as the Template for Thick-Film GaN Separation Grown by HVPE

China Electronics Technology Group Corporation No.46 Research Institute

Journal of Electronic Materials
http://dx.doi.org/10.1007/s11664-016-4726-8

In this paper, a microporous structure at the GaN/sapphire interface has been obtained by an electrochemical etching method via a selective etching progress using an as-grown GaN/sapphire wafer grown by metal organic chemical vapor deposition. The as-prepared GaN interfacial microporous structure has been used as a template for the following growth of thick-film GaN crystal by hydride vapor phase epitaxy (HVPE), facilitating the fabrication of a free-standing GaN substrate detached from a sapphire substrate. The evolution of the interfacial microporous structure has been investigated by varying the etching voltages and time, and the formation mechanism of interfacial microporous structure has been discussed in detail as well. Appropriate interfacial microporous structure is beneficial for separating the thick GaN crystal grown by HVPE from sapphire during the cooling down process. The separation that occurred at the place of interfacial microporous can be attributed to the large thermal strain between GaN and sapphire. This work realized the fabrication of a free-standing GaN substrate with high crystal quality and nearly no residual strain.

Correlation between structural and optical properties of GaN epi-layers by the cathodoluminescence technique

Research Unit: Physics of insulating and semi-insulating materials, Faculty of Sciences of Sfax, University of Sfax, Sfax, Tunisia

The European Physical Journal Plus
http://dx.doi.org/10.1140/epjp/i2016-16195-2

Structural and optical properties of GaN epi-layers were investigated. The X-ray diffraction and the SEM observations show a predominant hexagonal structure with minor cubic GaN microcristallites. Experimental results of cathodoluminescence (CL) were reported at room temperature (RT) and low nitrogen temperature (LNT). CL signals show ultraviolet (UV) light emission arising from a large band gap (3 to 3.5eV), a yellow band (YB) around 2.2eV and a peak at 1.73eV due to porous silicon. Simulation CL profiles show good agreement with experimental results when we take into account the minor cubic phase contribution. Our attention was also focused on the study of the effects of temperature, electron beam energy, and residual strain on the individual CL signal from both h-GaN and c-GaN phases.

Epitaxial growth of high quality AlN films on Si substrates

State Key Laboratory of Luminescent Materials and Devices, South China University of Technology, Guangzhou 510640, China
Engineering Research Center on Solid-State Lighting and its Informationisation of Guangdong Province, Guangzhou 510640, China

Materials Letters
http://dx.doi.org/10.1016/j.matlet.2016.07.003

Quality-enhanced AlN epitaxial films on Si substrates with Al buffer layer have been grown by the combination of molecular beam epitaxy (MBE) and pulsed laser deposition (PLD) technologies. MBE is deployed to grow Al buffer layer at first, and PLD is used to grow AlN epitaxial

films on the Al buffer layer. It is found that as the increase in the growth temperature, the property of as-grown ~300 nm-thick AlN epitaxial films is first increased and then decreased, and shows an optimized value at 750 °C. The as-grown ~300 nm-thick AlN epitaxial films grown at 750 °C show full-width at half-maximums of AlN (0002) and AlN () of 0.45° and 0.80°, respectively, a root-mean-square surface roughness of 1.4 nm. This work provides an effective approach for the growth of high-quality AlN epitaxial films on Si substrates for the future application of AlN-based devices.

Grouped and Multistep Nanoheteroepitaxy: Toward High-Quality GaN on Quasi-Periodic Nano-Mask

State Key Laboratory for Artificial Microstructures and Mesoscopic Physics, School of Physics, Peking University, Beijing 100871, P. R. China

ACS Appl. Mater. Interfaces
http://dx.doi.org/10.1021/acsami.6b05636

A novel nanoheteroepitaxy method, namely, the grouped and multistep nanoheteroepitaxy (GM-NHE), is proposed to attain a high-quality gallium nitride (GaN) epilayer by metal–organic vapor phase epitaxy. This method combines the effects of sub-100 nm nucleation and multistep lateral growth by using a low-cost but unique carbon nanotube mask, which consists of nanoscale growth windows with a quasi-periodic 2D fill factor. It is found that GM-NHE can facilely reduce threading dislocation density (TDD) and modulate residual stress on foreign substrate without any regrowth. As a result, high-quality GaN epilayer is produced with homogeneously low TDD of 4.51 × 107 cm–2 and 2D-modulated stress, and the performance of the subsequent 410 nm near-ultraviolet light-emitting diode is greatly boosted. In this way, with the facile fabrication of nanomask and the one-off epitaxy procedure, GaN epilayer is prominently improved with the assistance of nanotechnology, which demonstrates great application potential for high-efficiency TDD-sensitive optoelectronic and electronic devices.

THz Acoustic Spectroscopy by using Double Quantum Wells and Ultrafast Optical Spectroscopy

Institute of Physics, Academia Sinica, Taipei 11529, Taiwan

Scientific Reports
http://dx.doi.org/10.1038/srep28577

GaN is a pivotal material for acoustic transducers and acoustic spectroscopy in the THz regime, but its THz phonon properties have not been experimentally and comprehensively studied. In this report, we demonstrate how to use double quantum wells as a THz acoustic transducer for measuring generated acoustic phonons and deriving a broadband acoustic spectrum with continuous frequencies. We experimentally investigated the sub-THz frequency dependence of acoustic attenuation (i.e., phonon mean-free paths) in GaN, in addition to its physical origins such as anharmonic scattering, defect scattering, and boundary scattering. A new upper limit of attenuation caused by anharmonic scattering, which is lower than previously reported values, was obtained. Our results should be noteworthy for THz acoustic spectroscopy and for gaining a fundamental understanding of heat conduction.

Maximizing cubic phase gallium nitride surface coverage on nano-patterned silicon (100)

Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA and Micro and Nanotechnology Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA

Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4960005

Here we investigate the hexagonal-to-cubic phase transition in metalorganic-chemical-vapor-deposition-grown gallium nitride enabled via silicon (100) nano-patterning. Electron backscatter diffraction and depth-resolved cathodoluminescence experiments show complete cubic phase GaN surface coverage when GaN deposition thickness (hchc), etch depth (tdtd), and opening width (pp) obey hc≈1.06p−0.75tdhc≈1.06p−0.75td; in line with a geometrical model based on crystallography.

Cubic GaN uniformity is studied via electron backscatter diffraction and cathodoluminescence measurements. Atomic force microscopy reveals a smooth cubic GaN surface. Phase-transition cubic GaN shows promising optical and structural quality for integrated photonic devices.

OPTOELECTRONICS

RayVio and Boston University expand UV LED research to combat vitamin D deficiency disorders
Semiconductor Today

Health and hygiene company RayVio Corp of Haywood, CA, USA, which is commercializing deep-ultraviolet (UV) LEDs and consumer disinfection solutions, is expanding a research program with Boston University to develop new treatments for vitamin D deficiency (a disorder associated with osteoporosis, rickets and other metabolic bone diseases). Led by Dr Michael F. Holick, the research will expose various skin samples to UV light generated by RayVio's LEDs to determine appropriate exposure times and intensity that can be effectively and safely used to treat vitamin D deficiency disorders.

"Vitamin D deficiency affects more than 100 million Americans and over a billion people worldwide," notes Dr Michael F. Holick Ph.D., M.D., professor of Medicine, Physiology and Biophysics at Boston University School of Medicine, an endocrinologist at Boston Medical Center and lead researcher on the study. "Finding a solution will reduce the onset of catastrophic illnesses and potentially saves hundreds of thousands of lives," he adds.

"Our previous work with RayVio demonstrated that very low-intensity UV light from LEDs – the kind that might be incorporated into today's wearable technologies – will boost vitamin D production in skin and can improve peoples' health," continues Holick. "Our new program expands on that work to determine the best wavelength of light, appropriate duration and intensity that will optimize new and more effective treatments."

Vitamin D deficiency leads to debilitating diseases like osteoporosis, rickets and even increases the risk of developing common deadly cancers, diabetes, autoimmune diseases including multiple sclerosis and heart disease. Studies have also shown links between vitamin D deficiency and brain disorders including and Alzheimer's disease, depression and schizophrenia.

"At RayVio, we can produce LEDs targeted to specific wavelengths, and working with Dr Holick and his team will allow us to mass produce LEDs that provide the optimum UV light and intensity to address vitamin D deficiency," says RayVio's CEO Robert C. Walker Ph.D.

In addition to the joint research project with Holick, RayVio's latest deep UV LEDs are being applied to disinfection and water purification applications that have the potential to reduce hospital-acquired infections and illnesses that result from drinking unsafe water."
Read more

HexaTech demonstrates first-generation 263nm AlN-based UV-C LED
Semiconductor Today

HexaTech Inc of Morrisville, NC, USA - which manufactures aluminium nitride (AlN) substrates and long-life UV-C LEDs for disinfection applications, as well as developing deep UV lasers for biological threat detection, and high-voltage power semiconductors devices for smart grid and efficient power conversion - has demonstrated its first-generation UVSure UV-C LED, based on HexaTech's proprietary aluminium nitride (AlN) substrate material.

The 263nm-wavelength device achieves output power of 6mW in a 0.15mm2 active-area die. When scaled to the firm's second-generation larger footprint, the die is expected to produce about 24mW (twice the radiant flux of competing

products, it is reckoned). Further, when driven in pulse mode at a current of 300mA, the same 0.15mm2 active-area die can reach 19mW, or about 76mW in the large die format.

“This demonstration is a milestone in our business, and is the direct result of intense device R&D coupled with the use of our exclusive high-quality AlN substrate material,” says CEO John Goehrke. “This capability allows us to engage the UV-C LED market at the right moment, linking together incredibly strong interest with cutting-edge performance. It also clearly demonstrates our continued assertion that the best substrate material yields the best device performance, and this first-generation result is just the beginning,” he adds.

“With point-of-use (POU) sterilization applications alone representing a $400m+ opportunity in the coming years, we anticipate significant corporate expansion and strategic customer engagement,” says director of business development Gregory Mills.

“HexaTech's world-leading, high-quality bulk AlN substrates are the essential foundation for attaining these results, enabling near perfect epitaxial growth quality throughout the active region of the device, essential to produce both high internal quantum efficiency (IQE) and long component lifetimes,” says Dr Joseph Smart, director of LED development. “This is something that competing sapphire substrate technology simply cannot sustain at these wavelengths.”
Read more

Osram acquiring automotive LED module maker Novità

Semiconductor Today

As part of its three-pillar strategy announced last November, Osram GmbH of Munich, Germany is further expanding the leading position of its Specialty Lighting (SP) business by agreeing to acquire Novità Technologies of Hendersonville, TN, USA, a manufacturer of automotive LED modules that are used particularly in tail lights, fog lights and daytime running lights.

With about 100 staff, Novità ships mainly to headlight and tail-light manufacturers in the USA, and has annual sales of over €40m. The transaction is planned to be completed by October, and should immediately be margin-accretive in Osram's Specialty Lighting segment.

“The purchase of Novità Technologies is an outstanding addition to our project and system business and at the same time strengthens our position on the important US market,” believes Hans-Joachim Schwabe, CEO of Osram's Specialty Lighting business unit.

As technological changes continue to take place around LEDs, the requirements of manufacturers in the automotive industry are also changing with regard to the design and functionality of light, notes Osram. As a result, there is increasing demand for complete systems and modules rather than for the pure light sources. An example is the Ford F-150 pick-up truck, for which Osram has developed a complete LED-based front lighting system comprising low and high beam, turn indicators, parking light and control module. By purchasing Novità, Osram is complementing its LED module business with regard to the tail light and forward auxiliary lighting such as fog lights and daytime running lights (DRLs).

The global market for LED modules for front and rear lights is forecast to increase by an average of 20% per year by 2020. It is reckoned that Novità is well positioned in this sector, particularly in the USA, and therefore adds to Osram in terms of both the regional market and the LED automotive portfolio for project and system business. Founded in 2007 as an asset management buyout, Novità has recorded rapid growth in the last three years and is said to have a high level of engineering and manufacturing expertise, specifically in the LED module business.
Read more

Vishay launches mid-power 365nm UV LED delivering long lifetime in compact 1.6mm package
Semiconductor Today

Vishay Intertechnology Inc of Malvern, PA, USA has expanded its offering of mid-power UV LEDs in the 365nm wavelength range with a new device featuring a silicone lens in a compact 1.6mm by 1.6mm by 1.4mm surface-mount package. Designed to provide a reliable, energy-saving replacement for mercury lamps, the Vishay Semiconductors VLMU1610-365-135 delivers long lifetime for medical, industrial and printing applications.

