GANEX

Newsletter No. 78

July 2019

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

KnowMade

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 competitive environment, follow technology trends, and find out opportunities and threats in terms of technology and patents. **Knowmade** operates in the following industrial sectors: Compound Semiconductors, Power Electronics, RF & Microwave Technologies, LED/OLED Lighting & Display, Photonics, Memories, MEMS & Sensors, Manufacturing & Advanced packaging, Batteries & Energy management, Biotechnology, Pharmaceuticals, Medical Devices, Medical Imaging, Agri-Food & Environment. **Knowmade**'s experts provide prior art search, patent landscape analysis, scientific literature analysis, patent valuation, IP due diligence and freedom-to-operate analysis. In parallel the company proposes litigation/licensing support, technology scouting and IP/technology watch service. **Knowmade**'s analysts combine their technical and patent expertise by using powerful analytics tools and proprietary methodologies to deliver relevant patent analyses and scientific reviews.
www.knowmade.com

METHODOLOGY

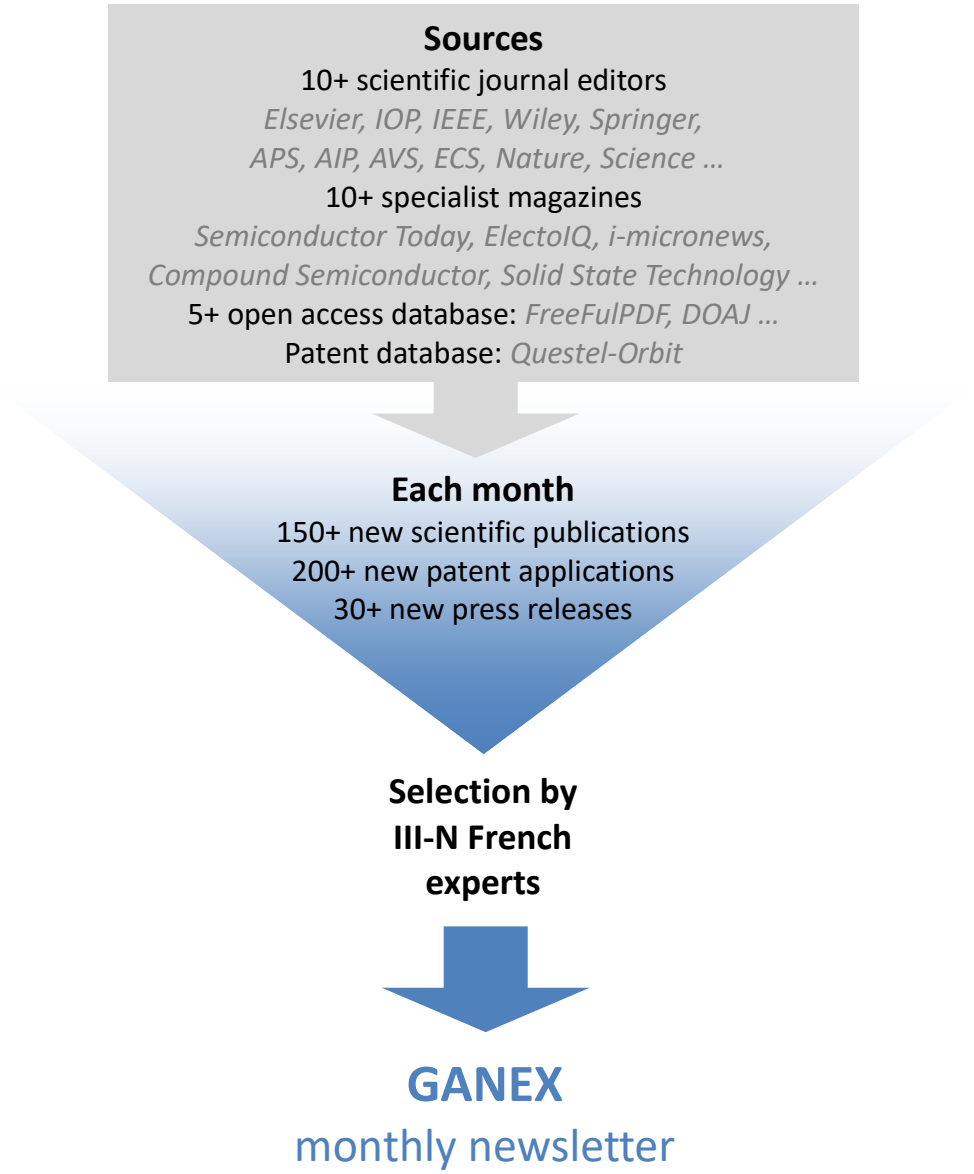


TABLE OF CONTENTS

(clickable links to chapters)

SCIENTIFIC PUBLICATIONS **4**

GROUP 1 - LEDs and Lighting 4

GROUP 2 - Laser and Coherent Light 9

GROUP 3 - Power Electronics 13

GROUP 4 - Advanced Electronics and RF 20

GROUP 5 – MEMS and Sensors 25

GROUP 6 - Photovoltaics and Energy harvesting 29

GROUP 7 - Materials, Technology and Fundamental 31

PRESS RELEASE **46**

PATENT APPLICATIONS **68**

SCIENTIFIC PUBLICATIONS

Selection of new scientific articles

GROUP 1 - LEDs and Lighting

Group leader: Benjamin Damilano (CRHEA-CNRS)

Information selected by Benjamin Damilano and Mathieu Leroux (CRHEA-CNRS)

Novel Scalable Transfer Approach for Discrete III-Nitride Devices Using Wafer-Scale Patterned h-BN/Sapphire Substrate for Pick-and-Place Applications

CNRS, UMI 2958, GT-CNRS, 2 rue Marconi, 57070 Metz, France
GT Lorraine, 2 rue Marconi, 57070 Metz, France
Institut Lafayette, 2 rue Marconi, 57070 Metz, France
Georgia Institute of Technology, School of Electrical and Computer Engineering, GT-Lorraine, 57070 Metz, France

Advanced Materials Technologies
https://doi.org/10.1002/admt.201900164

The mechanical release of III-nitride devices using h-BN is a promising approach for heterogeneous integration. Upscaling this technology for industrial level requires solutions that allow a simple pick-and-place technique of selected devices for integration while preserving device performance. An advance that satisfies both of these requirements is demonstrated in this work. It is based on a lateral control of the h-BN quality, using patterned sapphire with a SiO2 mask, to achieve localized van der Waals epitaxy of high-quality GaN based device structures. After process fabrication, the devices can be individually picked and placed on a foreign substrate without the need for a dicing step. In addition, this approach could reduce delamination of h-BN on large diameter substrates because each h-BN region is smaller, with independent device structures. Discrete InGaN LEDs on h-BN are grown and fabricated on 2 in. patterned sapphire using a SiO2 mask. A set of devices are selectively released and transferred to flexible aluminum tape. The transferred LEDs exhibit blue light emission around 435 nm. The approach presented here is scalable on any wafer size, can be applied to other types of nitride-based devices, and can be compatible with commercial pick-and-place handlers for mass production.

Ag–Pd–Cu alloy reflector to improve the opto-electrical performance and electromigration resistance of near ultraviolet GaN-based light-emitting diode

Department of Materials Science and Engineering, Korea University, Seoul, 02841, South Korea
Department of Nanophotonics, Korea University, Seoul, 02841, South Korea

Journal of Alloys and Compounds
https://doi.org/10.1016/j.jallcom.2019.06.119

We investigated the opto-electrical and electromigration properties of near ultraviolet light emitting diodes (UV-LEDs) fabricated with Ag–Pd–Cu (APC) and Ag only reflectors. It was shown that unlike Ag only sample, the APC sample revealed a smooth surface with hillocks when annealed at 600 °C. The 600 °C-annealed APC sample gave a reflectance of 84.2% at 400 nm, whereas the Ag sample had 69.0%. Both the samples exhibited ohmic behavior when annealed. The specific contact resistivity of the Ag and APC contacts annealed at 500 °C were estimated to be $2.59 \times 10{-}4$ and $1.85 \times 10{-}4$ Ωcm2, respectively. The X-ray photoemission spectroscopy Ga 2p core level results showed that for the annealed APC sample, the Ga 2p core level was shifted towards the lower binding-energies by 0.67 eV as compared to that of the as-deposited sample. Both UV-LEDs with the 500 °C-annealed Ag and APC reflectors gave the same forward voltage of 3.23 V at 20 mA. The UV-LED with the annealed APC reflector yielded 9.07% higher output at 100 mA than that with the annealed Ag reflector. The APC sample exhibited a longer median-time-to-failure (MTF) by a factor of 1.4 than the Ag sample. The activation energy for the electromigration of these samples was measured to be 0.58–0.7 eV. Electron back scatter diffraction (EBSD) and inverse pole figure (IPF) images revealed that the Ag sample was more <111>-textured than the APC sample. Based on the scanning electron microscopy, EBSD and IPF results, the better thermal

and electromigration properties of the APC sample are described and discussed.

Light-output enhancement of InGaN light emitting diodes regrown on nanoporous distributed Bragg reflector substrates

Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge, CB3 0FS, United Kingdom

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab0cfd

Utilising our novel wafer-scale electrochemical porosification approach which proceeds through the top surface by means of nanoscale vertical etching pathways, we have prepared full 2 inch wafers containing alternating solid GaN and nanoporous GaN (NP-GaN) layers that form distributed Bragg reflectors (DBRs), and have regrown InGaN-based light emitting diode (LED) heterostructures on these wafers. The NP-GaN DBR wafer is epi-ready and exhibits a peak reflectance of 95% at 420 nm prior to growth of the LED heterostructure. We observe a 1.8× enhancement in peak intensity of LED electroluminescence from processed devices, and delayed onset of efficiency droop with increased injection current.

Enhancing Light Extraction Efficiency of Vertical Emission of AlGaN Nanowire Light Emitting Diodes with Photonic Crystal

Provincial Key Laboratory of Micro-Nano Electronics and Smart System, College of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China

IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2019.2920517

AlGaN alloys have been widely used to make ultraviolet light-emitting diodes (UV-LEDs) because its energy bandgap covers 200–360 nm wavelength range. However, AlGaN shows strong transverse magnetic polarization in deep UV range, which severely prevents light extraction from top surface of UV-LEDs. In this paper, we propose a novel flip-chip AlGaN nanowire LED with top photonic crystals, for the purpose of improving light extraction efficiency (LEE) from top surface. Using three-dimensional finite-difference time domain simulation, we first investigate the LEE in vertical direction of nanowire LEDs. By carefully optimizing the size and density of nanowires, we demonstrate that nanowire structures can be designed to inhibit the emission of guided mode and promote light extraction from top surface. Based on the optimized nanowire structure, we also study the effect of top photonic crystals on the LEE of vertical emission. A high LEE up to 79.4% can be achieved by optimizing the height, spacing, and radius of top photonic crystals. Analyzing the lateral electric field distribution of AlGaN nanowire LEDs with and without top photonic crystals, we find that top photonic crystals can effectively improve the LEE of vertical emission by coupling the light trapped in epitaxial layers out of LEDs.

Modulating the layer resistivity by band-engineering to improve the current spreading for DUV LEDs

Institute of Micro-Nano Photoelectron and Electromagnetic Technology Innovation, School of Electronics and Information Engineering, Hebei University of Technology, Key Laboratory of Electronic Materials and Devices of Tianjin, 5340 Xiping Road, Beichen District, Tianjin, 300401, P. R. China
Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology

IEEE Photonics Technology Letters
https://doi.org/10.1109/LPT.2019.2920527

In this work, we propose to enhance hole injection efficiency by modulating the layer resistivity in the n-AlGaN layer for 280 nm AlGaN based deep ultraviolet light-emitting diodes (DUV LEDs). The layer resistivity for the n-AlGaN layer is controlled by generating energy barriers, which is enabled by locally engineering the energy band gap for the n-AlGaN layer, such that a thin n-AlGaN layer with high Al composition is inserted before growing the subsequent multiple quantum wells (MQWs). As a result, such inserted n-AlGaN layer is able to tune the current flow path, i.e., improving the current spreading effect in the p-type hole injection layer. The improved current spreading effect favors the promoted hole injection into the active region. We numerically and experimentally obtain the improved external quantum efficiency, the optical power and

the wall-plug efficiency, thanks to the better current spreading and the correspondingly enhanced hole injection capability.

Blue (In,Ga)N light-emitting diodes with buried n +– p + tunnel junctions by plasma-assisted molecular beam epitaxy

School of Electrical and Computer Engineering, Cornell University, Ithaca, New York 14853, United States of America
Paul-Drude-Institut für Festkörkperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany
Department of Materials Science and Engineering and Kavli Institute for Nanoscale Science, Cornell University, Ithaca, New York 14853, United States of America

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab1e78

Blue LEDs consisting of a buried n +–p + GaN tunnel junction (TJ), (In,Ga)N multiple quantum wells (MQWs) and a n +-GaN top layer are grown on Ga-polar n +-GaN bulk wafers by plasma-assisted molecular beam epitaxy. The (In,Ga)N MQWs show chemically abrupt and sharp interfaces in a wide range of compositions and are seen to have high structural and optical properties. The processed LEDs reveal clear rectifying behavior with a low contact and buried TJ resistivity. By virtue of the top n +-GaN layer with a low resistance, excellent current spreading in the LEDs is observed in this device structure.

Realization of high-power dimmable GaN-based LEDs by hybrid integration with AlGaN/GaN HFETs

Department of Printed Electronics Engineering, Sunchon National University, Jeonnam 540-742, Republic of Korea
Semiconductor Physics Research Center, Department of Semiconductor Science and Technology, Chonbuk National University, Jeonju, Jeonbuk 561-756, Republic of Korea

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab124a

We successfully demonstrated high-power dimmable GaN-based vertical injection LEDs (VI-LEDs) by integration with AlGaN/GaN-based heterojunction field-effect transistors (HFETs) using a flip-chip bonding technique. The high-power dimmable GaN-based VI-LEDs on AlGaN/GaN HFETs emitted no light in the off-state of the HFETs and operated normally in the on-state of the HFETs. Furthermore, the light-output power (LOP), forward current, and maximum electroluminescence (EL) intensity were efficiently modulated with the gate-to-source voltage (V GS) of the HFETs. The temperature rose by less than 20 °C when the devices were operated with a V GS of −3 V and supply voltage (V DD) of 10 V. These results suggest that the high-power dimmable GaN-based VI-LEDs can be fabricated through hybrid integration with AlGaN/GaN HFETs, and the devices could be applied to novel applications such as visible light communication (VLC) and adaptive headlights for vehicles.

Enhanced Performance of an AlGaN-Based Deep-Ultraviolet LED having Graded Quantum Well Structure

School of Microelectronics, University of Science and Technology of China, 12652 Hefei, Anhui China
Huazhong University of Science and Technology, 12443 Wuhan, Hubei China
Jacobs School of Engineering, University of California San Diego, 8784 La Jolla, California, United States
Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, 12443 Wuhan, Hubei, China

IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2019.2922280

AlGaN-based deep ultraviolet light-emitting diodes (DUV LEDs) suffer from severe quantum confined Stark effect (QCSE) due to the strong polarization field in the quantum wells (QWs) grown on c-plane substrates. In this work, we propose a novel DUV LED structure embedded with graded QWs in which the Al composition was linearly changed to screen the QCSE. A significant increase of the internal quantum efficiency and thus an enhancement of the light output power by nearly 67% can be achieved, attributing to the improvement of the electron-hole wave function overlap (Γe–hh) to 58.6% in the Increased-Al-composition graded QWs, as compared to the QW without grading (Γe–hh =40.4%) and reverse grading (Γe–hh =33.6%). Further investigations show that the grading profile of the Al composition in the QWs, including either linearly increases or decreases along the growth direction

and the thickness of graded QWs, determine the polarization electrical field in the QWs and as a result, significantly affecting the performance of the devices. In the end, a careful optimization of the graded QWs is called. The proposed structure with such unique graded QWs provides us an effective solution to suppress the QCSE effect in the pursuit of high performance DUV emitters.