The silicone lens enables extremely long lifetimes of up to 25,000hr compared with the typical mercury lamp lifetime of 10,000hr. The environmentally friendly UV LED is free of heavy metals and provides increased reliability through its shock resistance and immunity to degradation from frequent on/off switching. While mercury lamps require complex drive circuits and need 2-15 minutes to warm up, the VLMU1610-365-135 allows the use of simple low-voltage circuitry and requires no warm-up period.

Fabricated from indium gallium nitride (InGaN) technology, the new LED features typical radiant power of 18mW at 20mA and 50mW at 60mA in a wavelength range of 362.5-370nm. The VLMU1610-365-135 has an emission angle of 135°.

The LED's specifications make it suitable for UV curing in nail salon, dental, and poster printing applications; blood and counterfeit money detection; and photocatalytic purification.

RoHS-compliant, halogen-free and Vishay Green, the VLMU1610-365-135 is compatible with reflow soldering processes and features a Moisture Sensitivity Level of 3 in accordance with J-STD-020.

Samples and production quantities are available now, with lead times of 6-8 weeks.
Read more

Kingbright launches smallest SMD LED, using 0201 package
Semiconductor Today

LED maker Kingbright Co LLC City of Industry, CA, USA has launched what it claims is the industry's smallest SMD LED, the HELI-UM series.

The 0.65mm x 0.35mm x 0.20mm (0201) footprint of the HELI-UltraMiniature allows it to fit into ultra-compact designs for wearable, portable consumer products and disposable medical device applications. Engineered with either aluminium gallium indium phosphide (AlGaInP) or indium gallium nitride (InGaN) chips, various colors are available.

Compatible with automatic placement equipment, the HELI-UltraMiniature can be easily utilized, similarly to 0201 passive components, notes the firm.
Read more

UV-C LED water disinfection system first to receive NSF lead-free certification
Semiconductor Today

UV-C LED disinfection system manufacturer AquiSense Technologies LLC of Erlanger, KY, USA has received certification from the Water Quality Association (WQA) for its PearlAqua water disinfection system.

WQA is an independent public health organization that tests and certifies a wide range of plumbing and drinking water treatment products. Specifically, the PearlAqua meets the stringent requirements of NSF/ANSI 372 (an accreditation for providing lead-free water) and NSF/ANSI 61 (which certifies the PearlAqua for safe drinking water).

PearlAqua was the first-to-market UV-C LED water disinfection system, it is claimed, and is the first UV-C LED system to receive NSF/ANSI certification, confirming that it provides clean water without the use of lead (which has contaminated water in a number of communities around the world). “This is a significant step in our overall commercialization strategy,” says CEO

Oliver Lawal. "It further validates that switching over to semiconductor-based technology is viable in providing equal or safer water quality," he adds. Read more

Emergence of COB technology to boost LED packaging equipment market to $656m in 2020
Semiconductor Today

The global light-emitting diode (LED) packaging equipment market will rise at a compound annual growth rate (CAGR) of almost 2% to more than $656m in 2020, according to a report by Technavio.

The report considers the emergence of COB technology as one of the major trends that will gain traction in this market during the forecast period. "COB [chip-on-board] is a type of bare-chip technology used for LED lighting," says Navin Rajendra, one of Technavio's industry managers for sensors. "The lighting module for a COB LED is done by placing multiple LED chips in a small area. It is a comparatively new technology for LED packaging, and it involves multiple LED chips being mounted directly on the substrate to make an LED array in one lighting module," he adds. Benefits such as the capability to spread light across a large area, effective thermal management, homogenous luminosity, energy efficiency and compactness will ensure that the increased adoption of COB LEDs will require the adoption of new and advanced LED packaging processes, which will demand the replacement of older packaging equipment.

By process, as a proportion of the LED packaging equipment market in 2015, LED testing comprised 59.69%, die singulation 18.99%, die attach 15.12%, substrate separation 3.88%, and permanent bonding 2.33%.

LED testing

LED testing is required throughout the LED packaging process, and testing equipment is used for the inspection and qualification of incoming materials, process monitoring and control, and testing end-of-line product. The expected increase in demand for LEDs will subsequently boost demand for this market segment in the coming years.

Die singulation

The die singulation (wafer dicing) segment (valued at $124.7m in 2015) is used to separate individual dies on the finished wafer for further packaging and assembly. The process is carried out on the basis of the LED's end-application (e.g. different types of dies are used in general lighting systems than in automotive applications).

The size of dies, type of structure, and nature and type of substrates determine the singulation technique to be used. Cost and performance parameters are also taken into consideration. The evolution of new laser technologies for dicing and scribing purposes will create demand for equipment and will also help die singulation maintain its market share in the LED packaging equipment market.

Die attach

The success of a finished product depends on many key processes that achieve their individual quality goals and targets. Die attach involves the attachment or bonding of a die (chip) to an LED package. Requirements for the die attach process include:

thermal conductivity should dissipate the heat generated from the die;
perfect contact should exist between the chip and substrate without any voids;
the bond or attachment should be made carefully so that it does not destroy the chip; and
the bond or attachment should be able to withstand extreme temperatures without any degradation.
The size of wafers used for LED chip production has increased from 2-4 inches to 6-8 inches. The large wafer size allows manufacturers to reduce the overall cost by producing more LED chips per wafer. Intensifying price wars have compelled manufacturers to emphasize cost reduction and a shift toward large-diameter wafers for LED production.

Substrate separation

The substrate separation segment was valued at $25.45m in 2015. To maintain manufacturing efficiency, LED makers typically attach or populate multiple LED boards, with the boards being tied together. After this, a punching tool or a manual breaking process is used to separate the LED boards. Care is needed during the process, as the printed-circuit board can easily bend or flex due to excessive stress on the ceramic substrate and the LEDs soldered onto the substrate. Excessive stress may also result in a crack, creating defective LEDs.

APAC to account for 88% of market by 2020, driven by LED display panels

The report estimates that the Asia-Pacific region (APAC) will dominate the market, accounting for about 88% of LED packaging equipment revenue by 2020. The exponential rise in demand for consumer electronics - coupled with the rollout of long-term evolution (LTE) bandwidths in APAC countries such as India and China - has led to the expansion of LTE base-station infrastructure. This will drive the market for display panels that use LEDs as the backlighting source of the screen. Also, the presence of major LED display lighting panel manufacturers in this region will contribute to market growth, reckons Technavio.
Read more

Seoul Semiconductor wins revocation of Enplas' LED lens patent in Taiwan
Semiconductor Today

South Korean LED maker Seoul Semiconductor says that Japanese lens maker Enplas' LED lens patent has been revoked in Taiwan, adding to a series of legal victories against Enplas in the USA, Korea, and Europe. Enplas's patent has been revoked in Taiwan.

Since patent litigation between the two firms began, Seoul has pursued enforcement of its LED backlight lens and system patents against infringing products by Enplas. On 24 March, a US jury ruled that Enplas had actively induced infringement of Seoul's patented technology with respect to all of the patent claims presented by Seoul. The jury found that Enplas' infringement was willful. It also unanimously agreed that Seoul's LED backlight lens patents were valid, rejecting all of Enplas' invalidity arguments. The jury awarded Seoul $4.07m in damages for induced infringement.

Previously, in the USA, Seoul filed inter partes review (IPR) petitions against three backlight lens patents owned by Enplas. All three were invalidated by the US Patent Trial and Appeal Board. In Korea, the Supreme Court affirmed the decision of the USPTO, invalidating all the claims of Enplas' backlight lens patent. In Europe, the European Patent Office declined to register Enplas' backlight lens patent based on prior art references that were brought to its attention by Seoul.

On 26 January, Seoul filed an invalidation action against Enplas' backlight lens patent in Taiwan based on the same invalidity grounds. Enplas was unable to defend against these invalidation contentions and has had to cancel all of its patent claims, which has resulted in revocation of the patent.

“A series of patent litigations against Enplas has demonstrated that Seoul Semiconductor has pioneered patent portfolios regarding LED backlight technology,” says Seung Ryeol Ryu, Seoul's IT application R&D officer. “We are continuously monitoring third-party companies that are infringing our patented technology and will pursue enforcement actions where necessary to protect our company's long-standing investment in intellectual property.”
Read more

SemiLEDs sells stake in firm to Dr Peter Chiou
Semiconductor Today

LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has entered into a definitive agreement for Dr Peter Chiou to purchase 577,000 shares (about 19.6% of its outstanding common stock) at $5 per share.

Chiou also intends to subscribe to a $1,615,000 SemiLEDs' 0%-interest convertible note with a 29

September 2017 maturity date. Subject to shareholder approval at the next shareholders meeting, the note will be convertible into a number of shares equal to $1,615,000 divided by the conversion price ($3.40, or the 5-trading-day volume-weighted average price on the NASDAQ Stock Market ending on the maturity date, whichever is less).

These investments are expected to be made in three instalments, as follows:
* $1,000,000 (which has already been wired to the firm's bank account);
* $1,885,000 (to be wired to the firm on or before 15 August) - upon completion of the share purchase, Chiou will be appointed a member of SemiLEDs' board of directors (Chiou has agreed to waive any compensation for his services on the board);
* $1,615,000 (to be wired to the firm on or before 29 September).

SemiLEDs cautions that there is no assurance that it can successfully close the financing or if Dr Chiou is able to meet the funding requirements of the purchase agreement.

NASDAQ notice of listing non-compliance

As announced on 28 June, Arthur H. del Prado resigned from the board of directors (effective 22 June). On 30 June, SemiLEDs received a notice from The NASDAQ Stock Market indicating that it no longer complies with the audit committee requirements, and confirming the firm's opportunity to regain compliance (within the cure period provided in Listing Rule 5605(c)(4), either by 19 December 2016 if the next annual stockholders' meeting is held before then, or by 22 June 2017 if the next annual meeting is held after 19 December 2016).
Read more

Changelight qualifies Aixtron's AIX R6 and puts MOCVD system into LED mass production
Semiconductor Today

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says that optoelectronics manufacturer Xiamen Changelight Co Ltd of Xiamen, Fujian Province, China has finalized qualification of its AIX R6 Close Coupled Showerhead metal-organic chemical vapor deposition (MOCVD) system, which is designed particularly for LED mass production.

In the course of the qualification process, the AIX R6 not only demonstrated its production capabilities but also proved what is reckoned to be outstanding performances in terms of gas consumption, intrinsic yield and uniformity. Changelight has now put the AIX R6 system into production for LED high-volume manufacturing.

“By meeting Changelight's production standards, we have achieved another important customer qualification milestone for the AIX R6,” says Aixtron's executive VP & chief operating officer Dr Bernd Schulte. “Based on our long-standing and great business relationship with Changelight, we are looking forward to further deepening our cooperation in the fields of gallium arsenide (GaAs)- and gallium nitride (GaN)-based applications,” he adds.

Founded in 2006, Xiamen Changelight mainly produces full-color ultra-bright LED epitaxial wafers and chips, high-performance GaAs solar cells and LED lighting products. The firm also provides energy-saving lighting application solutions.
Read more

Seoul Viosys wins UV LED patent infringement lawsuit
Semiconductor Today

UV LED maker Seoul Viosys Co Ltd says that the US Federal District Court for the Southern District of Florida has issued a judgment in which Salon Supply LLC (which sells UV LED curing device) acknowledges infringement of its asserted patents as well as their validity. Salon Supply has agreed to pay past damages, as well as a license fee, and to stop using unlicensed infringing products.

Seoul Viosys' asserted patents span a wide range of UV LED technologies including, but not limited to, LED packaging, LED chips and epitaxial layers, and UV curing device structure. Together, these

technologies cover key components and features of UV LED curing devices.

Seoul Viosys was established in 2002 as Seoul Optodevice (a subsidiary of South Korean LED maker Seoul Semiconductor Co Ltd) based on a technical cooperation with Japan's Nitride Semiconductor Co Ltd (the first firm to develop long-wavelength UV LEDs, emitting at 360-400nm, in 2001). It is said to be the first firm specializing in UV LEDs (spanning epitaxy, chip, package and module manufacturing) and the first to develop short-wavelength UV LEDs. Seoul Optodevice was renamed Seoul Viosys in 2013 to denote its expansion from a visible LED and UV LED chip maker to a UV LED system provider.

In 2005 the firm made an equity investment in Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, and subsequently produced its first 254-340nm UV-C and UV-B (deep UV) LEDs. Seoul Viosys has since maintained close technical cooperation with SETi for over 10 years to commercialize UV LED chips with wavelengths below 350nm.