Impedance Elements of Significant Junctions in InGaN Light-Emitting Diodes Studied by Electric Modulus Spectroscopy

Department of Physics, National Chung Hsing University, Taichung 40227, Taiwan
Department of Applied Physics, Tunghai University, Taichung 40704, Taiwan

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2921393

The investigation of the heterojunction properties in InGaN-based light-emitting diodes (LEDs) is important to the development of LEDs, because charge carrier transport in the LED is governed by the junctions. In this paper, it is proven that the impedance properties of the significant junctions in InGaN/GaN multiple quantum well (MQW) LEDs can be characterized by electric modulus (M) spectroscopy. An equivalent circuit is given to represent the significant junctions of the LEDs. The bias and temperature dependence of impedance parameters of the main active junction and the p-type AlGaN/GaN junctions were studied by M spectroscopy. The existence of the AlGaN/GaN junction degrades the efficiency in ac signal transmission and causes a transition in the effective capacitance of the device.

1 Gbps free-space deep-ultraviolet communications based on III-nitride micro-LEDs emitting at 262 nm

Institute of Photonics, Department of Physics, University of Strathclyde, Glasgow G1 1RD, UK
Li-Fi R&D Centre, the University of Edinburgh, Institute for Digital Communications, Edinburgh EH9 3JL, UK

Photonics Research
https://doi.org/10.1364/PRJ.7.000B41

The low modulation bandwidth of deep-ultraviolet (UV) light sources is considered as the main reason limiting the data transmission rate of deep-UV communications. Here, we present high-bandwidth III-nitride micro-light-emitting diodes (μLEDs) emitting in the UV-C region and their applications in deep-UV communication systems. The fabricated UV-C μLEDs with 566 μm^2 emission area produce an optical power of 196 μW at the 3400 A/cm2 current density. The measured 3 dB modulation bandwidth of these μLEDs initially increases linearly with the driving current density and then saturates as 438 MHz at a current density of 71 A/cm2, which is limited by the cutoff frequency of the commercial avalanche photodiode used for the measurement. A deep-UV communication system is further demonstrated. By using the UV-C μLED, up to 800 Mbps and 1.1 Gbps data transmission rates at bit error ratio of 3.8×10−3 are achieved assuming on-off keying and orthogonal frequency-division multiplexing modulation schemes, respectively.

Process Optimization of Passive Matrix GaN-Based Micro-LED Arrays for Display Applications

Optoelectronics Technology LaboratoryMinistry of Education, Beijing University of Technology, Beijing, China
Quantum Device Physics Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, Göteborg, Sweden

Journal of Electronic Materials
https://doi.org/10.1007/s11664-019-07330-3

Passive matrix GaN-based micro light-emitting diode (LED) arrays with two resolutions of 32 × 32 and 128 × 64 are designed and fabricated, and a micro control unit is used to drive the devices and display Chinese characters. The process of the micro-LED display arrays is systematically optimized, where emphasis has been put on solving two specific technical problems. First, the deep isolation trench is etched in two steps in order to decrease the slope of the isolation trench so as to ease the p electrode to “climb”. In this way, the otherwise easily broken p metal line is now very reliable. Second, a secondary growth method is employed to deposit SiO2 onto the n metal line as an insulation layer between the p and n electrode layers. Between the two deposition steps, the chips are rotated with a certain angle. Therefore, the probability of pinhole overlap is significantly reduced, and the insulation between the p and n electrode layers is guaranteed. Using the optimized

micro-LED process, micro displays are fabricated and their electrical, optical, and thermal characteristics for two different pixel sizes are analyzed. Experiments show that the process optimization above helps realize the outstanding properties of the micro-LED display arrays, increase the device and system reliability. The work will contribute to the implementation of the GaN based micro-LED technologies in real life.

Recombination dynamics in GaInN/GaN quantum wells

Institute of Applied Physics, Braunschweig University of Technology, Mendelssohnstr. 2, D-38106 Braunschweig, Germany

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab2788

GaInN/GaN quantum wells are now at the heart of visible light emitting devices such as light emitting diodes and laser diodes. Radiative recombination of charge carriers provides the basis of light emission, while non-radiative recombination processes constitute unwanted loss mechanisms. In this review, the physics of both radiative and non-radiative recombination processes is discussed in detail, shining light on many peculiar properties of III-nitride quantum wells.

The sapphire substrate pretreatment effect on high-temperature annealed AlN template in deep ultraviolet light emitting diodes

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

CrystEngComm
https://doi.org/10.1039/C9CE00702D

Evolution of crystalline quality of AlN via high-temperature (HT) annealing induced by different sapphire pretreatments is investigated. It is found that after HT annealing at 1700 ℃ for one hour, AlN film grown on nitridation treated sapphire substrate presents much lower threading dislocation density (TDD) than that grown on alumination treated one, indicating that the combination of nitridation and HT annealing is a more effective approach to achieve high quality AlN. It is verified that the much greater grain density of the nucleation layer induced by nitridation can produce more columns with much smaller size so that they can more easily rotate during the HT annealing to reduce the TDD more effectively. A deep ultraviolet light-emitting diode (285 nm) with output power over 10 mW has been demonstrated on a HT annealed AlN template with sapphire substrate nitridation pretreatment, showing a great potential for applications.

Fast growth of high quality AlN films on sapphire using a dislocation filtering layer for ultraviolet light-emitting diodes

Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Luoyu Road 1037, Wuhan, 430074, China

CrystEngComm
https://doi.org/10.1039/C9CE00589G

High quality AlN templates are the foundation of high performance deep-ultraviolet (DUV) optoelectronic devices. Here, we demonstrate a low-cost method to grow high quality AlN films fast on sapphire by metal–organic chemical vapor deposition (MOCVD) without the use of the epitaxial lateral overgrowth (ELOG) or pulse atomic layer epitaxy (PALE) method. During the fast growth process, a dislocation filtering (DF) layer was employed to introduce a large number of AlN islands on the buffer layer, and a recovery layer with a growth rate of 86 nm min−1 was used to ensure the complete coalescence of AlN films. The full width at half maximum (FWHM) of the X-ray rocking curves (XRCs) of the (0002) and (10[1 with combining macron]2) planes was reduced from 63/453 to 140/267 arcsec compared with those of the AlN films grown by conventional methods. Benefiting from the improved crystal quality of the AlN template, a DUV-LED grown on AlN with a DF layer showed an increase of the light output power by 40% at 100 mA compared to the reference LED. Our strategy may provide a simple and cost-effective means toward the mass production of high quality AlN films suitable for fabricating high performance DUV devices.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowmade

450 nm GaInN ridge stripe laser diodes with AlInN/AlGaN multiple cladding layers

Faculty of Science & Engineering, Meijo University, Nagoya, Aichi, 468-8502 Japan
Research Center for Nano Devices and Advanced Materials, Nagoya Institute of Technology, Nagoya, Aichi, 466-8555 Japan
Akasaki Research Center, Nagoya University, Nagoya, Aichi, 464-8603 Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab12ca

We investigated and improved optical waveguides along the vertical and horizontal directions in 450 nm GaInN laser diodes. As a result, we demonstrated a low threshold current density (1.15 kA cm−2) of a GaInN ridge stripe laser diode containing a 3-pair 40 nm Al0.82In0.18N/25 nm Al0.03Ga0.97N multiple bottom cladding layer at room temperature under pulsed condition. This threshold current density is smaller than our typical value with a 1 µm Al0.03Ga0.97N bottom cladding layer. AlInN/AlGaN multiple layers are useful as n-type cladding layers in visible laser diodes to achieve higher optical confinement factors while smooth surfaces were obtained.

Green laser diodes with constant temperature growth of InGaN/GaN multiple quantum well active region

Suzhou Institute of Nano-tech and Nano-bionics, Chinese Academy of Sciences, Suzhou 215123, People's Republic of China
Key Laboratory of Nanodevices and Applications, Chinese Academy of Sciences, Suzhou 215123, People's Republic of China
School of Nano Technology and Nano Bionics, University of Science and Technology of China, Hefei 230026, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab21b6

Increasing trench defect density in green InGaN/GaN multiple quantum wells (MQWs) has been reported to be one cause for "green gap" and creates a challenge in fabricating high-performance green laser diodes (LDs). In this article, we report methods to suppress the density of trench defects. Suppressed defect density in InGaN/GaN MQWs results in greatly improved optical quality, as indicated by increasing photoluminescence (PL) intensity and nonradiative recombination lifetime, and decreasing PL full-width-half-maximums (FWHMs), which can be as narrow as 113 meV. This enabled constant temperature growth of the InGaN/GaN MQW active region of the green LD structure and greatly improved slope efficiency.

Study of crystalline defect induced optical scattering loss inside photonic waveguides in UV–visible spectral wavelengths using volume current method

School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85287, USA

Optics Express
https://doi.org/10.1364/OE.27.017262

In this work, we study the crystalline defect induced optical scattering loss inside photonic waveguide. Volume current method is implemented with a close form of dyadic Green's function derived. More specifically, threading dislocation induced scattering loss inside AlN waveguides in UV–visible spectrum wavelengths are studied since this material is intrinsically accompanied with high densities of dislocations (typically on order of 108–1010cm−2). The results from this study reveal that threading dislocations contribute significant amount of scattering loss when material is not MOCVD grown. Additionally, the scattering loss is strongly dependent on polarization and waveguide geometries: TM modes exhibit higher scattering loss compared with TE modes, and the multimode large core waveguides are more susceptible to threading dislocations compared with single mode waveguides and high-aspect-ratio waveguides. Conclusions from this work can be supported by several recently published investigations on III-N based photonic devices. The model derived from this work can also be easily

altered to fit other material systems with other types of crystalline defects.

Effect of the residual doping on the performance of InN epilayers as saturable absorbers for ultrafast lasers at 1.55µm

Grupo de Ingeniería Fotónica, Departamento de Electrónica (EPS) Universidad de Alcalá, Campus Universitario 28871 Alcalá de Henares, Madrid, Spain
CIMAP; UMR 6252, CNRS-ENSICAEN-CEA-UCBN, 14050 Caen, France
Univ. Grenoble-Alpes, CEA, INAC-PHELIQS, 17 av. Des Martyrs, 38000 Grenoble, France

Optical Materials Express
https://doi.org/10.1364/OME.9.002785

We report on the improvement of performance of InN-based saturable absorbers in fiber lasers operating at 1.55 µm by reducing the residual doping, due to the lower Burstein-Moss effect. The improved tuning of the band-to-band transition with respect to the operation wavelength leads to an enhancement of nonlinear optical effects, resulting in 30 % of modulation depth. We introduce the development of an ultrafast mode-locked fiber laser using an improved InN-based saturable absorber that incorporates a buffer layer between the active layer and the substrate. The laser delivers output pulses with a temporal width of ~220 fs, a repetition rate of 5.25 MHz, and high-pulse energy of 5.8 nJ.

Suppression of optical field leakage in GaN-based green laser diode using graded-indium n-InxGa1-xN lower waveguide

State Key Laboratory of Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, 100083, China
Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China
Suzhou Institute of Nano-tech and Nano-bionics, Chinese Academy of Sciences, Suzhou, 215123, China

Superlattices and Microstructures
https://doi.org/10.1016/j.spmi.2019.106153

Optical field leakage to the GaN substrate in GaN-based green laser diodes (LDs) can reduce the peak optical gain and weaken the output performance of LDs. In this study, a graded-indium composition n-InxGa1-xN lower waveguide (LWG) structure is proposed which should be more feasible to grow with high material quality and at the same time can effectively reduce the optical field leakage in GaN-based green LD, avoiding to use thick n-type Al0.08Ga0.92N cladding layer or thick n-InxGa1-xN LWG with high indium content. According to the optical and electrical characteristics of LDs calculated by LASTIP, it is found that the optical field has been concentrated around the active area and the optical field leakage has been eliminated effectively using graded-indium composition LWG in green LDs, which results in an obvious improvement of optical and electrical performance.

Growth and fabrication of GaN/Er:GaN/GaN core-cladding planar waveguides

Department of Electrical and Computer Engineering, Texas Tech University, Lubbock, Texas 79409, USA

Applied Physics Letters
https://doi.org/10.1063/1.5093942

Erbium doped gallium nitride (Er:GaN) bulk crystals have emerged as a promising optical gain material for high energy lasers (HELs) operating at the 1.5 µm "retina-safe" spectral region. Among the many designs of HEL gain medium, the core-cladding planar waveguide (PWG) structure is highly desired due to its abilities to provide excellent optical confinement and heat dissipation. We report the realization of a GaN/Er:GaN/GaN core-cladding PWG structure synthesized by hydride vapor phase epitaxy and processed by mechanical and chemical-mechanical polishing. An Er doping concentration of [Er] = 3 × 1019 atoms/cm3 has been attained in the core layer, as confirmed by secondary ion mass spectrometry measurements. A strong 1.54 µm emission line was detected from the structure under 980 nm resonant excitation. It was shown that these PWGs can achieve a 96% optical confinement in the Er:GaN core layer having a thickness of 50 µm and [Er] = 3 × 1019 atoms/cm3. This work represents an important step toward the realization of practical Er:GaN gain medium for retina-safe HEL applications.

Design of AlGaN-based lasers with a buried tunnel junction for sub-300 nm emission

Department of Electrical and Computer Engineering, The Ohio State University, Columbus, OH, USA
NRC Research Associate, Resident at Center for Computational Materials Science, US Naval Research Laboratory, Washington, DC, USA

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab19cd

This paper discusses the design of electrically-pumped AlGaN-based in-plane lasers emitting at ~290 nm. Our laser design utilizes strained Al0.5Ga0.5N quantum wells, and a novel polarization engineered AlGaN/InGaN/AlGaN-based tunnel junction. The low -resistive tunnel junction is used as an intracavity contact in the device in place of the resistive p-type contact; which leads to improved hole injection and a reduced threshold voltage. Hence, room-temperature continuous-wave laser operation could be enabled. Strategies to improve the performance of the tunnel junction contact through the incorporation of low concentrations of boron in the highly-doped AlGaN tunnel junction layers as a means to increase the polarization sheet charge are also discussed.

Effects of insertion loss, laser profile and inhomogeneity of dots distribution on properties of all-optical modulator based on GaN/AlN quantum dots

Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
Photonics and Nanocrystal Research Lab. (PNRL), Faculty of Electrical and Computer EngineeringUniversity of Tabriz, Tabriz, Iran
School of Engineering-Emerging Technologies, University of Tabriz, Tabriz, Iran

Optical and Quantum Electronics
https://doi.org/10.1007/s11082-019-1941-6

This paper reports the effects of insertion loss, laser profile and inhomogeneity of dots distribution on properties of an all-optical modulator based on spherical quantum dot. The aim of this paper is to give a quantitative description for the variation of main properties of an all-optical quantum dot modulator such as, absorption, transmission and modulation depth regard to insertion loss, laser profile and inhomogeneity of dots. To realize these points, first, we extract the field distribution in optical fiber and channel waveguide (modulator) which are defined by their structure characteristics and boundary conditions. Using the electric field equations, input coupling efficiency and insertion loss and also role of laser profile are observable. Finally we investigate the effect of size distribution and inhomogeneity of quantum dots on the modulator performance. In this structure we used electromagnetically induced transparency (EIT) in GaN/AlN structure, associated with inter-sublevel transitions.

Dominant Influence of Interface Roughness Scattering on the Performance of GaN Terahertz Quantum Cascade Lasers

State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, School of Physics, Peking University, Beijing, China
Collaborative Innovation Center of Quantum Matter, Beijing, China
Nano-optoelectronics Frontier Center of Ministry of Education (NFC-MOE), Peking University, Beijing, China

Nanoscale Research Letters
https://doi.org/10.1186/s11671-019-3043-6

Effect of interface roughness of quantum wells, non-intentional doping, and alloy disorder on performance of GaN-based terahertz quantum cascade lasers (QCL) has been investigated by the formalism of nonequilibrium Green's functions. It was found that influence of alloy disorder on optical gain is negligible and non-intentional doping should stay below a reasonable concentration of 1017 cm−3 in order to prevent electron-impurities scattering degradation and free carrier absorption. More importantly, interface roughness scattering is found the dominating factor in optical gain degradation. Therefore, its precise control during the fabrication is critical. Finally, a gain of 60 cm−1 can be obtained at 300 K, showing the possibility of fabricating room temperature GaN Terahertz QCL.

Dual wavelength lasing of InGaN/GaN axial-heterostructure nanorod lasers

Department of Chemistry, Kyung Hee University, Seoul 130-701, Korea
Department of Chemistry, Kookmin University, Seoul 136-702, Korea
Department of Materials Science and Engineering, Korea University, Seoul 136-701, Korea

Nanoscale
https://doi.org/10.1039/C9NR03906F

Optical confinement effects are investigated in InGaN/GaN axial-heterostructure nanolasers. Cylindrical nanorods with GaN/InGaN/GaN structures are prepared using combined processes of top-down and bottom-up approach. Lasing of InGaN is observed at a low threshold (1 μJ/cm2), which is attributed to efficient carrier transfer process from GaN to InGaN. Lasing of GaN is also found at the threshold range of 10–20 μJ/cm2 with a superlinear increase in emission intensity and high quality factors (Q = 1,000), implying that dual wavelengths of lasing are tunable as a function of excitation intensity. The non-classical Fabry–Pérot modes suggest strong light–matter interactions in nanorods by optical confinement effects. The polarization of lasing indicates that the non-classical modes are in the identical transverse mode, which supports formation of exciton–polariton in nanorods. The polariton lasing in a single axial-heterostructure nanorod is observed for the first time, which proposes small-sized light sources with low threshold, polarized light, and tunable wavelengths in a single nanorod.

GROUP 3 - Power Electronics

Group leader: Frédéric Morancho (LAAS-CNRS)

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

Realization of p-type gallium nitride by magnesium ion implantation for vertical power devices

School of Electronic Science and Engineering, Nanjing University, Nanjing, 210093, China
Department of Electronic Materials Engineering, Research School of Physics and Engineering, The Australian National University, Canberra, ACT 2601, Australia
Collaborative Innovation Center of Advanced Microstructures, Nanjing University, Nanjing, 210093, China
Australian National Fabrication Facility, Research School of Physics and Engineering, The Australian National University, Canberra, ACT 2601, Australia

Scientific Reports
https://doi.org/10.1038/s41598-019-45177-0

Implementing selective-area p-type doping through ion implantation is the most attractive choice for the fabrication of GaN-based bipolar power and related devices. However, the low activation efficiency of magnesium (Mg) ions and the inevitable surface decomposition during high-temperature activation annealing process still limit the use of this technology for GaN-based devices. In this work, we demonstrate successful p-type doping of GaN using protective coatings during a Mg ion implantation and thermal activation process. The p-type conduction of GaN is evidenced by the positive Seebeck coefficient obtained during thermopower characterization. On this basis, a GaN p-i-n diode is fabricated, exhibiting distinct rectifying characteristics with a turn-on voltage of 3 V with an acceptable reverse breakdown voltage of 300 V. Electron beam induced current (EBIC) and electroluminescent (EL) results further confirm the formation of p-type region due to Mg ion implantation and subsequent thermal activation. This repeatable and uniform manufacturing process can be implemented in mass production of GaN devices for versatile power and optoelectronic applications.

Realization of GaN PolarMOS using selective-area regrowth by MBE and its breakdown mechanisms

School of Electrical and Computer Engineering, Cornell University, Ithaca, NY 14853, United States of America
Department of Materials Science and Engineering, Cornell University, Ithaca, New York 14853, United States of America
Qorvo Inc., Richardson, TX 75080, United States of America
IQE RF LLC, Somerset, NJ 08873, United States of America
Department of Electrical Engineering, University of Notre Dame, Indiana 46556, United States of America
Kavli Institute for Nanoscale Science, Cornell University, Ithaca, New York 14853, United States of America

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab0f1b

GaN PolarMOS is a vertical power transistor incorporating the unique polarization-induced bulk doping scheme in III-nitrides for the body p-n junction. We report the realization of this device, wherein the vertical channel, source contact, and body contact regions are successfully formed using three steps of selective-area epitaxial regrowth, all by molecular beam epitaxy (MBE). The fabricated PolarMOS has an excellent on-current of >500 mA mm−1 and a specific on-resistance of 0.66 mΩ centerdot cm2. The reverse breakdown mechanisms of the PolarMOS are investigated. First, a pronounced source-drain vertical leakage is identified and attributed to the passivation of the buried p-type body, which is subsequently resolved by the sidewall activation method. With the body leakage eliminated, the breakdown voltage is found to be limited by a highly conductive path along the regrowth sidewall interface using the conductive scanning probe technique, despite the absence of apparent structural defects.

InGaN/(GaN)/AlGaN/GaN normally-off metal-oxide-semiconductor high-electron mobility transistors with etched access region

Institute of Electrical Engineering Slovak Academy of Sciences, Dúbravska cesta 9, 841 04 Bratislava, Slovakia
Institute for Technical Physics and Material Science, Centre for Energy Research, H-1525 Budapest, Hungary
Research Center for Integrated Quantum Electronics, Hokkaido Univ., Sapporo 060-0814, Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab06b8

The proposal and processing aspects of the prove-of-concept InGaN/GaN/AlGaN/GaN metal-oxide-semiconductor (MOS) high-electron mobility transistor with etched access regions are addressed. Full strain and decent quality of the epitaxial system comprising 4 nm In0.16Ga0.84N/3 nm GaN/5 nm Al0.27Ga0.73N are observed using a high-resolution transmission-electron microscopy and by deformation profile extractions. Large negative polarization charge in the MOS gate stack provides the HEMT normally-off operation, while free electrons are populated at access regions after etching. Consecutive passivation by 10 nm Al2O3 together with annealing at 300 °C improved the Al2O3/semiconductor interface, with the threshold voltage (V T) reaching 1 V. Improvements of the present concept in comparison to the previous one with a gate recess were proved by showing the decreased drain leakage current and increased breakdown voltage.

Change of characteristics of n-GaN MOS capacitors with Hf-rich HfSiOx gate dielectrics by post-deposition annealing

Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
International Center for Materials Nanoarchitectonics (WPI-MANA), National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan
Institute of Material and Systems for Sustainability, Nagoya University, Nagoya 464-8601, Japan

Microelectronic Engineering
https://doi.org/10.1016/j.mee.2019.111036

We investigated the characteristics of n-GaN/Hf0.64Si0.36Ox/Pt MOS capacitors fabricated by post-deposition annealing (PDA) at 800 °C in O2 (PDO), N2 (PDN), and 3%H2 (PDH) ambients. After PDO, the Hf0.64Si0.36Ox film was partially crystallized and had a thick interfacial layer (6.3 nm) at the n-GaN/Hf0.64Si0.36Ox interface, while the Hf0.64Si0.36Ox films after PDN and PDH maintained an amorphous structure. Furthermore, the n-GaN/Hf0.64Si0.36Ox/Pt MOS capacitors produced by PDN and PDH exhibited superior characteristics, such as a small flat-band voltage (Vfb) hysteresis of +50 mV and + 25 mV, a small Vfb shift of 0.74 V and − 0.06 V, high dielectric constants of 15.1 and 16.0, and high breakdown electric fields of 8.7 and 9.1 MV/cm, respectively. However, the PDH capacitor exhibited an order of magnitude larger Dit than the PDN capacitor, suggesting that a Ga2O3 intermediate layer at n-GaN/Hf0.64Si0.36Ox interface may be decomposed after PDH and results in significant Ga diffusion into the Hf0.64Si0.36Ox films and electrical defects generation at n-GaN/Hf0.64Si0.36Ox interface. These strongly indicate that the PDN process can produce superior Hf0.64Si0.36Ox films for use as gate dielectrics in GaN power devices.

Enhancement mode AlGaN/GaN HEMTs by fluorine ion thermal diffusion with high Vth stability

Nano Science and Technology Institute of the University of Science and Technology of China, Suzhou 215123, People's Republic of China
Nanofabrication Facility of the Suzhou Institute of Nano-tech and Nano-bionics, CAS, Suzhou 215123, People's Republic of China
School of Materials Science and Engineering, Nanjing University of Science and Technology, Nanjing 210094, People's Republic of China
The Department of Electronics Science and Technology, University of Science and Technology of China, Hefei 230026, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab1cfa

A method of fluorine ion thermal diffusion has been proposed to realize enhancement-mode AlGaN/GaN HEMTs. By AlF3 solid diffusion source, fluorine ion has successfully diffused in the gate region of AlGaN layer at 800 °C 2 h with a diffusion depth about 20 nm demonstrated by secondary ion mass spectrometry. The fabricated device exhibits a

positive threshold voltage of 1.8 V, a drain current density of 95 mA mm−1 at V g = 4 V, a peak transconductance of 50 mS mm−1, a breakdown voltage of 700 V. Besides, the device is also demonstrated with good Vth stability under different stress conditions.

GaN Transistors for Miniaturized Pulsed-Power Sources

Power and Wide-band-gap Electronics Research Laboratory (POWERlab), École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland

IEEE Transactions on Plasma Science
https://doi.org/10.1109/TPS.2019.2917657

In this paper, we discuss and demonstrate the potential of normally-on GaN high-electron-mobility transistors (HEMTs) as opening switches in miniaturized pulsed-power circuits. The high-breakdown electric field of GaN (~ 3 MV/cm) makes it possible to fabricate high-voltage devices in small dimensions, resulting in smaller parasitics and faster switching times. GaN HEMTs as opening switches are compatible with inductive topologies, which offer more than one order of magnitude higher energy density than capacitive topologies, allowing further miniaturization of pulsed-power systems. In this work, we demonstrate the application of fabricated 1.5-kV normally-on GaN HEMTs on an inductive switching topology, resulting in 300-fold voltage step-up, which makes it possible to generate high-voltage pulses with a low-voltage dc source in miniaturized circuits.

High-voltage normally-off recessed tri-gate GaN power MOSFETs with low on-resistance

Power and Wide-band-gap Electronics Research Laboratory (POWERLAB), Icole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland.

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2922204

In this letter, we present normally-off GaN-on-Si MOSFETs based on the combination of tri-gate with a short barrier recess to yield a large positive threshold voltage (VTH), while maintaining a low specific on resistance (RON,SP) and high current density (ID). The tri-gate structure offered excellent channel control, enhancing the VTH from +0.3 V for the recessed to +1.4 V for the recessed tri-gate, along with a much reduced hysteresis in VTH, and a significantly increased transconductance (gm). Additional conduction channels at the sidewalls of the tri-gate trenches compensated the degradation in ON resistance (RON) from the gate recess, resulting in a small RON of 7.32 ± 0.26 Ω.mm for LGD of 15 µm, and an increase in the maximum output current (ID max). In addition, the tri-gate inherently integrates a gateconnected field-plate (FP), which improved the breakdown voltage (VBR) and reduced the degradation in dynamic RON. With proper passivation techniques, these devices could be very promising as high performance power switches for future power applications.

Effect of In composition on electrical performance of AlInGaN/GaN-based metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) on Si

Research Center for Nano Devices and Advanced Materials, Nagoya Institute of Technology, Nagoya 466-8555, Japan
Innovation Center for Multi-Business of Nitride Semiconductors, Nagoya Institute of Technology, Nagoya 466-8555, Japan

Journal of Applied Physics
https://doi.org/10.1063/1.5098365

AlxInyGa(1−x−y)N/GaN heterostructures were grown on 4-in. p-type Si wafers to investigate the effect of In composition in the quaternary nitride layer on the electrical performance of Al2O3/AlInGaN/GaN-based normally-ON metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs). From the comparative study of the electrical measurements, it was observed that the transport properties of the devices were relatively poor in the presence of higher In composition in the quaternary-N layer. The deterioration of the electrical characteristics of MIS-HEMTs originated from the formation of deep pits on the AlInGaN epilayer surface caused by the segregation of In atoms during epitaxial growth. However, the formation of such pits was reduced for the quaternary epilayer with lower In content and exhibited better transport performance. A maximum current density (Id,max) of 780 mA/mm with a

specific ON-resistance of 0.71mΩcm2 was observed for the device fabricated on the wafer with an In composition of 9% in the AlInGaN epilayer. We have achieved a high breakdown voltage of 793 V with a device with the gate-to-drain distance (Lgd) of 20µm under the off-state condition.

Direct evidence of Mg diffusion through threading mixed dislocations in GaN p–n diodes and its effect on reverse leakage current

Graduate School of Engineering, Nagoya University, Nagoya 464-8603, Japan
Toshiba Nanoanalysis Corporation, Yokohama 235-8522, Japan
Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya 464-8601, Japan
National Institute of Material Science, Ibaraki 305-0047, Japan
Akasaki Research Center, Nagoya University, Nagoya 464-8603, Japan
Venture Business Laboratory, Nagoya University, Nagoya 464-8603, Japan

Applied Physics Letters
https://doi.org/10.1063/1.5097767

Mg diffusion is a common problem in GaN devices with p–n junctions. Although this impurity diffusion is reported to occur through threading dislocations (TDs), no direct evidence has yet been obtained. Therefore, we tried the direct observation of Mg diffusion by atom probe tomography (APT) analysis. The n-type drift layer of the fabricated p–n diode was exposed, and etch pits were formed on the drift layer to identify the TD position. The APT analysis around TDs was carried out by lifting out the drift layer around specific etch pits using a focused ion beam to include TDs. The relationship between the etch pit shape and the TD type was confirmed by cross-sectional scanning transmission electron microscopy observation. The APT analysis of two types of etch pits formed on the mixed dislocations was performed, and Mg diffusion was clearly observed through the mixed dislocations. In this work, we show direct evidence of Mg diffusion via mixed dislocations in GaN p–n diodes and its effect on reverse leakage current.

Investigation of the Trap States and VTH Instability in LPCVD Si_3N_4/AlGaN/GaN MIS-HEMTs with an In-Situ Si_3N_4 Interfacial Layer

Academy for Advanced Interdisciplinary Studies, Peking University, Beijing 100871, China
Institute of Microelectronics, Peking University, Beijing 100871, China
Founder Microelectronics International Corporation, Ltd., Shenzhen 518116, China

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2919246

A novel gate and passivation dielectric stack consisting of a thin metal-organic chemical vapor deposition (MOCVD) grown in-situ Si_3N_4 (3 nm) and a thick low-pressure chemical vapor deposition (LPCVD) grown Si_3N_4 (30 nm) in AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistor (MIS-HEMT) is proposed. The quality of the Si_3N_4/(Al)GaN interface and the effect on threshold voltage (VTH) instability and dynamic Ron in the MIS-HEMTs with/without the in-situ Si_3N_4 layer are investigated by high-frequency capacitance-voltage (HFCV), quasi-static (QS) C-V (QSCV), time-of-fly (TOF) stress/measure, and QS ID-VDS methods. It is founded that the in-situ Si_3N_4 interfacial layer is effective in improving the dielectric/III-N interface morphology. As a result, better VTH stability and lower Ron,D/Ron,S ratio are observed in devices with the in-situ Si_3N_4 interfacial layer due to the reduced density of traps close to the dielectric/III-N interface. Time-dependent dielectric breakdown and Weibull performance further verified that the proposed bilayer gate dielectric stack is a promising structure for the high-reliability power transistors.