Last August, with the approval of the US Committee on Foreign Investment in the US (CFIUS), Seoul Viosys acquired a majority stake in SETi, and has continued expanding and commercializing its UV LED business. In particular, Seoul Viosys' Violeds technology can be applied to biotechnology equipment and medical diagnosis equipment as well as skin and other medical treatment, including being used as part of the International Space Station (ISS) as well as MOSCLEAN (a mosquito trap).

“We have developed Violeds technology, not just for profit, but also to assist with critical health and environmental measures,” says Yeojin Yoon, VP of the UV Development Center at Seoul Viosys. “With our ability to mass produce these life-saving devices at a low cost, we can supply Violeds technology and its products to people around the world,” he adds. “We have invested tremendously to achieve this technology. We will strongly enforce our patents against infringers that do not respect our intellectual property, and we will initiate additional patent infringement lawsuit against such infringers within the next quarter of this year.”

Read more

LayTec offers EpiTT 280nm reflectance channel to sense AlGaN surface morphology in UV-C LED epi

Semiconductor Today

Aluminium gallium nitride (AlGaN) buffer layers with high aluminium content are necessary for optimal UV-C LED performance. But their band-edge lies below 300nm, so established 405nm in-situ reflectance is insensitive to the surface morphology of such AlGaN layers. To monitor precisely both the AlGaN growth rate and surface morphology during UV-C LED epitaxy, in-situ metrology system maker LayTec AG of Berlin, Germany is hence offering an additional 280nm reflectance channel that employs a UV-C LED as a light source.

The Figure shows the results measured in-situ during growth of an AlGaN layer: The Fabry-Perot oscillations of the final AlGaN layer are damping out because the band edge of the material shifts toward longer wavelengths at the growth temperature. The small reflectance reduction at 12,000s indicates a small roughening of the AlGaN surface. The green line delivers the high-resolution wafer bow data.

This study is supported by Advanced UV for Life funding (grant number 03ZZ0105C) from the German Federal Ministry of Education and Science (BMBF).

EpiCurveTT Gen3: high-resolution wafer bow measurements for CCS reactors

Detecting thin-film strain in-situ during epitaxial growth through the tiny openings of the showerhead view-ports of a metal-organic chemical vapor deposition (MOCVD) reactor is a challenge, notes LayTec. However, the firm says that, by using advanced software algorithms, it has improved the signal-to-noise ratio of its EpiCurveTT tool by a full order of magnitude.

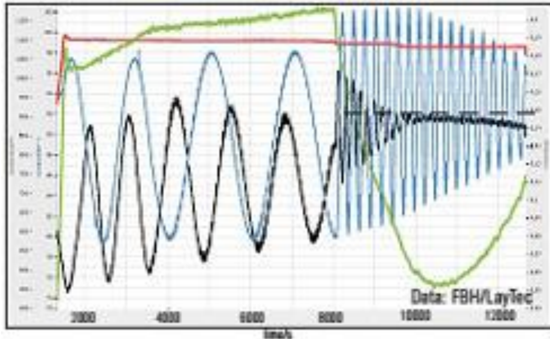


Figure 1: Growth of AlN/AlGaN(60%Al) on a sapphire/AlN template in an Aixtron CCS 6x2 reactor: black – 280nm reflectance; blue – 405nm reflectance; green – high-resolution wafer bow; red – true temperature.

The wafer bow data in Figure 1 (green line) shows that the wafer curvature noise in the Close Coupled Showerhead (CCS) reactor is now down to 0.3km-1. With this improvement, in-situ strain balancing or tuning the AlGaN lattice constant (Figure 2, strain changes from compressive to tensile during AlGaN growth at about 1000s) is now possible with accuracy levels formerly known only for ex-situ x-ray diffraction (XRD) methods, says the firm.
Read more

Sanan Opto Orders 17 Veeco MOCVD Systems
CompoundSemi

Sanan Optoelectronics, China's largest producer of LED epitaxial wafers and chips will place orders for 17 new-model MOCVD sets from US-based Veeco Instruments, Digitimes reported. The company will place the order in the fourth quarter of 2016 and will install the equipment in 2017, according to a Digitimes article, which cited industry sources. The article indicated that one MOCVD set from Veeco is equivalent to two MOCVD sets producing 2-inch wafers.

The government of Xiamen City of southeastern China has agreed to subsidize Sanan's purchases of MOCVD equipment. The subsidizing contract will expire at the end of 2016, according to the article.

Back in 2015. Sanan purchased 50 MOCVD sets from Veeco and another 50 from Germany-based Aixtron SE. Veeco has delivered the 50 MOCVD sets. However, Sanan canceled the order with Aixtron after Aixtron shipped three sets. Insiders speculate that the new Veeco order may be due to the canceled Aixtron order.

Sanan expects to obtain a total subsidy of about CNY5.5 million, whereas each individual system now costs about CNY7-8 million (US$1.05-1.20 million). Sanan is expected to complete the installation of the 17 MOCVD in during the summer of 2017.
Read more

Updated: US debates LED street lighting safety
Electronics Weekly

The Lighting Research Center of Rensselaer Polytechnic Institute is questioning some of the findings in a report on LED street lighting from the American Medical Association (AMA) – which advocates LED lighting, but urges caution on luminaire selection.

Last month, physicians at the AMA annual meeting adopted guidance on how street lighting planners should select LED lighting.
"Despite the energy efficiency benefits, some LED lights are harmful when used as street lighting," said AMA board member Dr Maya Babu. "The new AMA guidance encourages proper attention to optimal design and engineering features when converting to LED lighting that minimise detrimental health and environmental effects."
Cool-white LEDs (~5,000K) are more efficient than neutral white (4,000K) LEDs, which are more efficient that warm (3,000K) white LEDs, but the cooler the colour temperature, the more energy emerges as blue light. This is true of GaN+phosphor LEDs, the most common type by far.

According to the AMA:

- High-intensity LED lighting designs emit a large amount of blue light that appears white to the naked eye and create worse night-time glare than conventional lighting. Discomfort and disability from intense, blue-rich LED lighting can decrease visual acuity and safety, resulting in concerns and creating a road hazard.

- Blue-rich LED streetlights operate at a wavelength that most adversely suppresses melatonin during night. It is estimated that white LED lamps have five times greater impact on circadian sleep rhythms than conventional street lamps.
- Excessive outdoor lighting disrupts many species that need a dark environment – poorly designed LED lighting disorients some bird, insect, turtle and fish species.

It went on to recommend:

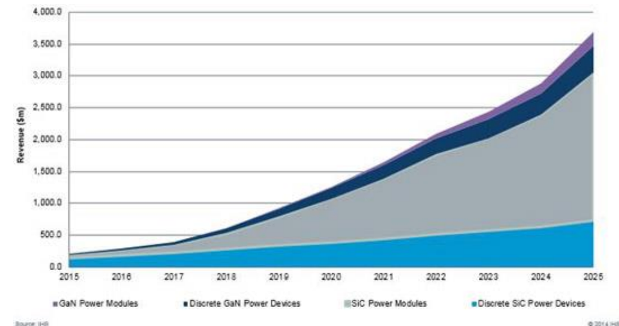
- Proper conversion to community-based LED lighting, which reduces energy consumption and decreases the use of fossil fuels.
- To encourage minimising and controlling blue-rich environmental lighting by using the lowest emission of blue light possible to reduce glare.
- The use of 3,000K or lower lighting for outdoor installations such as roadways.
- All LED lighting should be properly shielded to minimise glare and detrimental human and environmental effects, and consideration should be given to utilize the ability of LED lighting to be dimmed for off-peak time periods.

The full AMA report: '2-A-16, Human and environmental effects of light emitting diode (LED) community lighting', by the AMA Council on Science and Public Health (CSAPH), of is available [here on the website of darksky.org](#).
[Read more](#)

ELECTRONICS

Wide-bandgap power semiconductor device market to grow at 33% annually to $3.7bn in 2025
Semiconductor Today

Due to falling prices and the commercial availability of wide-bandgap (WBG) semiconductor power devices from multiple sources, the adoption of silicon carbide (SiC) and gallium nitride (GaN) power devices in power supplies for computers, telecom equipment, photovoltaic inverters, electric vehicles, military devices and many other applications is on the rise. The global market for SiC and GaN power semiconductors is hence rising at a compound annual growth rate (CAGR) of around 33% from $210m in 2015 to about $1.265bn in 2020 then $3.7bn in 2025, forecasts IEEE analyst Richard Eden in the latest SiC & GaN Power Semiconductors Report.



Graphic: The adoption of SiC and GaN power devices is being driven by declining prices and multiple sources of wide-bandgap-based power devices. (Image Credit: IEEE)

While SiC-based Schottky diodes have been available for over ten years, SiC-based MOSFETs, junction-gate FETs (JFETs) and bipolar junction transistors (BJTs) have emerged commercially in the last few years, including 900V SiC MOSFETs with a price comparable to silicon. Also, the number of suppliers of discrete SiC power devices has increased in the last few years, pushing more power supply designers toward SiC power devices. Consequently, IEEE is expecting SiC MOSFETs alone to generate revenue of $300m by 2025, becoming the second-best-selling discrete power device type in the next 5-10 years.

Meanwhile GaN-on-silicon power transistors are ramping up in production and GaN power modules are beginning to emerge. As a result, it is expected that, by 2020, GaN-on-Si power devices will achieve price parity with silicon MOSFETs and IGBTs. However, the IEEE report suggests the first GaN Schottky diodes are not expected to be commercially available before 2020. Accordingly, the GaN power market should surpass $600m by 2025. In the same timeframe, the SiC power market will generate over $3bn in revenue, the report concludes.
[Read more](#)

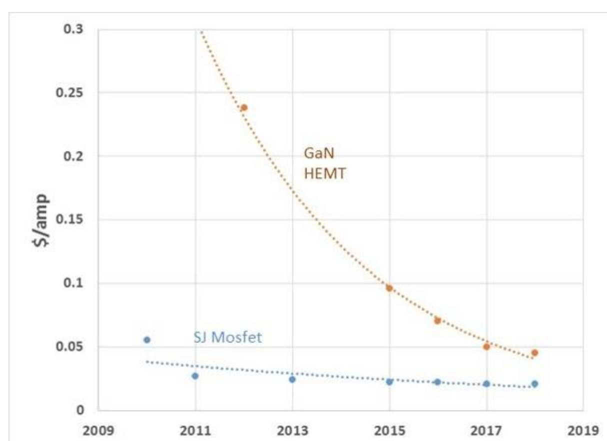
Transphorming the power transistor industry using GaN

i-micronews

Since 2010, new products have challenged the lead superjunction (SJ) MOSFETs retain today in the high-voltage power device market. SJ MOSFETs may be cheaper and offer lower on-resistance, gate and output charges than conventional MOSFETs, but they face competition from GaN-on-silicon (Si) HEMTs.

"GaN-on-Si HEMTs offer new capabilities, such as the possibility to work at higher frequencies," writes Elena Barbarini, Senior Cost Analyst at System Plus Consulting in her latest reverse costing report, 'GaN-on-Si HEMT vs SJ MOSFET: Technology and Cost Comparison'. "They are also competitive on manufacturing cost." The report analyzes the technology innovations and manufacturing processes of the main SJ MOSFET and GaN players to identify cost drivers and understand GaN devices' success.

To gain further insights into GaN-on-Si technology, Yole Développement and its sister company, System Plus Consulting, interviewed Philip Zuk, Senior Director Technical Marketing at Silicon Valley's Transphorm's office located in San Jose, California's. Philip discussed his company's strategy, position and challenges in supplying GaN power devices, and shared his vision of the industry.



GaN HEMT vs SJ MOSFET cost evolution (Source: GaN-on-Si HEMT vs SJ MOSFET: Technology and Cost Comparison report, System Plus Consulting, March 2016)

Yole Développement: *How is Transphorm positioned? What is your star product?*

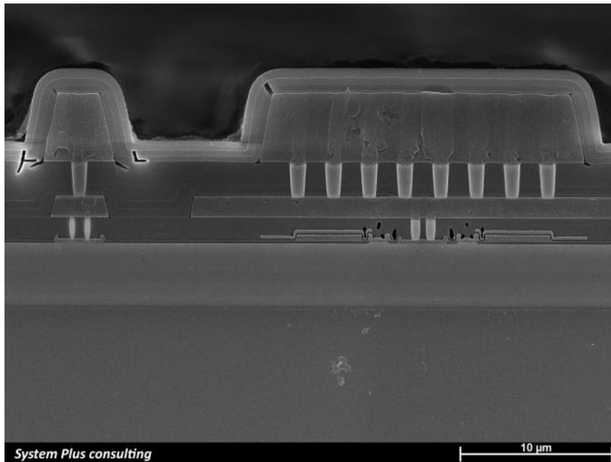
Philip Zuk: We offer a number of star products in our 650V, second generation cascode switch portfolio, from 35-290mΩ. Different power levels require different devices, so we are well positioned, offering solutions from 250W-4.5kW.