A Novel Kilovolts GaN Vertical Super Junction MOSFET with Trench Gate: Design and Optimization

State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China

IEEE Journal of Emerging and Selected Topics in Power Electronics
https://doi.org/10.1109/JESTPE.2019.2924333

In this work, a GaN vertical super-junction (SJ) MOSFET with trench gate is proposed and studied by TCAD simulation. In order to achieve the typical

electric field (E-field) modulation effect by the P+/N/N+ structure in the conventional Si SJMOS, the P-GaN/UID-GaN/N+-GaN stack is alternatively used by taking into account the unavailability of P+-GaN. In this manner, the P-GaN and N+-substrate serve as the field-stop (FS) layers in the proposed GaN SJ-MOS. In forward bias, the enhancement-mode function of the device is enabled by the gated side-wall and aperture composite channel that leads to a 1.47 V threshold voltage of the device. In reverse bias, the breakdown of the device is governed by two mechanisms: 1) the punch-through in the top P-GaN/N-drift junction due to the possible under design of the P-GaN thickness; 2) the avalanche breakdown triggered by high E-field due to the possible under design of the bottom UID-GaN thickness. Hence, from the uniform E-field distribution point of view, a device optimization approach for GaN vertical SJ-MOS is proposed. The hole and electron density of P-GaN and N-drift are optimized to achieve a uniform E-field distribution in the device both in lateral and vertical directions, which is found to be 6W1016 cm-3. Moreover, the thickness ratio of P-GaN/UID-GaN is designed to obtain an identical intrinsic breakdown for the top P-GaN/N-drift junction and bottom UID/N-drift region, which enables the maximum Baliga's figure-of-merit of the device. The concept of device design and optimization is of great interests for GaN vertical device for over kilovolts applications.

Dynamic On-Resistance in GaN Power Devices: Mechanisms, Characterizations and Modeling

College of Electrical Engineering, Zhejiang University, Hangzhou 310027, China
Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong

IEEE Journal of Emerging and Selected Topics in Power Electronics
https://doi.org/10.1109/JESTPE.2019.2925117

GaN power devices enable power electronic systems with enhanced power density and efficiency. Dynamic on-resistance (RON) degradation (or current collapse), originating from buffer trapping, surface trapping and gate instability, has been regarded as a primary challenge for the lateral GaN-on-Si power devices. In this paper, we present an overview and discussion of the mechanisms, characterizations, modeling and solutions for the degradation of dynamic RON in GaN power devices. The complex dynamics of acceptor/donor buffer traps and their impacts on dynamic RON have been analyzed and revealed by TCAD simulations and high-voltage back-gating measurements. The gate instability-induced dynamic RON increase in different GaN device technologies and the role of gate overdrive are also discussed. Wafer-level and board-level characterization techniques enabling accurate dynamic RON evaluation are reviewed. The dynamic RON performance of the state-of-the-art commercial GaN devices is presented, and a behavioral model with the dynamic RON degradation taken into consideration has been implemented for circuit analysis. The latest progress in GaN device technologies for enhanced dynamic performance is also reviewed and discussed.

Technology Computer Aided Design Study of GaN MISFET with Double P-buried Layers

Key Laboratory of RF Circuits and Systems, Ministry of Education, Hangzhou Dianzi University, Hangzhou 310018, China
National Institute of LED on Silicon Substrate, Nanchang University, Nanchang, Jiangxi 330047, China

IEEE Access
https://doi.org/10.1109/ACCESS.2019.2924999

In this paper, a performance-improved AlGaN-/GaN-Based metal-insulator-semiconductor field effect transistor (MISFET) with double P-buried layers MISFET (DP-MISFET) is proposed. The proposed structure is simulated, and its characteristics are analyzed by the Sentaurus TCAD tool; the results show that with a gate-drain spacing of 6 lm, the optimized DP-MISFET can achieve high Baliga's figure of merit of 3.23 GW·cm−2 due to the modulation of the electric field distribution. Compared with the conventional MISFET (C-MISFET) with the breakdown voltage (BV) of 503.9 V and specific on-resistance (Ron, sp) of 0.63 mΩ·cm2, the proposed structure can achieve a better trade-off between the breakdown voltage and specific on-resistance achieving Ron, sp and BV of 0.63 mΩ·cm2 and 1427 V, respectively.

High Breakdown Voltage and Low Dynamic ON-Resistance AlGaN/GaN HEMT with Fluorine Ion Implantation in SiNx Passivation Layer

School of Electronic Science and Engineering, State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu, China

Nanoscale Research Letters
https://doi.org/10.1186/s11671-019-3025-8

In this study, we proposed and experimentally demonstrated a high breakdown voltage (BV) and low dynamic ON-resistance (RON, D) AlGaN/GaN high electron mobility transistor (HEMT) by implanting fluorine ions in the thick SiNx passivation layer between the gate and drain electrodes. Instead of the fluorine ion implantation in the thin AlGaN barrier layer, the peak position and vacancy distributions are far from the two-dimensional electron gas (2DEG) channel in the case of fluorine ion implantation in the thick passivation layer, which effectively suppresses the direct current (DC) static and pulsed dynamic characteristic degradation. The fluorine ions in the passivation layer also extend the depletion region and increase the average electric field (E-field) strength between the gate and drain, leading to an enhanced BV. The BV of the proposed HEMT increases to 803 V from 680 V of the conventional AlGaN/GaN HEMT (Conv. HEMT) with the same dimensional parameters. The measured RON, D of the proposed HEMT is only increased by 23% at a high drain quiescent bias of 100 V, while the RON, D of the HEMT with fluorine ion implantation in the thin AlGaN barrier layer is increased by 98%.

A GaN RB-MISHEMT with a Schottky–MIS hybrid drain and An Al0–0.50Ga1–0.50N/GaN heterojunction

University of Electronic Science and Technology of China, Chengdu, China
Science and Technology on Monolithic Integrated Circuits and Modules Laboratory, Nanjing, China

Journal of Computational Electronics
https://doi.org/10.1007/s10825-019-01363-x

In this work, a GaN reverse-blocking (RB) MISHEMT with a Schottky–MIS hybrid drain and a thin-upward-graded-Al0−0.50Ga1−0.50N/GaN heterojunction is proposed and investigated by TCAD Sentaurus. The Schottky–MIS hybrid structure incorporated in the drain terminal of the proposed device is employed to provide the device with decent reverse-blocking capability. Moreover, the double-electron barrier from the Schottky–MIS hybrid drain can also effectively suppress the drain-induced barrier lowering (DIBL) in devices with short MIS-controlled channel, subsequently enabling the device to exhibit more stable and less geometry-dependent characteristic, and much shorter reverse recovery time (~ ns) than the conventional RB-MISHEMT. To reduce the turn-on voltage of the Schottky-contact structure, a thin-upward-graded-Al0−0.50Ga1−0.50N barrier layer (the 10 nm Al0−0.50Ga1−0.50N barrier layer) is employed to replace the conventional thick fixed-Aluminum-role AlGaN barrier layer (the 25 nm Al0.23Ga0.77N barrier layer), subsequently causing the proposed device possessing a low drain offset voltage of 0.60 V and low on-state voltage of 1.80 V.

A normally OFF GaN CAVET and its thermal and trap analysis

Department of Electronics Engineering, Jamia Millia Islamia (Central University), New Delhi, India
Department of Electronics and Communication Engineering, Al-Falah University, New Delhi, India
College of Computer Science and Information Systems, Najran University, Najran, Saudi Arabia
Department of Electrical Engineering and Computer Science, The Catholic University of America, Washington, USA

Journal of Computational Electronics
https://doi.org/10.1007/s10825-019-01360-0

We propose and investigate an enhancement-mode (normally OFF) current-aperture vertical electron transistor (CAVET) with a novel structure. The novelty lies in the achievement of the desired normally OFF/enhancement-mode operation through polarization engineering by employing a hybrid current-blocking layer (HCBL) made of an isolation material and aluminum nitride (AlN). The AlN introduces a conduction barrier for the electron gas located at the AlGaN–GaN interface, effectively making the proposed device operate in an enhancement/normally OFF mode. The isolation portion of the HCBL suppresses the off-state leakage current and drastically improves the breakdown

performance. Calibrated technology computer-aided design (TCAD) simulations show that the proposed polarization-engineered (PE)-CAVET structure displays normally OFF operation with a threshold voltage (VTH) of 2.2 V and a breakdown voltage twice that of the conventional GaN CAVET. A study of the thermal properties of the proposed structure reveals a significant improvement in the drain current due to the use of a heat sink, while the trap analysis shows that the leakage current in the CAVET structure can be suppressed by carefully choosing a proper acceptor trap concentration and energy level. On the other hand, donor traps degrade the performance of the CAVET, albeit not as severely as in the conventional device.

Three-level GaN inverter with SiC diodes for a possible three-phase high power solution

Research and development, Motion Control, Siemens plc, Congleton, UK
AVID Technology Group Ltd, Cramlington, NE23 1WG, UK
Research and Development, Motion Control, Siemens AG, Erlangen, Germany

The Journal of Engineering
https://doi.org/10.1049/joe.2018.8096

GaN device is a potential alternative to SiC as a wide band gap device. At present, there are almost no high-voltage GaN devices above 650 V, which makes an inverter design difficult for three-phase input using the standard two-level (2L) inverters. Therefore, at present, a three-level (3L) inverter is an obvious choice for the GaN inverter for three-phase 400/480 V input applications. Moreover, a 2L inverter suffers from drawbacks like increased filtering efforts, high d v /d t and limited switching frequency due to the effect of power loss on semiconductors. Therefore, at the medium-to-high-power level, a hard switched GaN inverter with a 2L structure is still questionable. To address some of the challenges, this study brings in a 700 V dc-link-based three-phase, 3L inverter with GaN and SiC diodes. This study discusses multiple aspects of the design such as (a) advantages over the 2L design at a higher power, (b) filters designs, (c) power losses in the devices and (d) design challenges of the inverter through comprehensive simulation models and experimental investigations. The study claims that the GaN inverter for the medium-to-high-power level makes more sense with a 3L design.

GROUP 4 - Advanced Electronics and RF

Group leader: Jean-Claude Dejaeger (IEMN)

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

Analysis of Gain Variation with Changing Supply Voltages in GaN HEMTs for Envelope Tracking Power Amplifiers

Centre for High Frequency Engineering (CHFE), School of Engineering, Cardiff University, Cardiff CF10 3AT, U.K.
Manufacturing Engineering Centre, Cardiff University, Cardiff CF10 3AT, U.K.
Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield S10 2TN, U.K.

IEEE Transactions on Microwave Theory and Techniques
https://doi.org/10.1109/TMTT.2019.2916404

Envelope tracking (ET) is a promising power amplifier (PA) architecture for current and future communications systems, which uses dynamic modulation of the supply voltage to provide high efficiency and potentially very wide bandwidth over a large dynamic range of output power. However, the dynamic nature of the supply voltage can lead to a problematic variation in transistor gain, particularly in GaN HEMTs. This paper describes and analyzes this behavior and the detrimental effect it can have on ET PAs. Contributing factors and origins of gain variation are described in detail along with how, for the first time, meaningful comparisons can be made between different devices. Using these guidelines, gain variation is shown to be a widespread issue effecting most GaN HEMTs presented in literature. To allow an analysis of the intrinsic device behavior, an extended transistor model is developed that takes the effect of gate and source field plates into account. This model is refined using measurement data and used to demonstrate the fact that the parasitic gate-drain capacitance (CGD) is the main contributor to the small-signal gain variation--a significant part of the overall gain variation. Based on this knowledge, possible strategies to reduce gain variation at the transistor technology level are proposed, allowing the optimization of GaN HEMTs specifically for ET PAs. One identified strategy involves reducing the length of the gate field plate and is shown to be a viable approach to reduce the gain variation in GaN HEMTs, albeit at an increased RF/dc dispersion.

A High-sensitivity AlGaN/GaN HEMT Terahertz Detector with Integrated Broadband Bow-tie Antenna

Center for Materials Characterization and Testing, Fraunhofer ITWM, D-67663 Kaiserslautern, Germany
Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), D-12489 Berlin, Germany
Physikalisches Institut, Johann Wolfgang Goethe-Universität, D-60438 Frankfurt am Main, Germany
Institute of Applied Electrodynamics and Telecommunications, Vilnius University, LT-10257 Vilnius, Lithuania

IEEE Transactions on Terahertz Science and Technology
https://doi.org/10.1109/TTHZ.2019.2917782

Many emerging applications in the terahertz (THz) frequency range demand highly sensitive, broadband detectors for room-temperature operation. Field-effect transistors with integrated antennas for terahertz detection (TeraFETs) have proven to meet these requirements, at the same time offering great potential for scalability, high-speed operation and functional integrability. In this contribution, we report on an optimized field-effect transistor with integrated broadband bow-tie antenna for THz detection (bow-tie TeraFET) and compare the detector's performance to other state-of-the-art broadband THz detector technologies. Implemented in a recently developed AlGaN/GaN MMIC process, the presented TeraFET shows a more than two-times performance improvement compared to previously fabricated AlGaN/GaN-HEMT-based TeraFETs. The detector design is the result of detailed modeling of the plasma wave-based detection principle embedded in a full-device detector model to account for power coupling of the THz radiation to the intrinsic gated FET channel. The model considers parasitic circuit elements as well as the high-frequency impedance of the integrated broadband antenna, and also includes optical losses from a silicon substrate lens. Calibrated characterization measurements have been performed at room temperature between 490 and 645GHz, where we find values of the optical (total beam power-

referenced) noise-equivalent power (NEP) of 25 and 31 pW/√Hz at 504 and 600GHz, respectively, in good agreement with simulation results. We then show the broadband detection capability of our AlGaN/GaN detectors in the range from 0.2 to 1.2THz and compare the TeraFETs' signal-to-noise ratio (SNR) to that of a Golay cell and a photomixer. Finally, we demonstrate an imaging application in reflection geometry at 504GHz and determine a dynamic range of >40dB.

Enhanced Mobility in InAlN/AlN/GaN HEMTs Using a GaN Interlayer

Department of Microtechnology and Nanoscience, Microwave Electronics Laboratory, Chalmers University of Technology, Gothenburg, Sweden
SweGaN, Linköping, Sweden
Thin Film Division, Linköping University, Linköping, Sweden
Department of Physics, Biology, and Chemistry, Linköping University, Linköping, Sweden

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2914674

An enhancement of the electron mobility (μ) in InAlN/AlN/GaN heterostructures is demonstrated by the incorporation of a thin GaN interlayer (IL) between the InAlN and AlN. The introduction of a GaN IL increases μ at room temperature (RT) from 1600 to 1930 cm 2 /Vs. The effect is further enhanced at cryogenic temperature (5 K), where the GaN IL sample exhibits a μ of 16000 cm 2 /Vs, compared to 6900 cm 2 /Vs without IL. The results indicate the reduction of one or more scattering mechanisms normally present in InAlN/AlN/GaN heterostructures. We propose that the improvement in μ is either due to the suppression of fluctuations in the quantum well subband energies or to reduced Coulomb scattering, both related to compositional variations in the InAlN. HEMTs fabricated on the GaN IL sample demonstrate larger improvement in dc- and high-frequency performance at 5 K; fmax increases by 25 GHz to 153 GHz, compared to an increase of 6 GHz to 133 GHz without IL. The difference in improvement was associated mainly with the drop in the access resistances.