YD: *What products is Transphorm planning to introduce?*

PZ: Now that our 650V second generation cascode switch portfolio has been released, we are working on our third generation 650V family that will go into production during the 2017 calendar year. Our third generation family will include ~30mΩ in a TO-247 package and 50mΩ in a PQFN 8x8 package. Along with our 650V innovation we are moving up the high voltage ladder to 900V products that will be available within the next 12-15 months. This will offer our customers additional options in the industrial, renewable energy, and automotive markets. We have additional R&D activities going on, but I'm unable to speak about them at this time.

YD: *Will you release enhancement-mode (E-mode), normally off, GaN transistors? How do you compare E-mode to your normally-off cascode solution? Which markets do E-mode and cascade target, respectively?*

PZ: E-Mode is a technology that will complement our cascode product portfolio. Looking into the past and comparing traditional single epitaxial layer silicon planar MOSFETs to superjunction silicon MOSFETs there was a definite technological advantage moving from the former to the latter. When comparing E-mode versus cascode it is more about offering flexibility to our customers. It ultimately comes down more to the customer, their application, and design preferences. For example, do they want to use TO-xxx or SMT packaging? What is the frequency of operation? Is the design continuous current mode (CCM) or critical continuous mode (CrCM)? And so on.



GaN HEMT Cross-Section – SEM view
(Source: GaN-on-Si HEMT vs SJ MOSFET: Technology and Cost Comparison report, System Plus Consulting, March 2016)

YD: *What will be the leading applications for GaN?*
PZ: At Transphorm we are focused on four markets:
o Renewable Energy (solar inverters)
o Industrial (motor drives/servo)
o Automotive (electric vehicles and charging)
o Telecom/Server/Industrial (power supplies)

Any of these have the potential to be leaders in the GaN space. We see any application that converts AC to DC and DC to AC as a possible solution for GaN. It ultimately comes down to the value proposition of GaN. Is the customer looking for a reduction in weight/size (increased power density), a reduced cost with respect to the overall system bill-of-material (BOM) cost, and/or a performance increase? Depending on how these three "value propositions" are defined in one's design will dictate how, when, and what will be used.

YD: *What are the challenges facing GaN?*
PZ: Adoption and incumbent technology. We still see adoption as a challenge for GaN, not from the standpoint of the GaN technology, more on being risk adverse and being an early adopter. GaN has been talked about for many years; many power supply companies have limited or no experience with it and require both hardware and firmware support.. It is like any new technology: time and energy are required to see the fruits of our labour. Our biggest incumbent is silicon superjunction technology and it is well known and can offer great performance at a low price. Silicon is not going away, but as customers demand higher power levels, increased efficiencies, and power densities GaN will surface as the only suitable solution.

YD: *How do you see the market evolving?*
PZ: There will be steady growth over the next couple of years as GaN adoption increases in production applications, with exponential growth being projected towards the end of the decade.

YD: *Have you considered low voltage GaN products, below 650V?*
PZ: Low voltage GaN is a technology that can be realized out of our existing technology, but today we are focusing on 650V and higher. As the technology becomes more mature this is an area that we may look at.

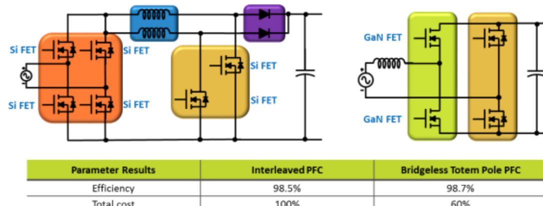
YD: *Do you think that there will be a high voltage GaN application, for example, in automotive applications?*
PZ: The two biggest semiconductor consumer markets – PCs and smartphones – are slowing down while the automotive market is growing, as semiconductor content in cars is growing. This trend is likely to intensify as the market progresses to self-driving cars. GaN fits nicely within this market as it can reduce size, weight, and overall BOM costs and increase performance over what silicon can offer today.

YD: *What about GaN-on-GaN? Do you see potential applications in power or anything other than LEDs?*
PZ: At this point I do not see GaN-on-GaN as a competitive threat due to manufacturing costs and the slow evolution of the technology.

YD: *What about the cost comparison with SJ MOSFET?*
PZ: GaN and SJ technology will continue to decrease in cost, but will it become cost parity, for products with the same on-resistance? In my opinion, unlikely in the high voltage markets. GaN is not an effective drop-in replacement technology due to the flexibility and advantages that it offers. It offers a system solution versus a device

solution. In my experience when comparing GaN to SJ, especially in a bridgeless totem pole power factor correction (PFC) circuit, a GaN device with double to triple the on-resistance can still offer better performance than SJ in the traditional, standard PFC topology. In many cases we are not comparing like-to-like devices, which is why the overall BOM needs to be looked at.

- Project: 3.3kW power supply
- Competition: Superjunction (silicon)
- Result: Higher efficiency, lower BOM cost
  - Reduction in part count, magnetics, EMI filter



Parameter Results	Interleaved PFC	Bridgeless Totem Pole PFC
Efficiency	98.5%	98.7%
Total cost	100%	60%

Wide Band Gap value proposition (Source: Transphorm)

YD: *What drives cost reduction in GaN manufacturing process?*
PZ: As with any new technology, design, process, epitaxy, and packaging. Transphorm offers a unique value chain were we have internal control of the design, epi, and manufacturing processes. This gives us the ability to be nimble, offer new generations quicker, and to maximize our operational efficiencies. As we move from our second to our third generation cascode, cost and performance advantages will continue to be realized.

YD: *What is the average manufacturing yield for GaN structures? Do you think there will be rapid improvement in the next five years?*
PZ: When looking at our fully-qualified cascode technology, manufacturing yield is not a problem, as we do not have leakage or high temperature dynamic on-resistance issues. Though I cannot speak to yield information, as it is proprietary, what I can say in some cases I see it higher than SJ.

YD: *Do you think you will face new competitors in the future?*
PZ: With GaN's adoption and the increased demands for power, more competitors will enter this market in order to grab market share to grow their business. GaN is the next evolution in power solutions and Transphorm will continue to lead this revolution.

Zuk TRansphormPhilip Zuk, Senior Director Technical Marketing, Transphorm

Philip leads the market strategy and market adoption of high voltage GaN technology in high power applications for Transphorm. He worked previously for Vishay (Siliconix) heading up their high voltage superjunction technology, Microsemi PPG running marketing efforts on their high voltage MOSFET, FRED diodes, IGBTs, and SiC efforts, Medallion Instrumentation Systems and Fairchild Semiconductor. He has expertise in microcontroller and power supply designed systems and applications, high power semiconductor devices and project management.
He holds a MBA (Hons) from I.H. Asper School of Business, University of Manitoba and has a Bachelor of Science in Electrical Engineering, University of Manitoba, and an Electronic Engineering Technology Associate Degree, Red River College.
Read more

EPC appoints Ismosys as European sales, marketing and technical support partner
Semiconductor Today

To support its accelerating growth throughout Europe, Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA - which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications - has appointed Ismosys (the principal trading division of the Spectrum Electronics Group) as its sales, marketing and technical support representative, assisting customers in adopting eGaN FETs and ICs for power conversion systems using gallium nitride.

Founded in 1994, Ismosys provides support to design houses, designers and engineers across

Europe. This is achieved through 10 regional offices covering the entire EMEA (Europe, Middle East and Africa) region and a centralized resource, fostering sales, driving marketing and enabling technical support.

“Ismosys has extensive reach and experience throughout Europe in making leading-edge electronics available to designers and engineers,” comments EPC's VP of sales & marketing Nick Cataldo. “Their technical knowledge, along with their ability to provide local support, will provide the personal touch for taking our products to markets throughout Europe,” he adds.

“Our new partnership with EPC is an exciting addition to our portfolio and will allow us to bring leading-edge power solutions to Europe,” says Ismosys' managing director Nigel Watts. “Gallium nitride technologies are an exciting innovation and will enable the design houses we are partnered with and the wider European design community to embrace GaN.”
Read more

Infineon to acquire Wolfspeed for $850m
Semiconductor Today

Infineon Technologies AG of Munich, Germany has entered into a definitive agreement to acquire the Wolfspeed Power & RF division of Cree Inc of Durham, NC, USA for $850m in cash (about €740m). The deal also includes the related silicon carbide (SiC) wafer substrate business for power and RF power.

The business to be acquired has generated pro-forma revenue of $173m in the 12 months ending 27 March. The acquisition will be immediately accretive to Infineon's adjusted earnings-per-share and margin. Infineon will fund the transaction with bank financing of $720m and $130m of cash-on-hand. The firm's capital structure should stay well within the previously communicated targets of €1bn gross cash plus 10-20% of revenue, and no more than two times the gross debt-to-EBITDA. Cree's board of directors and Infineon's supervisory board have approved the acquisition, which is expected to close by the end of calendar 2016 (subject to regulatory approvals in various jurisdictions).

Infineon says that the acquisition will enable it to provide the broadest offering in compound semiconductors and further strengthen it as a supplier of power and RF power solutions in high-growth markets such as electro-mobility, renewables and next-generation cellular infrastructure relevant for the Internet of Things (IoT).

Based in Research Triangle Park, NC, USA and part of Cree for almost three decades, Wolfspeed is a provider of SiC-based power and GaN-on-SiC-based RF power solutions. This also includes the related core competencies in wafer substrate manufacturing for SiC, as well as for SiC with a monocrystalline GaN layer for RF power applications. With more than 550 staff and an IP portfolio of about 2000 patents and patent applications, the deal complements Infineon's previous acquisition of International Rectifier in early 2015. Wolfspeed's SiC-based product portfolio adds to Infineon's existing offering.

“Joining forces with Wolfspeed represents a unique growth opportunity,” believes Infineon's CEO Dr Reinhard Ploss. “Wolfspeed's and Infineon's businesses and expertise are highly complementary, bringing together industry-leading experts for compound semiconductors. This will enable us to create additional value for our customers with the broadest and deepest portfolio of innovative technologies and products in compound semiconductors available in the market,” he reckons. “With Wolfspeed we will become number one in SiC-based power semiconductors. We also want to become number one in RF power. This will accelerate the market introduction of these innovative technologies, addressing the needs of modern society – such as energy efficiency, connectivity and mobility,” he adds.

“After much consideration and due diligence over the past year, we concluded that selling Wolfspeed to Infineon was the best decision for our shareholders, employees and customers,” comments Cree's chairman & CEO Chuck

Swoboda. “Wolfspeed will now be able to more aggressively commercialize its unique silicon carbide and gallium nitride technology as part of Infineon,” he believes.

“Wolfspeed will now have all the advantages of a global company in our sector, including the ability to leverage Infineon's market reach and infrastructure,” says Wolfspeed's CEO Frank Plastina. “With Infineon's complementary culture and additional investment, we'll be better positioned to unlock the potential of our portfolio and our people.”

Infineon stresses that power management solutions based on compound semiconductors have advantages enabling its customers to develop systems with higher energy efficiency, smaller footprints and lower system costs. By combining their portfolios of technologies, products and manufacturing capabilities, Infineon and Wolfspeed aim to accelerate the development of components enabling customers to develop differentiating systems. Major areas where applications will profit from SiC are renewables and especially automotive. Both benefit from the increased power density and improved efficiency. In automotive it fits well with the recent increased commitment of the industry to plug-in hybrid and all-electric vehicles (xEV), says Infineon. Combining both portfolios and competencies should accelerate time-to-market for new products based on compound semiconductors, the firm reckons.

Next-generation cellular infrastructure standards such as 5G and beyond will use frequencies up to 80GHz. Only compound semiconductors can deliver the required efficiencies at these high frequencies, notes Infineon. GaN-on-Si allows higher levels of integration and offers advantages at operating frequencies of up to 10GHz. GaN-on-SiC enables maximum efficiency at frequencies of up to 80GHz. Both technologies are crucial for next-generation cellular infrastructure standards, says the firm. Together with its Si-based LDMOS products, Infineon claims to be the industry's most complete provider for RF power components.

Infineon says that the combined portfolio advances its strategic 'Product to System' approach. Additionally, it will benefit from accelerating the adoption of SiC- and GaN-based components in early-adopter markets, e.g. electro-mobility, high-end photovoltaic inverter, xEV charging infrastructure, and RF power components in cellular infrastructure.
Read more

Infineon's acquisition of Wolfspeed just the beginning of collaborations in SiC power electronics, reckons Yole

Yole Développement

International Rectifier and Infineon Technologies, Fairchild Semiconductor and ON Semiconductor, Wolfspeed and APEI… Who will be next?