Hybrid Analog/Digital Continuous Class B/J Mode for Broadband Doherty Power Amplifiers

Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee, Roorkee, India

IEEE Access
https://doi.org/10.1109/ACCESS.2019.2920487

In this paper, a new digitally driven two input continuous mode Doherty power amplifier (DPA) architecture is proposed along with an analytical-based generic output combiner network design methodology. The load combiner provides the designer a choice to meet the optimum performance for any arbitrary back-off as well as for saturation. The PA's performance is further optimized with digital input splitting. To verify the proposed theory, a 20-W symmetrical continuous mode DPA is designed using 10-W GaN HEMTs. The proposed amplifier shows a drain efficiency between 56.0% and 75.4% at 41.4–44.6 dBm saturation power and between 45% and 56.5% at 35.7–38.5 dBm output power corresponding to 6-dB back-off. This performance is achieved over the band from 1.25 to 2.3 GHz that corresponds to 59.15% fractional bandwidth. The proposed hybrid analog/digital continuous mode DPA prototype is implemented using field-programmable gate array (FPGA)/DSP platform and qualifies the spectral mask when excited by a modulated long term evolution signal along with digital predistortion.

Monolithic Integration of Self-Biased C-band Circulator on SiC Substrate for GaN MMIC Applications

IDP Research, QORVO, Richardson, Texas, 75080, USA
IDP, Qorvo, Newbury Park, 950 Lawrence Drive, Newbury Park, CA 91320, USA
Applied Materials Division, Argonne National Laboratory, Lemont IL, 60439, USA

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2921090

We have designed and fabricated the first self-biased circulator operating in C-band, and monolithically integrated it with Qorvo's GaN MMIC technology by embedding a FeNi-based magnetic nanowire

composite (MNC) in a 100 lm thick SiC substrate. This integrated microstrip circulator shows a circulation frequency centered at 5.7 GHz, with an insertion loss of 2.7 dB and isolation of 14 dB. The circulator also demonstrated power handling of 9.6 W with continuous wave and at least 40 W under pulsed conditions. This work points a path to integrating miniaturized circulators into full-duplex GaN T/R MMICs with stringent form factor limits.

Nonlinear resistive switching features of rapid-thermal-annealed aluminum nitride dielectrics with modified charge trapping behaviors

Department of Electronic Engineering, Chang Gung University, Guishan Dist. 33302, Taoyuan, Taiwan
Department of Neurosurgery, Chang Gung Memorial Hospital, Linkou, Guishan Dist. 33305, Taoyuan, Taiwan
Department of Electronic Engineering, Ming Chi University of Technology, Taishan Dist. 24301, New Taipei City, Taiwan

Microelectronic Engineering
https://doi.org/10.1016/j.mee.2019.111033

Nonlinear resistive switching (RS) features of aluminum nitride (AlNx)-based resistance random access memories (RRAMs) with rapid thermal annealing (RTA) have been investigated. The operation voltages of AlNx-based RRAMs are improved by RTA because of the reduction in nitride traps within AlNx dielectrics. In addition, the centroids of nitride traps are modified by RTA and a tunneling barrier at the Ir/AlNx interface is formed for the enhancement of nonlinearity to more than 10 during RS operation. The nonlinear behaviors of AlNx-based RRAMs with RTA can be attributed to the combination of conduction mechanisms of direct tunneling (DT) and trap-assisted tunneling (TAT) at low- and high-voltage regions, respectively. Furthermore, superior device reliabilities of AlNx-based RRAMs with RTA are achieved such as an endurance of over 500 cycles and data retention of more than 104 s. The adjustable nonlinear features and superior memory properties render the annealed AlNx-based RRAMs promising for future high-density nonvolatile memory arrays.

Current collapse scaling in GaN/AlGaN/SiC high electron mobility transistors

Solid State Physics Laboratory, Lucknow Road, Timarpur, Delhi 110054, India

Solid State Electronics Letters
https://doi.org/10.1016/j.ssel.2019.04.002

This study reports the scaling of current collapse in GaN/AlGaN HEMTs with respect to the un-passivated gate drain distance on the gate edge. The source drain current reduction increased from 4 mA to 28 mA, when un-passivated gap increased from 200 nm to 600 nm respectively mainly due to virtual gate formation at gate edge as a result of applied large reverse bias between the gate/drain electrodes. The length of virtual gate is a function of un-passivated gap that modifies the lateral electric field between gate-drain region and results in variable current reduction due to variation in available traps with gap. The simulated E-field distribution is found to vary strongly with the un-passivated gap up to 200 nm and weakly thereafter. The HEMT knee voltage shifted from 0.5 V to 1.2 V when gap is increased from 200 nm to 600 nm respectively due to electric field distribution modification and hence electron trapping in the un-passivated gap resulting in increased device on-resistance (Ron). The current collapse finally resulted in reduction of device saturated RF power to 1.2 W/mm at 2.2 GHz for HEMT with an un-passivated gap of 600 nm.

Linearity improvement in E-mode ferroelectric GaN MOS-HEMT using dual gate technology

School of Electronics, VIT-AP University, India
National Institute of Technology, India

Micro & Nano Letters
https://doi.org/10.1049/mnl.2018.5499

In this work, an enhancement mode dual gate ferroelectric gallium nitride metal oxide semiconductor-high electron mobility transistor (GaN MOS-HEMT) is proposed with enhanced linearity characteristics. The different DC characteristics of the device are analysed and compared with available experimental data of single gate un-recessed ferroelectric GaN MOS-HEMT. In order to analyse the linearity performance of the devices, a look up table-

based large signal model is developed directly from technology computer-aided device simulation results built by feeding different small signal parameters. The different linearity characteristics such as input third-order intercept point (IIP3), the input gain compression point (P1dB), third-order intermodulation (IM3) and the carrier to intermodulation power ratio of both the devices are compared by harmonic balance simulation of the developed large signal models. The interlink between IIP3 and IM3 with transconductance indicates that the broader the transconductance distribution with respect to different gate voltage generates higher IIP3 and lower IM3, which results in an improved linearity performance. The dual gate device shows improved linearity performance resulting in applicability in radiofrequency front end receiver.

High Breakdown Voltage in RF AlN/GaN/AlN Quantum Well HEMTs

Cornell Univeristy, Ithaca, NY 14853

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2923085

In evaluating GaN HEMTs for high-power applications, it is crucial to consider the device-level breakdown characteristics. This work replaces the conventional AlGaN barrier and common AlGaN backbarrier with unstrained AlN, and it assesses the breakdown voltage of AlN/GaN/AlN quantum well HEMTs for gate-drain spacings in the range of 0.27 to 5.1 microns. Results are highlighted by a high breakdown voltage of 78 V for a gate-drain spacing of 390 nm, among the best reported for submicron-channel devices. Additionally, small-signal RF measurements showed record performance for HEMTs on the AlN platform, with ft=fmax = 161/70 GHz. Cutoff frequency and corresponding drain bias are benchmarked against stateof-the-art GaN HEMTs using the Johnson figure of merit, with measured devices highlighted by a JFoM value of 2.2 THzV. These results illustrate the potential for AlN/GaN/AlN quantum well HEMTs as a future platform for high-power RF transistors.

Influence of Different Fin Configurations on Small-Signal Performance and Linearity for AlGaN/GaN Fin-HEMTs

State Key Discipline Laboratory of Wide Band Gap Semiconductor Technology, School of Microelectronics, Xidian University, Xi'an 710071, China
School of Advanced Materials and Nanotechnology, Xidian University, Xi'an 710071, China

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2921445

In this paper, AlGaN/GaN high-electron mobility transistors (HEMTs) with different fin configurations are fabricated and analyzed. Through S-parameter measurements and modeling of the designed devices, a detailed RF investigation on small-signal model parameters is performed under different biasing conditions. Good agreements between measured and simulated scattering parameters up to 40 GHz illustrate the validity and accuracy of the model. The influence of different fin structures on model parameters and linearity improvement is examined, and this can help to improve the frequency characteristics of fin structure by optimizing the fin length, fin width, and trench width. The significant linearity of Fin-HEMTs is confirmed by the analysis of the model parameters, which is the first time to study the small-signal characteristic of AlGaN/GaN Fin-HEMTs in detail.

An Accurate Characterization of Capture Time Constants in GaN HEMTs

DETI, Instituto de Telecomunicações, Universidade de Aveiro, 3810-193 Aveiro, Portugal

IEEE Transactions on Microwave Theory and Techniques
https://doi.org/10.1109/TMTT.2019.2921338

This paper provides theoretical and experimental evidence that, contrary to what is a widely reported belief, the capture time constant of GaN high-electron-mobility transistor (HEMTs) deep-level traps is not infinitesimally shorter than the modulation envelope time features of usual excitation signals. Instead, it can have a nonnegligible impact on their power amplification. A specifically conceived test bench, capable of measuring capture time constants at guaranteed invariant thermal dissipation

conditions, revealed that the capture process can range from less than a microsecond up to a few tens of milliseconds. Furthermore, a theoretical justification based on the Shockley-Read-Hall statistics is provided to explain this widespread time constants' behavior of deep-level traps. As a practical application example of these findings, the detailed characterization of the capture time constants performed in this paper proved to constitute a valuable tool in understanding the behavior of GaN power amplifiers (PAs) designed for pulsed radar signals.

An Unequally Spaced Multi-Tone Load-Pull Characterization Technique for Simultaneous Linearity and Efficiency Assessment of RF Power Devices

XLIM Laboratory, University of Limoges, 19100 Brive La Gaillarde, France
Keysight Technologies, Santa Rosa, CA 95403 USA

IEEE Transactions on Microwave Theory and Techniques
https://doi.org/10.1109/TMTT.2019.2918799

This paper presents an innovative experimental method for microwave power devices linearity characterization, based on a carefully designed multi-tone signal. Measurements working deeper into the understanding of in-band (IB) signal-to-noise characterization of nonlinear devices are presented. The test signal used in this paper is based on an unequally spaced multi-tone (USMT) signal, which is a tailored stimulus signal with flexible statistics. Its originality stands in its inherent property of allowing signal and intermodulation (IM) distortion separation to facilitate the derivation of the IB signal-to-noise ratio or linearity degradation, without assuming any specific modulation format. For the first time, this paper reports measurements with small Δf frequency arrangement using an USMT signal to investigate low frequencies (LFs) parasitic effect on the current and the linearity. Furthermore, this test bench allows to analyze together LF phenomena (``trapping effect'', memory effect, etc.) and high-frequency phenomena under large-signal condition with a telecom like signal. Smith chart load-pull linearity contours under wideband USMT test signals are reported for the first time. This provides a new tool to check system-level design specifications and to optimize radio frequency (RF) power amplifier structures with modulated signals. The measurements were performed using a GaN high-electron-mobility transistors (HEMT) 3-W transistor.

High-efficiency Doherty power amplifier with wide OPBO range for base station systems

Hangzhou Dianzi University, People's Republic of China
University of Technology Sydney, Australia

IET Microwaves, Antennas & Propagation
https://doi.org/10.1049/iet-map.2018.5617

A high-efficiency, S-band Doherty power amplifier (DPA) with wide output power back-off (OPBO) range is presented. A novel parasitic capacitance compensation approach is applied at the output of Cree's GaN high-electron-mobility transistor to achieve high saturation efficiency in a wide OPBO range. Specifically, a parallel shorting microstrip line between the transistor output and its match network is adopted to realise parasitic capacitance compensation. The measurement results indicate good Doherty behaviour with 10 dB back-off efficiency of 40.6-44.2% and saturation efficiency of 70.2-73.3% over 2.9-3.3 GHz. When stimulated by a 20-MHz LTE signal with 7.5 dB PAPR, the proposed Doherty amplifier power, combined with digital pre-distortion, achieved adjacent channel leakage ratios below -47.2 dBc. The DPA demonstrate superior performance in OPBO range and efficiency, which makes it an ideal component for base station communication systems.

GROUP 5 – MEMS and Sensors

Group leader: Marc Faucher (IEMN)

Information selected by Knowmade

Room-temperature-operated fast and reversible vertical-heterostructure-diode gas sensor composed of reduced graphene oxide and AlGaN/GaN

School of Advanced Materials Science & Engineering, Sungkyunkwan University, Suwon, Gyeonggi-do 16419, Republic of Korea
SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University, Suwon, Gyeonggi-do 16419, Republic of Korea
Samsung Advanced Institute for Health Sciences & Technology (SAIHST), Sungkyunkwan University, Suwon, Gyeonggi-do 16419, Republic of Korea
Institute of Quantum Biophysics (IQB), Sungkyunkwan University, Suwon, Gyeonggi-do 16419, Republic of Korea
Biomedical Institute for Convergence at SKKU (BICS), Sungkyunkwan University, Suwon, Gyeonggi-do 16419, Republic of Korea
Device Platform Laboratory, Korea Advanced Nano Fab Center, Suwon, Gyeonggi-do 16229, Republic of Korea

Sensors and Actuators B: Chemical
https://doi.org/10.1016/j.snb.2019.126684

A vertical heterostructure diode (VHD) based on a van der Waals heterojunction between reduced graphene oxide (rGO) and Al0.3Ga0.7N/GaN/sapphire was fabricated for use in the chemical sensing of toxic gases. Target gases interacted with the atomically thin rGO layer, which served as a contact and sensing material; this interaction induced a change in the forward bias current of the VHD through modulation of the effective Schottky barrier height (SBH). The VHD gas sensor showed fast, repeatable, reproducible, recoverable, and stable room-temperature (RT)-operable gas-sensing performance for toxic gases, including nitrogen dioxide, sulfur dioxide, and ammonia. The variations of the SBH, ideality factor and series resistance of the VHD gas sensor upon gas exposure were systematically analyzed by studying the changes in the current transport mechanism through the vertical junction due to the presence of various gases. The analysis revealed that the variation of the SBH upon gas exposure is the primary sensing mechanism of the VHD gas sensor. The VHD device has great promise as the fundamental structure of simple, low-power, low-noise, and RT-operable chemical sensors.

Soft and flexible piezoelectric smart patch for vascular graft monitoring based on Aluminum Nitride thin film

Center for Biomolecular Nanotechnologies, Istituto Italiano di Tecnologia, 73010, Arnesano, Le, Italy
Università del Salento, 73100, Lecce, Italy
Università di Bari 'Aldo Moro', Department of vascular surgery, 70121, Bari, Italy

Scientific Reports
https://doi.org/10.1038/s41598-019-44784-1

Vascular grafts are artificial conduits properly designed to substitute a diseased blood vessel. However prosthetic fail can occur without premonitory symptoms. Continuous monitoring of the system can provide useful information not only to extend the graft's life but also to optimize the patient's therapy. In this respect, various techniques have been used, but all of them affect the mechanical properties of the artificial vessel. To overcome these drawbacks, an ultrathin and flexible smart patch based on piezoelectric Aluminum Nitride (AlN) integrated on the extraluminal surface of the prosthesis is presented. The sensor can be conformally wrapped around the external surface of the prosthesis. Its design, mechanical properties and dimensions are properly characterized and optimized in order to maximize performances and to avoid any interference with the graft structure during its activity. The sensorized graft is tested in vitro using a pulsatile recirculating flow system that mimics the physiological and pathological blood flow conditions. In this way, the ability of the device to measure real-time variations of the hemodynamics parameters has been tested. The obtained high sensitivity of 0.012 V Pa−1 m−2, joint to the inherent biocompatibility and non-toxicity of the used materials, demonstrates that the device can successfully monitor the prosthesis functioning under

different conditions, opening new perspectives for real-time vascular graft surveillance.

Aluminum Nitride Lamb Wave Delay Lines With Sub-6 dB Insertion Loss

Department of Electrical and Computing Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA

Journal of Microelectromechanical Systems
https://doi.org/10.1109/JMEMS.2019.2919031

We present a group of low-loss Lamb mode acoustic delay lines in an aluminum nitride (AlN) thin film. The low-loss acoustic delay lines are enabled by the thickness-field-excited single-phase unidirectional transducers. The fabricated miniature acoustic delay lines show a fractional bandwidth of 4.5%, a minimum insertion loss of 5.9 dB, outperforming the previously reported aluminum nitride delay platforms. The demonstrated delay ranges from 105 ns to 165 ns with center frequencies from 175 MHz to 255 MHz. The design approach and the significantly lower insertion loss described herein are expected to open new horizons for hybridized signal processing based on AlN and CMOS.

Functionalized GaN/GaInN heterostructures for hydrogen sulfide sensing

Institute of Functional Nanosystems, Ulm University, D-89069 Ulm, Germany
Institute of Quantum Matter/Semiconductor Physics Group, Ulm University, D-89069 Ulm, Germany

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab112b

Near-surface GaN/GaInN quantum wells (QWs) were investigated as optical transducers for the detection of hydrogen sulfide. The heterostructure sensors were grown by metal organic vapor phase epitaxy and later covered by a thin layer of Au by electron beam evaporation. The QW photoluminescence (PL) is sensitive to changes in the sensor surface potential. By the adsorption of hydrogen sulfide (H2S) on the Au cover layer, downward near-surface band bending results in an increase of the quantum confined Stark effect in the GaInN QW producing a red shift in its luminescence. Unexpectedly, an increase in PL intensity is also observed. A concentration of 0.01 parts per million of H2S in nitrogen has been successfully detected. This phenomenon may be helpful to detect trace amounts of H2S present in the human breath for early detection of diseases.

Formation of effective CuI-GaN heterojunction with excellent ultraviolet photoresponsive photovoltage

Department of Physical Science and Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan
Frontier Research Institute for Material Science, Nagoya Institute of Technology, Nagoya, Japan

physica status solidi a
https://doi.org/10.1002/pssa.201900200

Here, we demonstrate the formation of an effective heterojunction with the p-type γ-copper iodide (γ-CuI) and n-type gallium nitride (GaN) with excellent photodiode characteristics. The γ-CuI/GaN heterojunction showed good rectification characteristics upto applied bias voltage of ±20 V with low saturation current, confirming the suitability of γ-CuI film. The heterojunction diode and UV photoresponsive characteristics of the device were elucidated with temperature-dependent transport behavior analysis. Enhancement in reverse saturation current was observed with increase in temperature, whereas the diode ideality factor reduced with increase in temperature. The heterojunction device showed ultraviolet (UV) photoresponsive photovoltaic action with a prominent photovoltage of 0.93 V. The temperature dependent photovoltaic action was also investigated in the temperature range of 298∼373 K, where the open circuit voltage (Voc) decreased with increase in temperature. The photovoltaic action was obtained at a temperature as high as 373 K, indicating that the γ-CuI/GaN photoresponsive device is quite stable with excellent photovoltage. Our studies revealed the effectiveness of γ-CuI/GaN heterojunction and diode properties to fabricate a heterojunction photodiode with excellent photovoltage and photoresponsivity.

Role of ZrO2 Passivation Layer Thickness in the Fabrication of High-Responsivity GaN Ultraviolet Photodetectors

Semiconductor Materials Lab., Materials Science Section, Raja Ramanna Centre for Advanced Technology, Indore 452013, India
Homi Bhabha National Institute, Training School Complex, Anushakti Nagar, Mumbai 400094, India

physica status solidi rrl
https://doi.org/10.1002/pssr.201900265

The importance of a ZrO2 passivation layer in the fabrication of high-responsivity GaN-based ultraviolet (UV) photodetectors (PDs) is discussed. It is found that an optimum thickness of the ZrO2 layer exists, which plays a critical role in controlling the photoresponse and transient response of the device. Beyond the optimal thickness, the performance of PDs deteriorates, which is limited by the restricted tunneling of photogenerated carriers across the oxide layer. At an optimum ZrO2 thickness of 3 nm, a spectral responsivity of 27 A W−1 at 361 nm is achieved at 4 V applied bias along with the fast response of the device with a rise (fall) time of 28 ms (178 ms), respectively. Such characteristics are found to be similar or better than the recently reported state-of-the-art values for visible blind metal–semiconductor–metal PDs fabricated on GaN. The results confirm that the surface passivation with an optimal thickness of an oxide layer can be used to develop high-responsivity GaN-based UV PDs irrespective of having a large dark current, which is often inevitable due to the presence of a large density of dislocations in GaN epitaxial layers grown on foreign substrates.

Hydrogen Sensing Characteristics of a Metal–Oxide–Semiconductor Diode with Bimetallic Catalysts and a GaOx Dielectric

Department of Electrical Engineering, Institute of Microelectronics, National Cheng-Kung University, Tainan, Taiwan

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2917206

A new metal–oxide–semiconductor (MOS) diode with bimetallic catalysts and a GaO x dielectric is employed herein to fabricate a hydrogen sensor. Bimetallic catalysts, including Pt nanoparticles (NPs) and a Pd thin film, are formed by the proper vacuum thermal evaporation (VTE) approach, and a GaO x dielectric is produced by H 2 O 2 treatment on the GaN surface. The presence of this bimetallic structure can effectively increase the surface area-to-volume ratio and provide a “spill-over” effect. This can substantially enhance the dissociation and adsorption of hydrogen molecules and atoms. The use of a GaO x dielectric effectively suppresses the surface leakage current and increases the adsorption sites for hydrogen atoms. Experimentally, excellent hydrogen sensing properties, including a very high sensing response of 1.1×107 under 1% H 2 /air gas at 300 K, an extremely low detection level (≤100 ppb H 2 /air), a widespread hydrogen concentration sensing range, and a relatively fast sensing speed, were obtained. From a thermodynamic analysis, it is clear that the hydrogen adsorption of the studied device is an exothermic reaction. Therefore, based on the above-mentioned advantages, the studied Pt NP/Pd thin film/GaO x /GaN-based MOS diode shows promise for high-performance hydrogen sensing applications.

Polarization-graded AlGaN Solar-blind p-i-n Detector with 92 % Zero-bias External Quantum Efficiency

Centre for Nanoscience and Engineering, Indian Institute of Science, Bangalore, India, 560012

IEEE Photonics Technology Letters
https://doi.org/10.1109/LPT.2019.2923147

We report on record high zero-bias external quantum efficiency (EQE) of 92 % for back-illuminated Al0.40Ga0.60N p-i-n ultra-violet (UV) photodetectors on sapphire. The zero-bias responsivity measured 211 mA/W at 289 nm, which is the highest value reported for solar-blind, p-i-n detectors realized over any epitaxial wide band gap semiconductor. This is also the first report for a p-i-n detector, where a polarization-graded Mg-doped AlGaN layer is utilized as the p-contact layer. The devices exhibited a ten-orders of magnitude rectification, a low reverse leakage current density of 1 nA/cm2 at 10 V, a high R0A product of 1.3 × 1011 Y.cm2 and supported fields exceeding 5 MV/cm. The light-to-dark current ratio and the UV-to-visible rejection ratio for the detectors exceeded six-orders of magnitude and the thermal

noise limited detectivity (D*) measured 6.1 × 1014 cmHz1/2W-1. The state-of-the-art performance parameters can be attributed to a high crystalline quality absorbing AlGaN epi-layer resulting from the use of an AlN/AlGaN superlattice buffer and an improved p-contact via polarization-grading.

GROUP 6 - Photovoltaics and Energy harvesting

Group leader: Eva Monroy (INAC-CEA)

Information selected by Knowmade

Investigation of the p-GaN layer thickness of InGaN-based photoelectrodes for photoelectrochemical hydrogen generation

Electrical Engineering, King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia
Department of Applied Physics, Tokyo University of Science, Katsushika, Tokyo 125-8585, Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab09d7

We investigated photoelectrochemical hydrogen generation using InGaN-based photoelectrodes with different p-GaN layer thicknesses. It was confirmed that the photocurrent density and hydrogen generation can be enhanced at zero bias between the photoelectrode and counterelectrode. We found that the maximum energy conversion efficiency was 2.0% when using an InGaN-based photoelectrode with a 20-nm-thick p-GaN layer; this was one order larger than for a photoelectrode without a p-GaN layer. The p-GaN layer can pull the potential of the InGaN layer upward, leading to efficient electron–hole separation in the photoabsorption layer and improving carrier transfer from the InGaN layer. By measuring incident photon to current efficiency, it was confirmed that the InGaN layer worked as a photoelectrode since the absorption edge wavelength was around 400 nm.

High Power Density CMOS Compatible Micro-machined MEMs Energy Harvester

Department of Electronics and Communication Engineering, Indian Institute of Technology Roorkee, Roorkee 247667, India
Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee 24767

IEEE Sensors Journal
https://doi.org/10.1109/JSEN.2019.2923972

Optimization of piezoelectric energy harvester (PEH) to convert ambient vibrational energy into maximum electrical energy has been of continued interest. The integration of the proof mass with optimum cantilever width significantly enhances the output power of PEH. In this work, we propose an optimized design of PEH which outperforms the existing AlN based design in terms of power density. We analytically optimize the design of (i) cantilever to harvester length and (ii) cantilever to harvester width (proof mass width) ratios for the maximum output power. The optimized harvester is fabricated using a novel integration scheme for the bottom electrode with Au as an interlayer. The Au interlayer is used to grow a good quality of AlN film with piezoelectric coefficients, d33 = 12 pm/V and d31 = −2.37 pm/V. It is found that in order to achieve the optimum output from PEH, the fractional length and width occupied by cantilever are 28-40% and 38-45%, respectively. The optimized designs are fabricated using a CMOS compatible process. The maximum power density measured from the fabricated PEHs is found to be 9.36 µW/mm3, which is better than similar reported data. The optimized and compact low power PEHs reported in this work have high potential to be integrated with the system on chip (SOC) and other wireless sensor applications.

A nanoporous GaN photoelectrode on patterned sapphire substrates for high-efficiency photoelectrochemical water splitting

School of Electronic Information and Engineering, Hubei University of Science and Technology, Xianning, 437005, China
School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan, 430074, China

Journal of Alloys and Compounds
https://doi.org/10.1016/j.jallcom.2019.06.234

The photoelectrode of highly ordered nanoporous GaN on patterned sapphire substrate (PSS) is exploited to address issues of optical absorption and photocarrier separation efficiency in solar water splitting. The introduced PSS reduces the threading dislocation (TD) density and defects of the GaN epilayer, resulting in the improved crystalline quality,

which suppresses recombination of electron-hole pairs. A single-step top-down etching approach is developed to fabricate the nanoporous GaN using an anodic aluminum oxide (AAO) mask conveniently and economically. The highly ordered nanoporous morphologies of AAO membrane are well transferred into the GaN surface grown on PSS via inductively coupled plasma (ICP) dry etching. Surface nanostructuring significantly increases surface-volume ratio of GaN, more incident light is trapped and absorbed by nanoporous structure, and the unabsorbed light scattered by PSS upwards is re-absorbed in nanoporous GaN. The ultraviolet light absorptance and reflectance of nanoporous GaN grown on PSS were improved significantly, close to 89% and 9% respectively. The resulting improved absorption in the nanoporous GaN further enhances the generation of photocarriers. The increasing surface-volume ratio also contributes to increasing of photoelectrochemical (PEC) reaction area and photocarrier separation efficiency, decrease of photocarrier migration distance towards the GaN-electrolyte interface, more holes participate in the PEC reaction, leading to an improved PEC efficiency and photocurrent density by 470% times with respect to planar counterpart. This work will pave the way towards low-cost and mass production of nanoporous GaN photoelectrode for efficient solar water splitting.

Analytical Study of Performance Parameters of InGaN/GaN Multiple Quantum Well Solar Cell

Hybrid Nanodevice Research Group (HNRG), Electrical Engineering, IIT Indore, Indore 453552, India

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2920934

An analytical study has been carried out to obtain the device performance parameters of InGaN/GaN-based multiple quantum well solar cell (MQWSC). Significant improvements are made upon the preexisting models reported in the literature for predicting device performance matrix for MQWSC. The American Society for Testing and Materials (ASTM) standards data sheets are utilized for attaining photon flux density instead of blackbody radiation formula. Furthermore, the photon flux density is utilized to evaluate the performance parameters of MQWSC and bulk p-i-n solar cell. Results suggest that by incorporating QWs in the intrinsic region ($x = 0.1$ in $In_xGa_{1-x}N$), ~27% increment in the conversion efficiency can be achieved as compared to that from the bulk solar cell. Moreover, the impact of operating temperature in the solar cell performance is also studied. The rise in temperature leads to an increase in short-circuit current density; however, open-circuit voltage and conversion efficiency decrease. A decrement of ~9.7% in the conversion efficiency of MQWSC is observed with the rise in temperature from 200 to 400 K as compared to ~11.6% decline in p-i-n solar cell.

GROUP 7 - Materials, Technology and Fundamental

Group leader: Jean-Christophe Harmand (LPN-CNRS)

NANO

Information selected by
Jesús Zúñiga Pérez (CRHEA-CNRS)

Role of hole confinement in the recombination properties of InGaN quantum structures

Leibniz-Institut für Kristallzüchtung, Berlin, Germany
Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany
Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany
Paul-Drude-Institute of Solid-State Electronics, Berlin, Germany

Scientific Reportsvolume
https://doi.org/10.1038/s41598-019-45218-8

We study the isolated contribution of hole localization for well-known charge carrier recombination properties observed in conventional, polar InGaN quantum wells (QWs). This involves the interplay of charge carrier localization and non-radiative transitions, a non-exponential decay of the emission and a specific temperature dependence of the emission, denoted as “s-shape”. We investigate two dimensional In0.25Ga0.75N QWs of single monolayer (ML) thickness, stacked in a superlattice with GaN barriers of 6, 12, 25 and 50 MLs. Our results are based on scanning and high-resolution transmission electron microscopy (STEM and HR-TEM), continuous-wave (CW) and time-resolved photoluminescence (TRPL) measurements as well as density functional theory (DFT) calculations. We show that the recombination processes in our structures are not affected by polarization fields and electron localization. Nevertheless, we observe all the aforementioned recombination properties typically found in standard polar InGaN quantum wells. Via decreasing the GaN barrier width to 6 MLs and below, the localization of holes in our QWs is strongly reduced. This enhances the influence of non-radiative recombination, resulting in a decreased lifetime of the emission, a weaker spectral dependence of the decay time and a reduced s-shape of the emission peak. These findings suggest that single exponential decay observed in non-polar QWs might be related to an increasing influence of non-radiative transitions

Infrared luminescence from N-polar InN quantum dots and thin films grown by metal organic chemical vapor deposition

Materials Department, University of California, Santa Barbara, California 93106, USA
Electrical and Computer Engineering Department, University of California, Santa Barbara, California 93106, USA

Applied Physics Letters
https://doi.org/10.1063/1.5109734

N-polar InN quantum dots and thin layers grown by metal organic chemical vapor deposition were shown to exhibit tunable emission from around 1.00 µm to longer than 1.55 µm at room temperature. The emission wavelength was dependent on both the growth temperature and quantum dot size or InN layer thickness. No measurable change in InN quantum dot emission wavelength or intensity was observed after capping of the InN quantum dots with GaN, paving the way for incorporating N-polar InN quantum dots into buried regions of device structures.