Last week, Infineon Technologies’ acquisition of Wolfspeed for US$850 million in cash made lots of noise in the compound semiconductor world.
Indeed, this acquisition comes in a power electronics industry where SiC technology benefits are well-known and where business opportunities have been clearly identified by industrial companies. In its latest compound semiconductor technology & market analysis report Power SiC 2016: Materials, Devices, Modules, and Applications (June 2016, Yole Développement), the “More than Moore” market research and strategy consulting company Yole Développement (Yole) announced a US$200 million market in 2015 and a 19% CAGR between 2015 and 2021, reaching US$550 million by the period’s end.
Both Wolfspeed and Infineon Technologies are the market leaders and this pact reinforces their dominant market position. The deal also includes the related SiC wafer substrate business for power electronics and RF power electronics. According to Yole’s analyst Dr. Hong Lin, Infineon Technologies market share should increase more than 50% if the full acquisition is confirmed.
This year again, Yole has followed the compound semiconductor industry and especially the WBG market segment. The power electronics industry landscape is evolving, showing “a new face”, and power electronics consolidation is increasing, confirmed Yole’s analysts (Source: Status of the Power Electronics Industry 2016 report, Yole

Développement, June 2016). International Rectifier and Infineon Technologies, Fairchild Semiconductor and ON Semiconductor, Wolfspeed and APEI … Today Infineon Technologies and Wolfspeed. The story is still unfolding. So who will be next?
"Wolfspeed and Infineon Technologies are leaders in the SiC power devices industry. The combination of both players will clearly strengthen the leading position of Infineon Technologies in the SiC power business," explains Dr. Lin, Technology & Market Analyst at Yole.
"This is a win-win acquisition," says Dr. Lin. Yole continues its research within the power electronics & compound semiconductor industry day after day. The consulting company is a leader in this sector, releasing numerous technology and market reports each year and establishing dedicated custom collaborations with multiple companies throughout the supply chain. Dr. Lin provides the following analysis from Yole's report:

- First, Infineon Technologies and Wolfspeed are both established SiC diodes players.

- Wolfspeed has developed a powerful SiC MOSFET solution, which is clearly more advanced than Infineon Technologies' solutions, within the commercialization phase: Wolfspeed's Gen 3 has already been commercially available for two years and has a good reputation. From its side, Infineon Technologies just released its MOSFET component in May 2016. Within a SiC MOSFET market that is just taking off, Infineon's acquisition of Wolfspeed ensures its development in this market segment.

- In parallel, as No.1 in the incumbent silicon power business, Infineon Technologies has a well-established client portfolio. The German company has a strong understanding of the market's needs, its players, and the technical specifications related to power electronics applications.

- The company also has significant experience in power packaging for semiconductors, which is considered the main SiC business bottleneck for power electronics today. Last year, Cree's division, Wolfspeed acquired APEI to reinforce their packaging capability. Today, with the support from Infineon Technologies, Wolfspeed can further accelerate their product development and reaffirm the leadership of its technology approach.

- Finally, Infineon's investment and large-scale production capability could support Wolfspeed in ramping up production and expansion.

This acquisition includes more than just Wolfspeed's SiC devices for power electronics applications. It also includes the company's activities focused on GaN on SiC for RF applications. According to Yole's report entitled GaN RF Devices Market: Applications, Players, Technology, and Substrates 2016–2022 report (Yole Développement, June 2016), the GaN RF devices market will double in the next five years, thanks to widespread adoption within various market segments. As a result, Wolfspeed's merger with Infineon gives them direct access to the emerging GaN RF market.
"At Yole, we see this acquisition as the beginning of a series of impressive collaborations within the SiC power business in the coming years," says Dr Pierric Gueguen, Business Unit Manager at Yole. "And this industry trend is likely to continue and to further increase in the future." Several recent mergers and acquisitions, such as Infineon Technologies and International Rectifier, ON Semiconductor and Fairchild Semiconductor, have launched the power electronics industry's consolidation phase.
Infineon Technologies reaffirms its leading market position with both acquisitions during an 18-month period (from Jan. 2015 to Jul. 2016). The company secures its activities within the emerging WBG technology sector. What strategy will other power electronics companies adopt in response to Infineon Technologies? Do they have to make strategic technical choices? Will we see new collaborations, mergers or acquisitions in the near future? According to Yole's analysts, it's likely we will. So let's see what story the following chapters will tell…
Read more

Infineon acquired Wolfspeed: what will be the impacts?

i-micronews

In the past week, the most prominent news in the compound semiconductors and power electronics fields was the acquisition of the Cree (Wolfspeed) Power and RF division by Infineon for $850M in cash. The announced acquisition also includes Cree's related SiC wafer substrate business for power and RF power.
Wolfspeed has two main activities: SiC power devices and GaN-on-SiC RF devices. Yole Développpement has followed both markets for a long time. Today, we are going to share our points of view on the acquisition and the impact on both SiC power and GaN RF area.

Dominance in the SiC power business
Infineon and Wolfspeed are the current leaders in SiC power devices. The combination of the two companies will clearly strengthen Infineon's leading position in the SiC power business. If the acquisition is completed, Infineon's post-acquisition SiC market share is estimated to be more than 50%, as per Yole Développement's latest compound semiconductor report, Power SiC 2016: Materials, Devices, Modules & Applications.

SiC power business: player market share estimate (captive + open market)

(Source: Power SiC 2016: Materials, Devices, Modules & Applications report,
Yole Développement, June 2016)

We consider the acquisition as a win-win affair. Infineon and Wolfspeed are both established players in SiC diodes. When it comes to SiC MOSFET, Wolfspeed is more advanced in SiC MOSFET commercialization. Its Gen 3 has already been commercially available for two years and has a good reputation, while Infineon just released its MOSFET in May 2016. As the SiC MOSFET market takes off, the acquisition of Wolfspeed bolsters Infineon's position.

On the other hand, as the #1 player in the silicon power business, Infineon has a well-established client portfolio and a good understanding of the needs of power electronics applications. The company also has vast experience in power semiconductor packaging, which is frequently considered a bottle neck for the SiC power business. In July 2015, Wolfspeed acquired APEI to reinforce its packaging capability. With Infineon's support, Wolfspeed could further accelerate its product development. Last but not least, Infineon's investment and large-scale production capability could support the market's ramp-up and expansion.

Yole Développement sees this acquisition as a precursor to a series of SiC power business events in the coming years, mostly in power electronics. Several recent M&A activities - Infineon acquiring IR, ON Semiconductor acquiring Fairchild - have commenced the power electronics business's consolidation phase. Faced with a leader that's well-positioned in both the incumbent silicon devices market and the emerging wide band-gap devices market, other market players will be forced to react, and consolidation among some players is likely. The SiC power business's next chapter is about to be written.

Infineon becomes serious challenger for title of "RF GaN business champion"

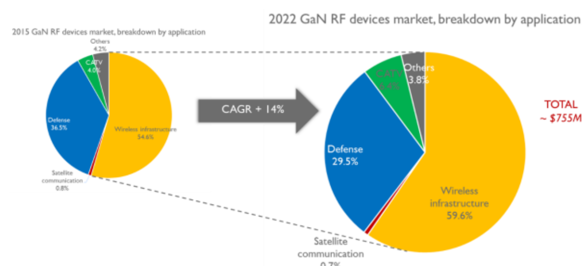
Cree (Wolfspeed) released its first GaN-on-SiC RF device in 2000. Since then, Cree (Wolfspeed) has gradually expanded its product line, and today offers more than 110 products ranging from VHF to Ku band, 28V to 50V. With long-time support from the U.S. Department of Defense (DOD) on its GaN RF development, Cree (Wolfspeed) is well-situated in the military/defense segments. In recent years, the company has introduced more products for the civilian market, particularly for the first glowing wireless infrastructure market. Besides manufacturing its own brand products, Cree (Wolfspeed) also offers foundry services for different companies. According to Yole Développement's estimate in our latest GaN RF

Devices Market: Applications, Players, Technology, and Substrates 2016 - 2022 report, Cree (Wolfspeed) ranks #2 in the GaN RF market, behind Sumitomo Electric Device Innovations (SEDI).

Meanwhile, Infineon just released its first GaN HEMT in 2015 (using the foundry services of Cree (Wolfspeed)), so the company has some ground to make up in the GaN RF business. Infineon seems up to the challenge, though; in an official press release, Infineon's CEO said, "We also want to become number one in RF power". Today, Infineon is among the top three Si LDMOS players. As part of the Si LDMOS market, especially the wireless segment which is gradually being taken over by GaN, Infineon's acquisition of Cree (Wolfspeed) will allow the company to leverage Wolfspeed's GaN-on-SiC RF expertise and reap the full benefits of a rapidly growing market. GaN-on-SiC technology will also complement the GaN-on-Si technology that Infineon is developing internally, giving the German company a strategic advantage in the GaN RF business.

This acquisition can be seen as the first shot fired in the "Battle for the GaN RF Business". The competition is expected to intensify amongst different players, including early players like SEDI and Qorvo; traditional RF power players such as Infineon (+ Wolfspeed), NXP (ex-Freescale), and Ampleon (ex-NXP; entered the GaN RF market in 2012 and 2016, respectively); and also MACOM, which is focusing on GaN-on-Si RF technology.

Along with the development of 5G and other RF power markets, it is still too early to forecast the victor in the GaN RF market's clash of the titans. One thing is for sure, though - over the next 5 - 10 years, the fight will be fierce.



(Source: GaN RF Devices Market: Applications, Players, Technology, and Substrates 2016 - 2022 report, Yole Développement, June 2016)

[Read more]

RF high-power semiconductor market for wireless infrastructure flattening out in 2016 despite overall market exceeding $1.5bn in 2015

Semiconductor Today

Spending on RF high-power semiconductors for the wireless infrastructure markets has flattened out this year, despite the fact that the overall market hit well over $1.5bn in 2015, according to ABI Research's report 'RF Power Semiconductors'. While certain market and sub-market segments are showing moderate growth, it is gallium nitride (GaN) that is capturing meaningful market share in RF high-power semiconductors, especially in wireless infrastructure, the report notes.

"GaN is increasing its market share in 2016, and we believe it will be a significant force by 2021," says research director Lance Wilson. "This now mainstream technology bridges the gap between two older technologies, exhibiting the high-frequency performance of gallium arsenide and power handling capabilities of silicon LDMOS."

Outside of wireless infrastructure in the RF high-power semiconductor business, defense-oriented market segments show the strongest performance. Despite the poor press for defense-oriented electronic hardware, the actual performance in 2015 was better than originally thought for some sub-segments. In total, these defense-oriented segments will be a significant market and one to keep an eye in future, Wilson believes.

[Read more]

EPC and ASD partner to speed customer designs from conception to manufacturing for eGaN-based wireless power charging applications

Semiconductor Today

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA - which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power

management applications - has joined forces with Hong-Kong-based ASD Technology Ltd, which delivers solutions for applications using eGaN technology.

EPC develops technology for displacing incumbent MOSFETs with eGaN FET and ICs that offer significant advantages in end-applications such as DC-DC converters, wireless power transfer, envelope tracking, RF transmission, power inverters, remote sensing technology and Class-D audio amplifiers.

Focused on imaging electronic components, ASD has over 14 years of experience in providing comprehensive customer solutions, from concept development to product manufacturing. The firm offers design and manufacturing services to those seeking products for shipments worldwide to customers in global markets including the USA, Europe and Greater China.

“Delivering innovative solutions while reducing time to market has been a challenge for many customers, especially when new technologies are involved,” says ASD's CEO Patrick Lee. “The potential of the gallium nitride technology will lead the next uptake of the semiconductor industry, while customers also look for effective solutions from product conception to development and to manufacturing,” he believes. “We are very excited to be able to partner with EPC by integrating its state-of-the-art eGaN technology with sophisticated designs for our customers who engage us to innovate hand-in-hand from conception to implementation,” he adds.

“We have been looking for business partners who have extensive, proven system design experience from conception to implementation by supporting the ever-growing market demand for eGaN technology,” says EPC's CEO & co-founder Alex Lidow. “In quarters ahead, we look forward to EPC and ASD's value-added partnership, which can support customers in their eGaN-based wireless charging designs and other applications while expanding our joint GaN business development worldwide,” he adds. “We can see the markets for GaN-based products have been growing fast, and GaN-based applications are expected to displace MOSFET-based applications going forward.”
Read more

Plextek RFI unveils phased-array GaN MMIC reference design

Semiconductor Today

Plextek RFI Ltd of Cambridge, UK, which designs and develops RFICs, MMICs and microwave/millimeter-wave modules, has announced a new reference design for a gallium nitride (GaN) power amplifier (PA) monolithic microwave integrated circuit (MMIC) for use in X-band active phased-array radar applications.

“Active phased arrays require numerous PAs, which need to have high efficiency, and to have a small size and relatively low cost,” notes CEO Liam Devlin. “Our new design has a die size of only 1.5mm x 2mm, which means around 2300 PAs can be fabricated on a single 4-inch (100mm)-diameter wafer. This makes the cost very competitive compared with other commercially available MMICs offering this level of RF output power.”

The X-band GaN PA MMIC covers frequencies of 9.0–11.5GHz and delivers 7W (+38.5dBm) of RF output power from a +29dBm input, with a power-added efficiency (PAE) of 42%. This means that it can be driven by readily available gallium arsenide (GaAs) parts when used as the output PA stage.

Plextek RFI designed the MMIC using Keysight ADS 2015 electronic design automation (EDA) software, and it was manufactured by United Monolithic Semiconductors (UMS) using its GH25 0.25μm-gate-length GaN-on-SiC foundry process.

“As the IC is designed and manufactured in Europe, it will have the added advantage of not being subject to US export control,” notes Devlin.
Read more

Peregrine unveils fastest GaN FET driver
Semiconductor Today

Peregrine Semiconductor Corp of San Diego, CA, USA – a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) – has launched what it claims is the fastest gallium nitride (GaN) field-effect transistor (FET) driver.

Built on Peregrine's UltraCMOS technology, the PE29100 GaN driver is targeted at enabling design engineers to extract the full performance and speed advantages from GaN transistors. Designed to drive the gates of a high-side and a low-side GaN FET in a switching configuration, the PE29100 delivers what are claimed to be the industry's fastest switching speeds, shortest propagation delays and lowest rise and fall times to AC-DC converters, DC-DC converters, class D audio amplifiers and wireless charging applications.

Peregrine notes that, in the power conversion market, GaN-based FETs are displacing silicon-based metal–oxide–semiconductor field-effect transistors (MOSFETs), as they operate much faster and have higher switching speeds in the smallest possible volume. GaN promises to dramatically reduce the size and weight of any power supply. To reach their performance potential, GaN transistors need an optimized FET driver that must charge and discharge gate capacitance as fast as possible and must have very low propagation delay to allow fast signals. It also must avoid 'shoot through' by not turning on high-side and low-side FETs at the same time. The PE29100 is designed specifically for this purpose.

"Our enhancement-mode GaN (eGaN) transistors deliver a whole new spectrum of performance compared to MOSFETs," claims Alex Lidow Ph.D., CEO & co-founder of Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes eGaN power FETs for power management applications. "GaN FET drivers like Peregrine's UltraCMOS PE29100 enable design engineers to unlock the true potential of eGaN FET technology," he adds. "The availability of the PE29100 further enhances our ability to deliver the best possible solution into the power conversion market where size, efficiency and simple design are critical."

As the driving force behind the PE29100's speed, Peregrine's UltraCMOS technology platform enables integrated circuits to operate at much faster speeds than conventional CMOS technologies. The speed of Peregrine's new GaN FET driver results in much smaller power converters, offering the design engineer increased power density.

"Design engineers are increasingly using GaN transistors for applications where higher switching frequency and high power is required," says Mark Moffat, director of Peregrine's power management product line. "However, the currently available gate drivers and controllers do not support the full potential of GaN," he adds. "With the enabling power of UltraCMOS technology, the PE29100 achieves the industry's fastest switching speeds at frequencies higher than competing products."

Manufactured on a truly insulating substrate, UltraCMOS technology has no bulk or well junctions, and therefore has low parasitics. It also has low on-resistance for improved efficiency and low off-capacitance at higher operating frequency.

The PE29100 is a half-bridge GaN FET driver with internal dead-time control. The high-speed driver operates at switching frequencies up to 33MHz and handles voltages up to 80V. It delivers a short propagation delay of 8ns, and has a rise time of 2.5ns and fall time of 1.8ns when driving a 1000pF load and 1ns rise and fall times with 100pF load. The PE29100 has a one-pin, single-phase input mode, and an output source current of 2A and an output sink current of 4A.

Volume-production parts, samples and evaluation kits for the PE29100 are available now. Offered as a 2mm x 1.6mm flip-chip die, pricing for the PE29100 is $1.80 each for 1000-unit orders.
Read more

Fairview launches portfolio of GaN solid-state power amplifiers offering high power and gain across up to 7.5GHz

Semiconductor Today

Fairview Microwave Inc of Allen, TX, USA, which supplies on-demand microwave and RF components, has launched a new line of gallium nitride (GaN) solid-state amplifiers, offering designers what is claimed to be a unique solution of off-the-shelf, in-stock components that typically require months of lead time to acquire.

The rugged connectorized amplifier designs have high output load impedance, offering easier impedance matching over wider bandwidths using lower-loss components. The high thermal conductivity of GaN helps to dissipate heat more effectively, resulting in amplifier designs with much higher output power levels over broadband and narrowband frequencies. Common applications include commercial and military radar, jamming systems, medical imaging, communications, and electronic warfare.

Fairview's newest range of GaN RF amplifiers includes models with very high gain levels from 43dB to 60dB across mostly broad frequency bands ranging from 30MHz to 7.5GHz. Saturated output power levels range from 10W to 100W with up to 35% power-added efficiency (PAE). All of the high-power GaN amplifiers have single voltage supplies that are internally regulated. The 50 ohm input/output-matched designs are adaptable to a range of power and modulation requirements. The GaN solid-state power amplifiers also show harmonic response of -15dBc to -20dBc, under worst-case conditions. The new GaN amplifiers are designed to withstand environmental conditions such as humidity, altitude, shock and vibration. Some models are also equipped with integrated heat-sinks and cooling fans. Most designs are EAR99.

Read more

US Army grants Raytheon $1.1m to develop GaN-based front-ends for Next Generation Radar program

Semiconductor Today

The US Army Research Laboratory (ARL) has entered into a collaborative alliance via a $1.1m grant with Raytheon Company of Waltham, MA, USA to develop Scalable, Agile, Multimode, Front End Technology (SAMFET) for the Army's Next Generation Radar (NGR) program.

As part of a 24-month cooperative research agreement within ARL's Advanced RF Technologies Program, Raytheon will help to create and demonstrate modular building blocks that can easily integrate with next-generation radar systems.

NGR will enhance radar-reliant Air Defense and Counter Rocket and Mortar system performance, particularly in portable configurations such as hand-held, vehicle-mounted and airborne deployments. Raytheon will work with ARL to explore new approaches for the design and fabrication of modular components that will fit into NGR's open architecture, offering processing flexibility, agility and efficiency across radar bands.

“Raytheon's storied track record of innovation in applied radar technologies uniquely positions us to play a critical role in the development of the US Army's Next Generation Radar system,” reckons Colin Whelan, Raytheon's vice president of Advanced Technology. “With the Army Research Lab, our team will leverage Raytheon's deep investment and unmatched expertise as a pioneer in gallium nitride technology to dramatically improve radar capabilities.”

Raytheon's efforts to mature GaN for military production earned it the highest OSD (Office of the Secretary of Defense)-rated manufacturing readiness level of any organization in the defense industry. As a semiconductor material that can efficiently amplify high-power signals at microwave frequencies, GaN enables radars to operate up to five times more powerfully than they would with older semiconductor technology, it is reckoned, and without overheating.

Raytheon's GaN components generate RF at a third of the cost per watt compared to gallium arsenide (GaAs) alternatives, deliver higher power density and efficiency, and have demonstrated mean time between failures (MTBF) of 100 million hours.
Read more

Airbus Defence and Space awarded third contract in 18 months for GaN-based satellite amplifiers
Semiconductor Today

Airbus Defence and Space, which is reckoned to be the world's second largest space company (and a division of Airbus Group, Europe's top defence and space enterprise), has won its third contract in 18 months for its latest gallium nitride (GaN)-based solid-state power amplifiers (SSPAs), bringing the total ordered to more than 350.

In satellites, SSPAs are used to amplify the signals from the ground ready to be broadcast down to Earth. Satellites must take a signal, clean it, and amplify it more than a billion times before re-broadcasting it so it can be picked up by small satellite dishes on Earth.

Investment leading to the development of the latest GaN SSPA by Airbus Defence and Space was carried out as part of the European Space Agency's Advanced Research in Telecommunications Systems program, which is supported by the UK Space Agency.

Designed for use in both communications and navigation satellites, the GaN-based SSPAs are claimed to have superior performance and 50% less mass per Watt of RF output compared with previous generations of SSPA technology. In particular, the flight L-band SSPAs deliver RF power of 50–100W and are 15% more efficient than previous models. In laboratory demonstrations, the latest GaN SSPAs have produced RF power in excess of 200W in L-, S- and C-bands.

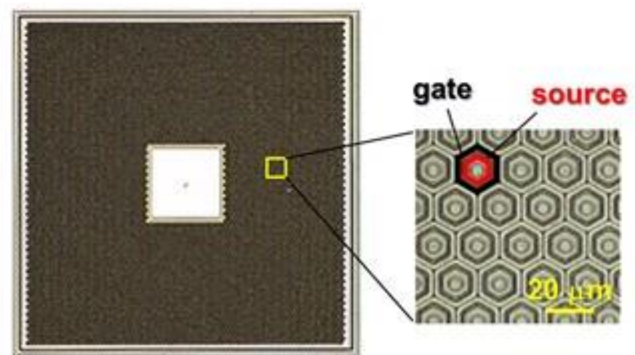
"These significant orders prove that the R&D investments we have made over the last few years are paying off," says Charlie Bloomfield, Airbus Defence and Space's head of Communication Products UK. "Our experts are now looking at how we can further improve our design to give customers more power for less mass."
Read more

Toyoda Gosei develops high-voltage GaN power semiconductor device for large-current operation
Semiconductor Today

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has developed what is claimed to be the first 1.2kV-class power semiconductor device chip capable of large-current operation exceeding 20A.

Using gallium nitride (GaN) crystal growth technology developed since 1986 for the production of blue LEDs, Toyoda Gosei began research on GaN-based power semiconductor devices in 2010. Previously, low-loss 1.2kV-class MOSFETs were fabricated on GaN substrates and then empirically tested (achieving 1.8mΩcm2, when current is passed via a structure in which current flow is perpendicular to the substrate and gate trenches).

Toyoda Gosei says that it has now established wiring technology for parallel operation of elements, passing a current exceeding 20A in a vertical GaN transistor with a 1.5mm x 1.5mm chip size (the first time that this has been achieved, reckons the firm).



Picture: Toyoda Gosei's new MOSFET chip (photomicrograph).

The technology can be applied to circuits for power controllers in hybrid vehicles that handle large amounts of power, and to power converters such as those in solar power generation,

promising to contribute significantly to making these devices more compact and efficient.

Toyoda Gosei says that it will continue research to increase the current-handling capacity and test reliability, with the aim of developing commercial applications by 2018-2020 in collaboration with semiconductor and electronics manufacturers.

A report on this technology was presented as a 'late news' paper at the 28th IEEE International Symposium on Power Semiconductor Devices and ICs (ISPSD) in Prague, Czech Republic (12-16 June).
Read more

Imperial College London wins GaN Systems Geoff Haynes Future Power Challenge
Semiconductor Today

At a ceremony at the UK Engineering and Physical Sciences Research Council (EPSRC) National Centre for Power Electronics Annual Conference 2016 in Nottingham, UK, a post-graduate team from Imperial College London received the £2000 prize for winning the first annual GaN Systems Geoff Haynes Future Power Challenge.

Sponsored by GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications), the competition was open to all UK power electronics postgraduate students who submitted research papers or posters that contributed to accelerating the use of GaN transistors in future power conversion or control applications.

Professor Mark Johnson of The University of Nottingham and professor Barrie Mecrow of Newcastle University judged the competition at the annual summer school event organized by the PhD students of the 10 universities that form the EPSRC National Centre for Power Electronics. The summer school is a student-led event intended to increase communication and co-operation between the research teams and to provide an opportunity for the students to meet with prospective employers and research partners. Entries covered subjects as diverse as the design of a novel compact motor with embedded filter windings, through a reliability study and optimized PWM (pulse width modulation) control strategy for an A-NPC (active neutral-point-clamped) converter.

Picture: Left to right: Mark Johnson, Paul Mitcheson, Sam Aldhaher, Dave Yates, Juan Manuel Arteaga Saenz, George Khelis, Geoff Haynes and Girvan Patterson at the GaN Systems Geoff Haynes Future Power Challenge award ceremony.