Role of Ga Surface Diffusion in the Elongation Mechanism and Optical Properties of Catalyst-Free GaN Nanowires Grown by Molecular Beam Epitaxy

Universite Grenoble Alpes, CEA, INAC, F-38000 Grenoble, France
Institut Néel, Université Grenoble Alpes, CNRS, Grenoble INP, F-38000 Grenoble, France

NanoLetters
https://doi.org/10.1021/acs.nanolett.9b00023

We have shown that both the morphology and elongation mechanism of GaN nanowires homoepitaxially grown by plasma-assisted molecular beam epitaxy (PA-MBE) on a [0001]-oriented GaN nanowire template are strongly affected by the nominal gallium/nitrogen flux ratio as well as by additional Ga flux diffusing from the

side walls. Nitrogen-rich growth conditions are found to be associated with a surface energy-driven morphology and reduced Ga diffusion on the (0001) plane. This leads to random nucleation on the (0001) top surface and preferential material accumulation at the periphery. By contrast, gallium-rich growth conditions are characterized by enhanced Ga surface diffusion promoting a kinetically driven morphology. This regime is governed by a potential barrier that limits diffusion from the top surface toward nanowire side walls, leading to a concave nanowire top surface morphology. Switching from one regime to the other can be achieved using the surfactant effect of an additional In flux. The optical properties are found to be strongly affected by growth mode, with point defect incorporation and stacking fault formation depending on gallium/nitrogen flux ratio.

Hybrid simulation of light extraction efficiency in multi-quantum-shell (MQS) NW (nanowire) LED with a current diffusion layer

Meijo Univ., Aichi 468-0073, Japan
Akasaki Research Center, Nagoya Univ., Aichi 464-8601, Japan
Toyoda Gosei Co., Ltd., Aichi 452-8564, Japan
Koito Manufacturing CO., LTD., Tokyo 108-8711, Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab06b6

A multi-quantum-shell (MQS) grown on a GaN nanowire is a promising three-dimensional active region and it is expected to show excellent performance, compared with conventional nitride-based LEDs. However, there are no suitable simulators for calculating optical properties of MQS-LEDs, because of their complex structure. In this study, a hybrid simulation, which is composed of the finite-difference time-domain method, the rigorous coupled wave analysis method, and the ray tracing method, is developed. Applying this useful tool to the calculation of the light extraction efficiency (LEE) of MQS-LEDs, we have found considerable light absorption loss by the large refractive index steps between the active layer, ITO layer and air in the commonly used MQS-LED structure with the ITO electrode. Thus, to eliminate the large refractive index steps, the MQS-LED buried with the n-GaN current diffusion layer, which has a high LEE, was proposed.

Ground-state resonant two-photon transitions in wurtzite GaN/AlN quantum dots

Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstrasse 36, D-10623 Berlin, Germany

PHYSICAL REVIEW B
https://doi.org/10.1103/PhysRevB.99.245303

Two-photon transition rates are investigated in resonance to the ground state in wurtzite GaN/AlN quantum dots. The ground-state transition is two-photon allowed because of the electron-hole separation inherent to polar wurtzite III–nitride heterostructures. We show that this built-in parity-breaking mechanism can allow deterministic triggering of single-photon emission via coherent two-photon excitation. Radiative lifetimes obtained for single-photon relaxation are in good agreement with available time-resolved microphotoluminescence experiments, indicating the reliability of the employed computational framework based on eight-band k·p wave functions. Two-photon singly induced emission is explored in terms of possible cavity and nondegeneracy enhancement of two-photon processes.

Dual wavelength lasing of InGaN/GaN axial-heterostructure nanorod lasers

Department of Chemistry, Kyung Hee University, Seoul 130-701, Korea
Department of Chemistry, Kookmin University, Seoul 136-702, Korea
Department of Materials Science and Engineering, Korea University, Seoul 136-701, Korea

Nanoscale
https://doi.org/10.1039/C9NR03906F

Optical confinement effects are investigated in InGaN/GaN axial-heterostructure nanolasers. Cylindrical nanorods with GaN/InGaN/GaN structures are prepared using combined processes of top-down and bottom-up approach. Lasing of InGaN is observed at a low threshold (1 μJ/cm2), which is attributed to efficient carrier transfer process from GaN to InGaN. Lasing of GaN is also found at the threshold range of 10–20 μJ/cm2 with

a superlinear increase in emission intensity and high quality factors (Q = 1,000), implying that dual wavelengths of lasing are tunable as a function of excitation intensity. The non-classical Fabry–Pérot modes suggest strong light–matter interactions in nanorods by optical confinement effects. The polarization of lasing indicates that the non-classical modes are in the identical transverse mode, which supports formation of exciton–polariton in nanorods. The polariton lasing in a single axial-heterostructure nanorod is observed for the first time, which proposes small-sized light sources with low threshold, polarized light, and tunable wavelengths in a single nanorod.

NON/SEMI POLAR

Information selected by Philippe de Mierry

The dependence of AlN molar fraction of AlGaN in wet etching by using tetramethylammonium hydroxide aqueous solution

Department of Materials Science and Engineering, Meijo University, Nagoya 468-8502, Japan
Asahi-Kasei Corporation, Fuji, Shizuoka 416-8501, Japan
Akasaki Research Center, Nagoya University, Nagoya 464-8603, Japa

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab112a

We investigated the etching rate of the m-plane of AlGaN by wet etching with tetramethylammonium hydroxide aqueous solutions (25 wt%, 85 °C). After dry etching was performed along the m-plane of AlGaN, wet etching was performed to stably form the m-plane facet of AlGaN. Also, the etching rate increases as the increased AlN molar fraction. In the case of forming a heterojunction such as a UV light-emitting diode, by performing wet etching for 5 min, the flat m-plane facets were formed even though there was a large dependence in AlN molar fraction. These facets were almost vertical and flat with respect to the c-plane, so it has the potential for the use as laser mirror. Also, no change in current density–voltage characteristics was confirmed after the wet etching. Therefore, this method is effective for deep UV laser diode fabrication technology on sapphire substrate.

Formation of m-plane AlN on plasma-nitrided m-plane sapphire

Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 300, Taiwan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab0ad3

Microwave plasma using a gas mixture of N2 and H2 has been applied for the nitridation of m-plane sapphire substrate to form a thick epitaxial AlN film. The X-ray diffraction results show that the AlN films formed on the sapphire surface by nitridation for a period from 10–60 min are in (10-10) orientation and have an epitaxial relationship with the substrate. The thickness of the nitride film increases with nitridation time and approaches about 0.5 µm after nitridation for 1 h, while the film surface becomes rough. The film quality is reasonably good, as evaluated with the X-ray rocking curve of (10-10) AlN. Faceted voids in the sapphire substrate underneath the AlN are also observed with inclined a-plane facets after nitridation.

Comparison of optical properties of polarization-matched c-plane and lattice-matched a-plane BInGaN/GaN quantum well structures

Department of Electronics Engineering, Catholic University of Daegu, Hayang, Kyeongsan, Kyeongbuk, 38430, Republic of Korea

Physica B: Condensed Matter
https://doi.org/10.1016/j.physb.2019.06.014

Light emission characteristics of polarization-matched polar (c-plane) and lattice-matched nonpolar (a-plane) BInGaN/GaN quantum well (QW) structures were investigated as a function of B content and well width. The peak intensity of the lattice-matched a-plane BInGaN/GaN QW structure is shown to be similar to that of the polarization-matched c-plane BInGaN/GaN QW structure, which is about two and half times larger than that of the conventional InGaN/GaN QW structure. The peak intensity is a weak function of the In content. Also, the QW structure with thick well width shows the

peak intensity comparable to that for the QW structure with thin well width. Hence, we expect that the lattice-matched a-plane BInGaN/GaN QW structure could be used as a thick BInGaN active layer for a high efficiency and a reduced droop. In addition, nonpolar QW structures show high polarization ratio, which ranges from 0.976 to 0.992 in investigated In content and well width.

Insight into the impact of atomic- and nano-scale indium distributions on the optical properties of InGaN/GaN quantum well structures grown on m-plane freestanding GaN substrates

Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge CB3 0FS, United Kingdom
Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom
Department of Electrical Engineering, University College Cork, Cork T12YN60, Ireland
Photonics Theory Group, Tyndall National Institute, Dyke Parade, Cork T12R5CP, Ireland
Photon Science Institute, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom

Journal of Applied Physics
https://doi.org/10.1063/1.5097411

We investigate the atomic scale structure of m-plane InGaN quantum wells grown on bulk m-plane GaN templates and reveal that as the indium content increases there is an increased tendency for nonrandom clustering of indium atoms to occur. Based on the atom probe tomography data used to reveal this clustering, we develop a $k \cdot p$ model that takes these features into account and links the observed nanostructure to the optical properties of the quantum wells. The calculations show that electrons and holes tend to colocalize at indium clusters. The transition energies between the electron and hole states are strongly affected by the shape and size of the clusters. Hence, clustering contributes to the very large line widths observed in the experimental low temperature photoluminescence spectra. Also, the emission from m-plane InGaN quantum wells is strongly linearly polarized. Clustering does not alter the theoretically predicted polarization properties, even when the shape of the cluster is strongly asymmetric. Overall, however, we show that the presence of clustering does impact the optical properties, illustrating the importance of careful characterization of the nanoscale structure of m-plane InGaN quantum wells and that atom probe tomography is a useful and important tool to address this problem.

Continuous-wave operation of a semipolar InGaN distributed-feedback blue laser diode with a first-order indium tin oxide surface grating

Department of Electrical and Computer Engineering, University of California, Santa Barbara, California 93106, USA
Materials Department, University of California, Santa Barbara, California 93106, USA

Optics Letters
https://doi.org/10.1364/OL.44.003106

A novel approach to realize DFB gratings on GaN based laser diodes is presented and continuous-wave single longitudinal mode operation is achieved. The first order gratings were fabricated on the surface of indium tin oxide (ITO) on top of the laser ridge, which combines the benefits of simplified fabrication, easy scalability to wider ridges, and no regrowth or overgrowth. Under continuous-wave operation, the laser emits with a full FWHM of 5 pm, a SMSR of 29 dB and output power from a single facet as high as 80 mW. To the best of authors' knowledge, this is also the first demonstration of a DFB-LD on semipolar InGaN/GaN system.

Metalorganic vapor phase epitaxy of pit-free AlN homoepitaxial films on various semipolar substrates

Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.06.010

Semipolar AlN homoepitaxial films, which are expected to act as underlying layers of highly efficient light emitters, are fabricated on 15°-off (0 0 0 1), (1 0 2), and (1 1 2) AlN substrates using the

metalorganic vapor phase epitaxy method. In conventional (0 0 0 1) AlN growth, low reactor pressures are preferred to enhance the migration of Al adatoms and to suppress parasitic reactions between trimethylaluminum and ammonia. In contrast, low-pressure growth generates numerous pits on the surface of semipolar AlN grown homoepitaxially, which are derived from defects formed in the initial growth stage. Herein we experimentally demonstrate that higher-pressure growth can drastically decrease the pit density. A higher-pressure growth realizes atomically smooth surfaces, strong near-band-edge emissions with narrow line widths (1–2 meV), and well-suppressed deep level emissions. The optimal reactor pressure to eliminate pits is 500 Torr in terms of the growth rate and nucleation density.

Effects of indium surfactant and MgN intermediate layers on surface morphology and crystalline quality of nonpolar a-plane AlGaN epi-layers

Advanced Photonics Center, Southeast University, Nanjing 210096, Jiangsu, China

Optik
https://doi.org/10.1016/j.ijleo.2019.162978

High quality non-polar a-plane AlGaN epi-layers with dual MgN interlayers were successfully grown on semi-polar r-plane sapphire substrates with the indium-surfactant-assisted metal organic chemical vapor disposition (MOCVD) technology, and characterized with atomic force microscopy, cathode luminescence (CL), and high-resolution X-ray diffraction rocking curve. It was found that both surface morphology and crystalline quality of the non-polar AlGaN films were strongly dependent on the mass flow of indium surfactant in the MOCVD growth process. In fact, the great suppression of the deep energy level impurity-related transitions in the CL spectra indicates a significant enhancement in crystalline quality for the non-polar AlGaN films. Moreover, with the optimization of the indium surfactant mass flow, a root mean square value as small as 10.9 nm was achieved, demonstrating a remarkable improvement in surface morphology for the a-plane AlGaN epi-layer.

Barrier Inhomogeneity of Schottky Diode on Nonpolar AlN Grown by Physical Vapor Transport

College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China

IEEE Journal of the Electron Devices Society
https://doi.org/10.1109/JEDS.2019.2923204

An aluminum nitride (AlN) Schottky barrier diode (SBD) was fabricated on a nonpolar AlN crystal grown on tungsten substrate by physical vapor transport. The Ni/Au-AlN SBD features a low ideality factor n of 3.3 and an effective Schottky barrier height (SBH) of 1.05 eV at room temperature. The ideality factor n decreases and the effective SBH increases at high temperatures. The temperature dependences of n and SBH were explained using an inhomogeneous model. A mean SBH of 2.105 eV was obtained for the Ni-AlN Schottky junction from the inhomogeneity analysis of the current-voltage characteristics. An equation in which the parameters have explicit physical meanings in thermionic emission theory is proposed to describe the current-voltage characteristics of inhomogeneous SBDs.

Intersubband Transitions in Nonpolar GaN-based Resonant Phonon Depopulation Multiple-Quantum Wells for Terahertz Emissions

Department of Physics, College of Electronic Information and Electrical Engineering, Shangluo University, Shangzhou, China
Department of Physics, Beijing Jiaotong University, Beijing, China
College of Chemical Engineering and Modern Materials, Shangluo University, Shangzhou, China

Journal of the Korean Physical Society
https://doi.org/10.3938/jkps.74.1039

We investigate the polarization effect in intersubband transitions in polar and nonpolar GaN-based multiple-quantum well (MQW) structures for terahertz (THz) emissions by using systematic comparisons and design a nonpolar GaN/Al0.2Ga0.8N two-well-based MQW structure with an emitting photon of 7.27 THz (30.07 meV). Its lower energy separation (92.7 meV) matches the resonant phonon depopulation condition for better

population inversion. It shows a lower threshold current density Jth at all temperatures (1.548 kA/cm2 at 90 K) and a higher output power of up to 86.1 mW at 5.8 K and 33.6 mW at 100 K. Our results for the polar GaN MQW are very close to the experimental data in the literature. We find that the Jth of the nonpolar GaN MQW increases more slowly than that of the polar GaN MQW as temperature increases, indicating the nonpolar GaN MQW may be a worth-trying direction for improving the operation temperature. These results can provide meaningful references for the design and fabrication of nonpolar GaN-based THz MQW or quantum cascade structures.

Anisotropic mosaicity and lattice-plane twisting of an m-plane GaN homoepitaxial layer

Center for GaN Characterization, Research Network and Facility Services Division (RNFS), National Institute for Materials Science (NIMS), Tsukuba, 305-0047 Japan
Synchrotron X-ray Group, Research Center for Advanced Measurement and Characterization, NIMS, Kouto, Sayo, 679-5148 Japan
Synchrotron X-ray Station at SPring-8, RNFS, NIMS, Kouto, Sayo, 679-5148 Japan
Innovative Devices Section, Center for Integrated Research of Future Electronics, Institute of Materials and Systems for Sustainability, Nagoya University Furocho, Chikusa, Nagoya, 464-8603 Japan

CrystEngComm
https://doi.org/10.1039/C9CE00463G

We have observed anisotropic mosaicity of an m-plane GaN homoepitaxial layer by X-ray diffraction topography imaging over a wafer and X-ray rocking curves measured at various wafer points. Crystal domains were well aligned along the [0001] directions, but showed higher mosaicity along the [-12-10] direction. Images reconstructed from the full-width at half maximum showed stripe patterns along the [0001] direction. From the bending-angle images at two different azimuthal angles, we found that GaN (10-10) planes were twisted along the [-12-10] direction, which generated anisotropic features. High resolution X-ray rocking curves revealed the multi-domain structure of GaN (10-10) along the [-12-10] direction. The evaluated bending-angle distribution of 0.030 ± 0.013° mainly originated from the epitaxial layer twisting. We propose two possible mechanisms for this anisotropic feature and the stripe patterns correlated with epitaxial layer twisting.