Ph.D. students George Kkelis and Juan Arteaga together with research assistants Sam Aldhaher and David Yates of Imperial College London's Department of Electrical and Electronic Engineering, supervised by Dr Paul Mitcheson, first presented their work at the IEEE Wireless Power Transfer Conference in May. The team developed two inverter prototypes, each based on a Class EF topology using GaN Systems' GS66504B switches. Their new design maintains zero-voltage switching and delivers a constant-output AC current regardless of the load resistance value. The design allows a Class E or Class EF inverter to operate efficiently for any load. This was shown to significantly relax the requirement for accurate alignment of transmit and receive coils in a wireless power application.

The annual GaN Systems Geoff Haynes Future Power Challenge was established in recognition of Geoff Haynes' critical role in establishing GaN Systems, and championing the use of gallium nitride for power applications. Geoff Haynes retired last year as vice president of GaN Systems but continues to drive the application of the technology by engaging with the research activities of the engineers of the future. Presenting the award, GaN Systems' president & co-founder Girvan Patterson underlined the importance of supporting the research initiatives

between industry and academia to accelerate the adoption of disruptive technologies and inspire a new generation of engineers.
Read more

EPC launches wireless multi-mode demo system compatible with all wireless power charging standards
Semiconductor Today

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has announced the availability of a complete demonstration multi-mode wireless power charging kit.

EPC says that the superior characteristics of eGaN FETs and ICs enable a lower-cost single transmit amplifier solution that can wirelessly charge devices regardless of the standard used in the receiving device. The purpose of the EPC9121 demonstration system is hence to simplify the evaluation process of using eGaN FETs and ICs for highly efficient multi-mode wireless power charging systems that can cut across any standard used in the receiving units.

Wireless power has arrived, but along with its emergence are two industry standards to which end-products are being built – the Wireless Power Consortium (Qi) standard and the AirFuel Alliance standard – based on two different technologies for accomplishing wireless power charging. The Qi standard, based on inductive coupling technology, uses a low-frequency (<300kHz) approach, whereas the AirFuel standard uses a magnetic resonant technology and has both low-frequency (100kHz through 315kHz) and high-frequency (6.78MHz) requirements.

There is therefore a need for a multi-mode solution, with a single transmitter that can power a receiver built using either standard. The EPC9121 is claimed to be the first implementation of a single-amplifier multi-mode solution. GaN enables high efficiency for both low- and high-frequency modes, plus the solution also saves space and lowers cost, adds the firm.

The 10W EPC9121 demonstration system has four components:

- A multi-mode-capable EPC9511 source (transmitter or power amplifier) board specifically designed to be compatible with all the wireless standards. It can operate at either high or low frequency.
- A multi-mode source coil (transmit coil) compatible with both the AirFuel Class 2 standard and Qi (A6)/PMA standards.
- An AirFuel-compatible Category 3 AirFuel device coil (receive coil) with rectifier and DC output.
- A Wireless Power Consortium (Qi)- and Power Matters Alliance (now AirFuel)-compatible device coil (receive coil) with rectifier and DC output.

The EPC9121 demonstration kit hence contains all the components needed to demonstrate and evaluate multi-standard wireless power charging.

The EPC9121 wireless power charging demonstration system is priced at $907.20 and is available via distributor Digi-Key.
Read more

Comtech awarded $11.8m order for solid-state power amplifiers for in-flight connectivity
Semiconductor Today

Comtech Telecommunications Corp says that its subsidiary Comtech Xicom Technology Inc of Santa Clara, CA, USA - a part of Comtech's Commercial Solutions segment that makes tube-based and solid-state power amplifiers (SSPAs) for military and commercial satellite communication (SATCOM) uplink applications - has received an $11.8m follow-on production order for solid-state power amplifiers (SSPAs) to be used in an airborne in-flight connectivity application.

“These [gallium nitride-based] products will enable high-speed satellite connectivity for airlines based in the Americas, Europe, and Asia,” says Comtech Telecommunications Corp's president & CEO Dr Stanton Sloane. “Comtech continues to increase its presence in this market and we look forward to a long period of growth as we transition to higher-volume production to

meet the worldwide demand for continuous connectivity."

Comtech Xicom Technology's SSPA product range encompasses power levels from 8W to 3kW, with frequency coverage in sub-bands within the 2-45GHz spectrum. Amplifiers are available for fixed and ground-based, ship-board and airborne mobile applications.
Read more

EpiGaN's production facility certified as compliant to ISO9001:2015
Semiconductor Today

EpiGaN nv of Hasselt, near Antwerp, Belgium, which supplies commercial-grade 150mm- and 200mm-diameter gallium nitride on silicon (GaN-on-Si) epitaxial wafers, says that on 7 June it received official notification from the International Organization for Standardization that its production facility is now fully certified to the quality management system ISO9001:2015.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nanoelectronics research center Imec of Leuven, Belgium. The founders jointly developed GaN-on-Si technology at Imec, part of which has been licensed to EpiGaN.

In 2011, EpiGaN was joined by start-up investment firms Robert Bosch Venture Capital, Capricorn CleanTech Fund and LRM to enable the installation of its wafer production facility. In June, Beijing/Brussels-based Euro-Asia private equity fund A Capital joined the initial investors to fund expansion of EpiGaN's sales and support base to Asian markets. EpiGaN is now undertaking volume production and wafer characterization at its Research Campus Hasselt in the Eindhoven-Leuven-Aachen high-tech triangle. In January, the firm signed a global representation agreement for its 150mm and 200mm GaN-on-Si power semiconductor product solutions with silicon substrate maker SunEdison Semiconductor of St. Peters, MO, USA.

EpiGaN now delivers GaN-on-Si and GaN-on-SiC epiwafers to device makers worldwide for power switching, RF millimeter-wave power and sensor applications, specifically shipping epitaxial (Al,Ga)N heterostructures grown on silicon substrates up to 200mm in diameter. In particular, EpiGaN is producing GaN structures on Si substrates up to 200mm diameter at the 600V node to enable its customers to position themselves in rapidly growing market segments.

ISO9001:2015 certification "reassures our commercial customers and institutional program partners on a global scale of our unwavering commitment to the professional quality management of our wafer deliveries," says Germain. "It proves that EpiGaN is a well-established entity in its field," she adds. "There are not many organizations that are certified to the new updated version of the standard."

The full range of quality management measures according to ISO9001 has been in place internally at EpiGaN's Hasselt campus since 2012. "The EpiGaN quality management system has grown up together with the company: all the prescribed standardization procedures had been installed, documented and maintained according to the ISO9001 requirements," notes Domenica Visalli Ph.D., GaN project engineer & quality manager. "The formal application procedure for ISO9001:2015 was launched in January 2016 and we received the final notification within the usual time frame on 7 June."
Read more

OTHER

Riber's first-half revenue rises 23% year-on-year, driven by MBE system sales
Semiconductor Today

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has reported a 23% rise in revenue from €5.7m in first-half 2015 to €7m in first-half 2016, comprising 56% from Asia (up from 43%), 24%

from the USA (up from 6%) and 20% from Europe (down from 40%).

MBE systems sales were solid during first-half 2016. The number of systems sold has fallen from four research machines in first-half 2015 to two machines, but one of these was a production machine, so revenue rose by 29% from €2.8m to €3.6m.

Sales of services & accessories (€2.4m, up 14% from €2.1m) and cells & sources (€1m, up 25% from €0.8m) are up 17% collectively on first-half 2015. This growth reflects Riber's improved commercial performance in its long-standing markets, combined with the development of its position in the USA following its acquisition of MBE Control Solutions of Santa Barbara, CA, USA in March 2015.

Order have risen by 40% from €6.3m in first-half 2015 to €8.8m in second-half 2016. Specifically, MBE system orders (for delivery in 2016) have risen by 33% from €4.5m to €6m, comprising five machines (including one production machine). Orders for services & accessories have grown strongly by 90% from €1.1m to €2.1m. Orders for cells & sources are level at €0.7m.

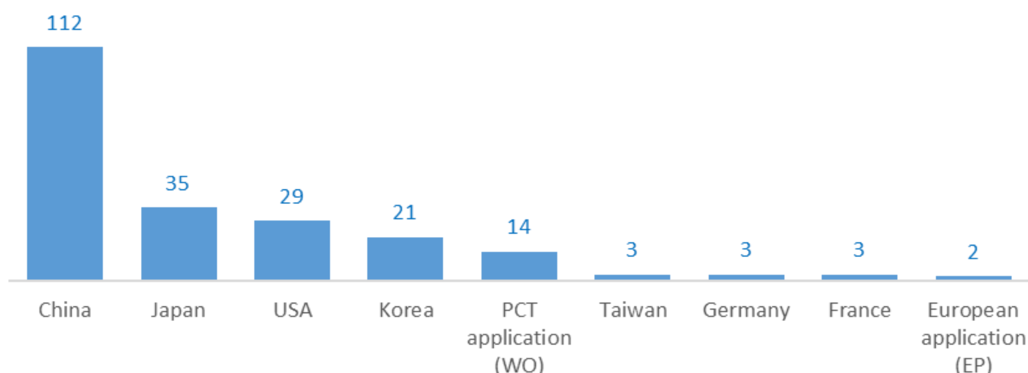
Riber says that, against a backdrop of moderate growth for the MBE market, the upturn in commercial business has been driven by the signing of several new contracts and supported by development of the range of services and accessories offered.

Based on these factors, Riber confirms its full-year 2016 revenue target of at least 30% growth on 2015.
[Read more]

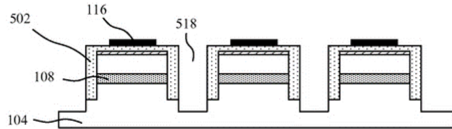
PATENT APPLICATION

More than **180 new patented inventions** were published between **2016-07-02** and **2016-08-01**.

<table>
<tr><th>Patent Applicants</th><th>Number of new patent applications</th></tr>
<tr><td>Toshiba</td><td>9</td></tr>
<tr><td>Jin An Optoelectronics</td><td>7</td></tr>
<tr><td>Xiamen Changelight</td><td>7</td></tr>
<tr><td>Focus Lightings Technology</td><td>7</td></tr>
<tr><td>Xidian University</td><td>7</td></tr>
<tr><td>Nagoya University</td><td>5</td></tr>
<tr><td>Lattice Power</td><td>4</td></tr>
<tr><td colspan="2">Other patent applicants: Sun Yat Sen University, Enraytek Optoelectronics, LG Innotek, Mitsubishi Electric, Ulvac, No 55 Institute Of China Electronics Science & Technology, Institute Of Semiconductors, Xiangneng Hualei Optoelectronic Corppration, Sanan Optoelectronics, Shanghai Simgui Technology, Korea Institute Of Science & Technology, Fujitsu, Nthdegree Technologies Worldwide, Lg Electronics, Toyota Motor, Cnrs - Centre National Recherche Scientifique, Boe Technology, Shanghai University, China Bright Photoelectricity, Korea Advanced Nano Fab Center, Sumitomo Electric Industries, 13th Research Institute Of China Electronics Technology, Korea Photonics Technology Institute, Shanghai Institute Of Technical Physics Chinese Academy Of Sciences, Anhui Sanan Optoelectronics Technology, Taiyuan University Of Technology, Hebei University Of Technology, Seoul Viosys, Mitsubishi Chemical, Shimadzu, Furukawa, Sixpoint Materials, Seoul Semiconductor, St Microelectronics, Fudan University, Epi Photoelectric Material, Guangxi Normal University, Murata Manufacturing, Rohm, Panasonic, Rayvio, Bolb, Unist, Toyota Central Research & Development Labs, Ricoh, Dowa Electronics Materials, Hubei University Of Technology, Shijiazhuang University, China Three Gorges University, China Electronic Technology, Byd, Stanley Electric, Toyoda Gosei, National Chiao Tung University, Macronix International, Iljin Led, Research Cooperation Foundation Of Yeungnam University, Kaga Electronics, Fuji Electric, Marubun, Tokyo Ohka Kogyo, Toshiba Machine, Riken, University Of Electronic Science & Technology Of China, Shineon Technology, Zhejiang University, Taiwan Semiconductor Manufacturing, Hongik University Industry Academia Cooperation Foundation, Korea Electric Power, University Malaya, Swegan, Wuhu Ceprei Information Industry Technology Research Institute, Chunghsin Technology, Hangzhou Silan Azure, Silan, Tianjin San An Optoelectronics, Soko Kagaku, Shandong Tide China Light Photoelectron, Zhang Xijuan, Tsinghua University, Nanjing University Of Posts & Telecommunications, Zheng Keyong, University National Central, Apple, Bae Systems, Yale University, Disco, Eugenetech Materials, Suzhou Institute Of Nano Technology & Nano Bionics Chinese Academy Of, Kyungpook National University Industry Academic Cooperation Foundation …</td></tr>
</table>

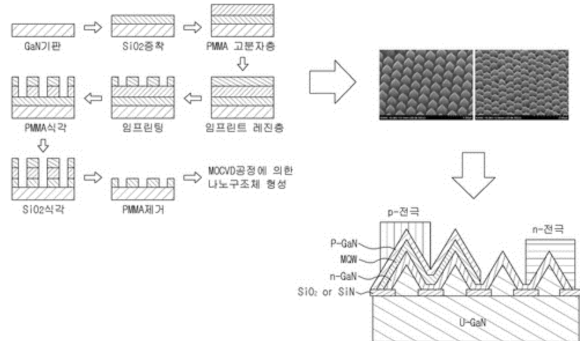


LED structures for reduced non-radiative sidewall recombination
Publ. Nb: US2016197232, WO2016111789
Patent Applicant: Apple (US)



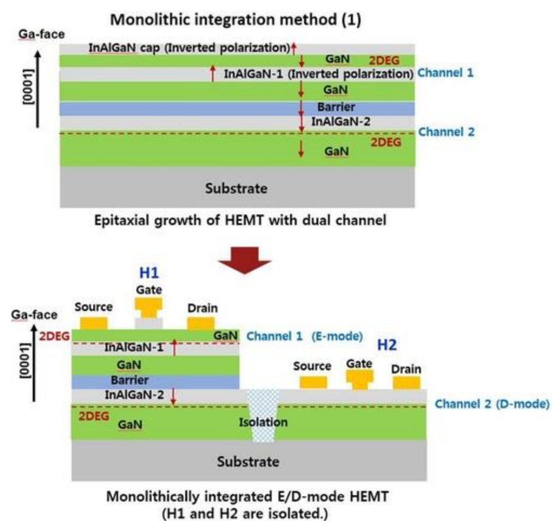
LED structures are disclosed to reduce non-radiative sidewall recombination along sidewalls of vertical LEDs including p-n diode sidewalls that span a top current spreading layer, bottom current spreading layer, and active layer between the top current spreading layer and bottom current spreading layer.
Read more

Manufacturing method of white led using nano-structure and white led thereby
Publ. Nb: KR101653530
Patent Applicant: Korea Advanced Nano Fab Center (Korea)



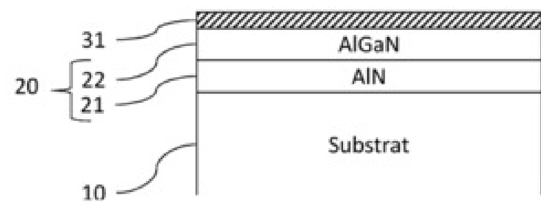
This invention fluorescent body application process is unnecessary and (phosphor-free) about the white luminous element as the thing, to on the GaN board mask layer the low of forming plaque turning does a first phase and a minute description mask layer and some territory of the minute description GaN board at the time of exposure as for height nano pattern the low of forming grows to second phase and minute description nano pattern about under confronting to on the minute description GaN board GaN as selectively and in order for each other different crystal plane to be exposed, the GaN nano structural body at the time of growth as for height to on 3rd phase and the minute description GaN nano structural body active layer as for under including nano layer of structure at the time of growth as for height fourth phaseAbout under including although becomes accomplished, the minute description active layer according to the crystal plane of the minute description GaN nano structural body content of the effective composition manufacturing method of the white luminous element which used the nano structural body the control of dollar luminous wavelength thing possibly with feature and by him does the white luminous element which used the nano structural body which is manufactured with technical essential. Depends hereupon, the crystal plane which active layer is exposed about under controlling content of each effective composition about under controlling will be able to control the luminous wavelength of active layer an advantage in blood growth process becomes, in the single element blue and yellow radiation about under inducing will be able to embody the white radiation there is.
Read more

Monolithic multi channel semiconductor power device and manufacturing method thereof
Publ. Nb: KR20160083256
Patent Applicant: Korea Advanced Nano Fab Center (Korea)



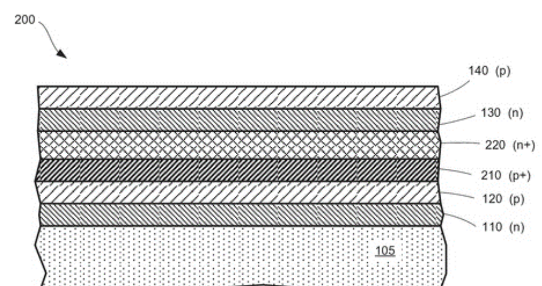
Following this invention as for glow style multi Channel power semiconductor device borad. The 1st HEMT structural body which is formed to on the minute description borad. And the 2nd HEMT structural body which is formed to on the minute description borad. Includes, and the minute description first and the second HEMT structural body 4 won origin Nitride semiconductor layer included. With the minute description 1st HEMT structural body the minute description 2nd HEMT structural body separates to the location which from identical board place differed with horizontal direction, with normal to be formed to each other wrong floor, by a barrier layer each other electrically. If the minute description 1st HEMT structural body sequential to on minute description barrier layer the gallium, epitaxial includes the first GaN buffer layer which grew, a first InAlGaN layer and a first GaN cap layer, and minute description first InAlGaN layer, In and the Aluminum are reversed, with having the creation expense of prescribed, in order for the compressive stress about under operating polarization to face an upper direction to minute description first InAlGaN layer, accomplished a E-mode (Depletion mode) operation. If the minute description 2nd HEMT structural body sequential to on the minute description board the gallium, epitaxial to include the second GaN buffer layer which grew and a second InAlGaN layer, and In and the Aluminum with having the creation expense of prescribed, tensile stress about under operating between minute description second GaN buffer layer and minute description second InAlGaN layer accomplished the D-mode (Depletion mode) operation 2DEG to be formed to the interface.
Read more

Production of a semiconductor support based on group III nitrides
Publ. Nb: FR3031834, FR3031833, WO2016116715, WO2016116713
Patent Applicant: CNRS – French National Center for Scientific Research (France)



The invention relates to a method for producing a support for the production of a semiconductor structure based on group III nitrides, characterised in that the method comprises the steps of: formation (100) of a buffer layer (20) on a substrate (10), said buffer layer comprising an upper surface layer based on group III nitrides; and deposition (200) of a crystalline layer (30) on the buffer layer, said crystalline layer being deposited from silicon atoms so as to cover the entire surface of the upper layer based on group III nitrides. The invention also relates to a support produced by the method, to a semiconductor structure based on the support, and to the method for the production thereof.
Read more

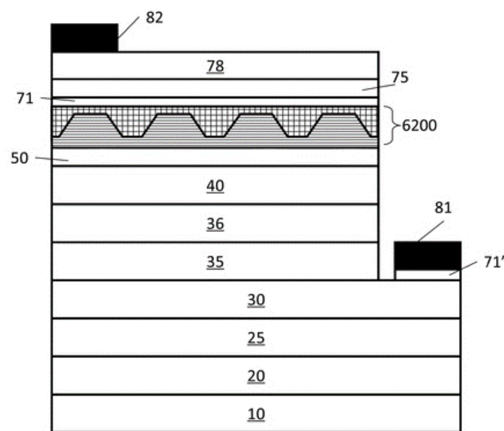
Method to make buried, highly conductive p-type III-nitride layers
Publ. Nb: US2016197151
Patent Applicant: Yale University (US)



A conductive, porous gallium-nitride layer can be formed as an active layer in a multilayer structure adjacent to one or more p-type III-nitride layers, which may be buried in a multilayer stack of an integrated device. During

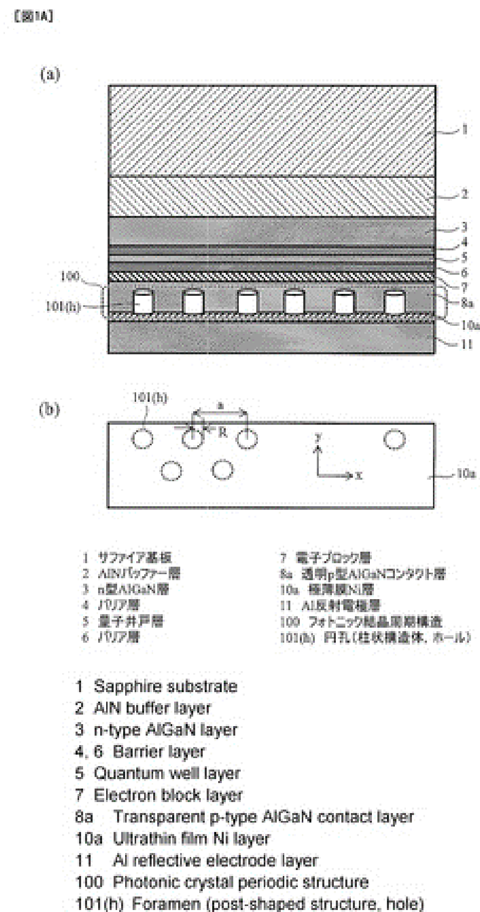
an annealing process, dopant-bound atomic species in the p-type layers that might otherwise neutralize the dopants may dissociate and out-diffuse from the device through the porous layer. The release and removal of the neutralizing species may reduce layer resistance and improve device performance.
Read more

Ultraviolet light-emitting device with lateral tunnel junctions for hole injection
Publ. Nb: US9401455
Patent Applicant: Bolb (US)



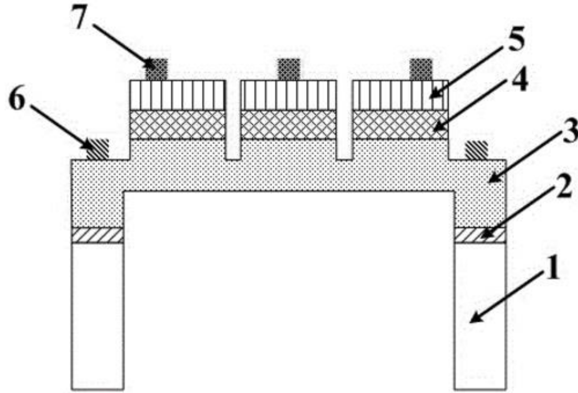
An ultraviolet light-emitting device with a lateral tunnel junction for hole injection includes a PN tunnel junction structure formed on a p-type layer at one side of an active region. The PN tunnel junction structure includes a p-type structure containing a plurality of alternately laminated p-AlGaN barrier layers and p-AlGaN well layers, and an n-type structure containing a plurality of alternately laminated n-AlGaN barrier layers and n-AlInGaN well layers, with the p-type structure facing the p-type layer. Both the p-type structure and the n-type structure have a plurality of projections extending from their surface. The n-type structure is formed on the p-type structure with the projections of the n-type structure fully filling void portions of the p-type structure.
Read more

Deep ultraviolet led and method for manufacturing same
Publ. Nb: WO2016113935
Patent Applicant: Marubun (Japan), Toshiba (Japan), Riken (Japan), Ulvac (Japan)



Provided is a deep ultraviolet LED having a design wavelength of λ, characterized by having, in order starting at the opposite side from the substrate, an Al reflecting electrode layer, an ultrathin film metal layer, and a transparent p-type AlGaN contact layer, and having a photonic crystal periodic structure within a range in the thickness direction of the transparent p-type AlGaN contact layer, the photonic crystal periodic structure having a photonic bandgap.
Read more

Suspended p-n junction quantum well devices monolithically integrated system and method for its preparation and the optical waveguide
Publ. Nb: CN105742383
Patent Applicant: Nanjing University of Posts & Telecommunications (China)



The present invention discloses a floating p?N junction and a quantum well devices and methods of making optical waveguide monolithically integrated system, the integrated system includes a silicon substrate layer, an epitaxial buffer layer disposed on the silicon substrate layer, the epitaxial buffer layer disposed on the plurality of p?N junction quantum well devices, p?The quantum well devices are provided between the n junction isolation trenches, two adjacent p?Connected to the light waveguide through quantum-n. The present invention can realize multi-space and planar photonic information transmission system for signal detection channel plurality of functions, of visible light photons plane performs dual-channel and p-space optical signal transmission information perceived doubling the probe, while being capable of independently sensing space optical signal, receives the detection of a three-way to the optical signal is achieved.
[Read more](#)

2405 route des Dolines, CS 10065
06902 Sophia Antipolis, France
contact@knowmade.fr
www.knowmade.com