MATERIAL / CHARACTERIZATION / EQUIPMENT / NUMERICAL SIMULATION

Information selected by Agnès Trassoudaine (Université d'Auvergne), Yvon Cordier and Mathieu Leroux (CRHEA-CNRS)

Analysis of strain and dislocation evolution during MOCVD growth of an AlGaN/GaN power high-electron-mobility transistor structure

STR Group—Soft-Impact, Ltd., 64 Bolshoi Sampsonievskii pr., Build. "E" 194044, St. Petersburg, Russia
ON Semiconductor Czech Republic, s.r.o., 1. maje 2230 Roznov pod Radhostem, 756 61 Czechia

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab138e

We present the results of a comprehensive analysis of GaN-on-Si based HEMT epi-wafers grown by metal-organic chemical vapor deposition (MOCVD) in a production-scale reactor. An AlGaN/AlN superlattice was used as the buffer layer. Detailed characterization was combined with process modeling by STREEM-AlGaN software. Comparative analysis of modeling results, characterization data, and in situ curvature measurements allows the study of the evolution of structural properties of the epi-wafer during growth. The initial compressive mean stress in the superlattice gradually decreases during starting period of the growth and then becomes almost constant. The filtering of the dislocations is more effective in the bottom part of the SL, as both experiment and modeling demonstrate large inclination of dislocations in AlGaN layers of the superlattice, while the predicted dislocation density decreases due to annihilation. Proposed buffer layer and growth recipe resulted in final reduction of the dislocation density to ~2 centerdot 108 cm−2 with good structural uniformity over 6'' wafers and a residual bow below 50 µm.

GaN growth via tri-halide vapor phase epitaxy using solid source of GaCl3: investigation of the growth dependence on NH3 and additional Cl2

Department of Applied Chemistry, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, Japan
Yamanaka Hutech Corporation, Nantan, Kyoto 629-0153, Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab09da

Gallium nitride (GaN) growth via a tri-halide vapor phase epitaxy method using a solid source of GaCl3 and gaseous NH3 was investigated both on Ga-polar and N-polar GaN templates. The relationship between gallium precursor molecule and growth polarity was clarified; it was found that a small amount of GaCl3 could be reduced by H2 originating from the decomposition of NH3 to produce GaCl, and additional Cl2 could suppress the reduction process. Accordingly, GaCl3 was found to be a proper Ga precursor for N-polar GaN growth, whereas GaCl was the proper precursor for Ga-polar GaN growth. The state of the Ga precursor molecule could be predicted by thermodynamic analysis. Furthermore, the decomposition ratio of NH3 could be determined by a combination of the experimental results and the calculated value of the thermodynamic analysis.

Intensive luminescence from a thick, indium-rich In0.7Ga0.3N film

State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, School of Physics, Peking University, 100871 Beijing, People's Republic of China
Institute of Physics, Otto-von-Guericke-University Magdeburg, 39106 Magdeburg, Germany

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab1a5b

An In0.7Ga0.3N layer with a thickness of 300 nm deposited on GaN/sapphire template by molecular beam epitaxy has been investigated by highly spatially resolved cathodoluminescence (CL). High crystal film quality without phase separation has been achieved. The InGaN layer shows intense emission in the IR spectral region. The lateral as well as the vertical luminescence distribution is used to probe the In composition ([In]) homogeneity: the thick InGaN film exhibits laterally a rather homogeneous emission intensity at 1.04 eV (~1185 nm) with a FWHM of only 63 meV. Carrier localization into regions of enhanced In concentration originating from compositional fluctuations is revealed. The evolution of emission in growth direction has been explored by a cross-sectional CL linescan showing a slight spectral redshift from the bottom to the surface of the InGaN film corresponding to an increase of [In] of only 0.5% within the layer thickness of 300 nm.

Cumulative dose γ-irradiation effects on material properties of AlGaN/GaN hetero-structures and electrical properties of HEMT devices

MMIC Fabrication Division, Solid State Physics Laboratory, Lucknow Road, Delhi-India
Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi-India
Semiconductor Device Research Laboratory, Department of Electronic Science, University of Delhi, South Campus, New Delhi–India

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab11a0

The effects of γ-ray irradiation on AlGaN/GaN epitaxial layers and on high electron mobility transistor (HEMT) devices have been systematically investigated. The layer structure and HEMT device has been irradiated cumulatively with γ-ray dose of the order of 16 kGy. The x-ray diffraction (XRD) analysis of irradiated sample shows a lowering in full width at half maximum (FWHM) values along (102) and (002) planes in comparison to the pristine sample due to partial annealing effect. A decrease in the in-plane biaxial stress from 1.20 GPa to 0.75 GPa has been observed. Raman spectrum analysis also corroborates the reduction in stress post γ-ray irradiation. Edge dislocation density is reduced from 2.7 × 108 cm−2 to 1.75 × 108 cm−2 whereas the screw dislocation density remains almost unaffected. Further, Hall measurement shows an improvement in the mobility from 1580 cm2 V−1 s−1 to 2070 cm2 V−1 s−1 with reduction in sheet resistance. This improvement in mobility is attributed due to the decrease in surface roughness as confirmed by atomic force microscopy (AFM)

characterization and also due to re-arrangement of the local defect centers as confirmed by cathodoluminescence (CL) imaging analysis. Finally, an increase in drain current from 99.5 mA mm−1 to 121.2 mA mm−1 with reduction in leakage current has been observed in case of HEMT device due to the improvement found in various material parameters.

Electron mobility calculation for two-dimensional electron gas in InN/GaN digital alloy channel high electron mobility transistors

Graduate School of Engineering, Osaka University, Suita, Osaka 565-0871, Japan

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab0409

The InN/GaN digital alloy is a superlattice-like nanostructure formed by periodically stacking ultra-thin InN and GaN layers. In this study, we calculate the electron mobility in InN/GaN digital alloy channel high electron mobility transistors (HEMTs) by performing a single-particle Monte Carlo simulation. The results of the simulation show that alloy-induced scatterings have little impact and the electron mobility significantly improves as the effective indium mole fraction of the channel increases. This contrasts with InGaN alloy channel HEMTs, where alloy disorder and random dipole scatterings have a strong impact and the electron mobility decreases as the indium mole fraction of the channel increases.

Characterization of 60 mm AlN Single Crystal Wafers Grown by the Physical Vapor Transport Method

Ultratrend Technologies Inc., Hangzhou 310000, China

physica status solidi a
https://doi.org/10.1002/pssa.201900118

Crack-free bulk AlN single crystals up to 60 mm in diameter are successfully grown for the first time using a series of proprietary techniques by the physical vapor transport method. The single crystals are sliced into on-axis (±0.2°) wafers and then lapped/polished following common wafering standards. The obtained wafers are characterized by Raman spectroscopy and high-resolution X-ray diffraction (HRXRD). The Raman spectra show an E2(high) full width at half maximum (FWHM) of 2.85–2.87 cm−1. The symmetric and asymmetric HRXRD rocking curves show FWHMs of 172–288 and 103–242 arcsec, respectively. The optical transmission spectra reveal that the entire wafers exhibit excellent ultraviolet (UV) transparency with absorption coefficients of 14–21 cm−1 in the UV range 4.43–4.77 eV (260–280 nm). The average etch pit density (EPD) determined by preferential chemical etching is about 2.3×105 cm−2. The major impurities determined by evolved gas analysis and glow discharge mass spectrometry are carbon at 7.4×1018 cm−3 (45 ppmw), oxygen at 1.2×1019 cm−3 (100 ppmw), and silicon at 6.8×1017 cm−3 (9.7 ppmw). The usable area of the 60 mm wafers exceeds 98%.

Adaptive low-temperature covalent bonding of III-nitride thin films by extremely thin water interlayers

Fraunhofer Institute for Applied Solid State Physics, Tullastrasse 72, 79108 Freiburg, Germany
Fraunhofer Institute for Microstructure of Materials and Systems, Walter-Huelse-Strasse 1, 06120 Halle, German

Applied Physics Letters
https://doi.org/10.1063/1.5095816

Direct low-temperature bond technologies for III-nitride thin film devices are of great interest to both improve device performance and enable on-wafer integration with other semiconductor technologies. However, thin films released from their growth substrate are rather rough and difficult to prepare for direct bonding. Here, we present a bond technique, which transforms a thin AlN surface layer into a 30 nm solid aluminum hydroxide bond layer. This chemical process is based on the dissolution of AlN and recrystallization of aluminum hydroxides within several nanometers of interfacial water, thereby restructuring and adapting the interfaces to form a homogeneous bond contact without any interfacial voids. AlGaN/GaN microwave transistors bonded on diamond demonstrate an excellent electrical, thermal, and mechanical performance of this bond technology

for high-frequency devices as well as many other III-nitride applications.

Room-temperature infrared photoluminescence in GaN doped with various impurities

Institute of Photonics and Nanotechnology, Vilnius University, Sauletekio av. 3, LT-10257, Vilnius, Lithuania

Optical Materials
https://doi.org/10.1016/j.optmat.2019.05.054

The steady-state infrared-photoluminescence spectra (IR-PL) emitted from about 400 µm thick, free-standing GaN wafers, grown by the ammono-thermal and hydride vapour-phase epitaxy GaN, and containing carbon, magnesium, manganese and iron doping have been examined. The room-temperature IR-PL spectra are correlated with pulsed-photo-ionization spectra using van Roosbroeck-Schockley approach for spectrum conversion. It has been revealed that iron and carbon dopants appear as the most efficient impurities for the room temperature of infra-red emission from GaN grown using different technologies.

Low surface damage during ohmic contact formation in AlGaN/GaN HEMT by selective laser annealing

College of Electrical Engineering, Zhejiang University, People's Republic of China

Electronics Letters
https://doi.org/10.1049/el.2019.0549

The formation of ohmic contact in AlGaN/GaN high electron mobility transistor (HEMT) with low surface damage by selective laser annealing is reported. With selective laser annealing, the device exhibits a smaller sheet resistance, which is 74.9% of the device with the conventional rapid thermal annealing process. The dynamic ON-resistance is 1.35 times higher than the static ON-resistance after off-state drain voltage stress of 200 V, which benefits from the low surface defects using laser annealing. While the dynamic ON-resistance with rapid thermal annealing shows 8.66 times higher than the static ON-resistance after off-state drain voltage stress of 125 V. X-ray photoelectron spectroscopy analysis indicates that the AlGaN surface damage related to the oxidation reaction under the high-temperature condition is eliminated by using selective laser annealing, even in the air ambient.

Trapping dipolar exciton fluids in GaN/(AlGa)N nanostructures

L2C, Universit´e de Montpellier, CNRS, place Eugène Bataillon, F-34095, Montpellier, France
CRHEA, Université Cote d'Azur, CNRS, Rue Bernard Gregory, F-06560, Valbonne, France

NanoLetters
https://doi.org/10.1021/acs.nanolett.9b00914

Dipolar excitons offer a rich playground for both design of novel optoelectronic devices and fundamental many-body physics. Wide GaN/(AlGa)N quantum wells host a new and promising realization of dipolar excitons. We demonstrate the in- plane confinement and cooling of these excitons, when trapped in the electrostatic potential created by semitransparent electrodes of various shapes deposited on the sample surface. This result is a prerequisite for the electrical control of the exciton densities and fluxes, as well for studies of the complex phase diagram of these dipolar bosons at low temperature.

Wurtzite phonons and the mobility of a GaN/AlN 2D hole gas

School of Applied and Engineering Physics, Cornell University, Ithaca, New York 14853, USA
School of Electrical and Computer Engineering, Cornell University, Ithaca, New York 14853, USA
X Development LLC, 100 Mayfield Ave., Mountain View, California 94043, USA
Intel Corporation, 2501 NE Century Blvd., Hillsboro, Oregon 97124, USA
Department of Materials Science and Engineering, Cornell University, Ithaca, New York 14853, USA
Kavli Institute at Cornell, Ithaca, New York 14853, USA

Applied Physics Letters
https://doi.org/10.1063/1.5099957

To make complementary GaN electronics a desirable technology, it is essential to understand the low mobility of 2D hole gases in III-Nitride

heterostructures. This work derives both the acoustic and optical phonon spectra present in one of the most prominent p-channel heterostructures (the all-binary GaN/AlN stack) and computes the interactions of these spectra with the 2D hole gas, capturing the temperature dependence of its intrinsic mobility. Finally, the effects of strain on the electronic structure of the confined 2D hole gas are examined and a means is proposed to engineer the strain to improve the 2D hole mobility for enhanced p-channel device performance, with the goal of enabling wide-bandgap CMOS.

Thermal atomic layer etching of crystalline GaN using sequential exposures of XeF2 and BCl3

Department of Chemistry, University of Colorado, Boulder, Colorado 80309, USA
U.S. Naval Research Laboratory (NRL), Washington, D.C. 20375, USA

Applied Physics Letters
https://doi.org/10.1063/1.5095938

Gallium nitride (GaN) is a wide-bandgap semiconductor that is useful for optoelectronics and high speed and high power electronics. Fabrication of GaN devices requires etching for many processing steps. Gas phase thermal atomic-layer-controlled etching is desirable for damage-free isotropic etching. In this letter, the thermal atomic layer etching (ALE) of crystalline GaN was demonstrated using sequential exposures of XeF2 and BCl3. GaN ALE was achieved with an etch rate of 0.55 Å/cycle at 195 °C using XeF2 exposures for 20 s at 40 mTorr and BCl3 exposures for 0.5 s at 50 mTorr. At the same reactant exposures, GaN etch rates varied with temperature from 0.18 Å/cycle at 170 °C to 0.72 Å/cycle at 300 °C. The GaN etch rates increased slowly with increasing XeF2 exposure. In addition, the GaN etch rate was self-limiting with respect to both increasing BCl3 pressures and BCl3 exposure times. This self-limiting behavior for BCl3 is consistent with a ligand-exchange mechanism for GaN ALE. Alternative fluorination reactants were also investigated including HF, SF4, and NF3 plasma. Sequential exposures of NF3 plasma and BCl3 yielded GaN etch rates of 2.5–2.9 Å/cycle at 250 °C. In contrast, the HF and SF4 fluorination reactants could not etch crystalline GaN.

Epitaxial growth optimization of AlGaN/GaN high electron mobility transistor structures on 3C-SiC/Si

Fraunhofer Institute for Applied Solid State Physics (IAF), Tullastr. 72, 79108 Freiburg, Germany

Journal of Applied Physics
https://doi.org/10.1063/1.5092653

The excellent characteristics of high electron mobility transistors based on AlGaN/GaN heterostructures rely on the properties of the substrate used for their epitaxial growth. In this work, we evaluate 3C-SiC as an alternative to the commonly used 4H-SiC. Up to 2 µm thick 3C-SiC layers on Si templates have been used as substrates to develop an epitaxial growth process for high-quality AlGaN/GaN heterostructures. We demonstrate the deposition of up to 5 µm crack-free heterostructures on 2 µm thick 3C-SiC on Si by using a metalorganic chemical vapor deposition process. Several characteristics of these structures, such as crystal quality, morphology, and electrical properties, are close to what can be achieved when using 4H-SiC substrates. The results of this work motivate further development in order to obtain thicker and semi-insulating 3C-SiC layers to be used instead of the expensive and size-limited 4H-SiC substrates.

The critical role of N-vacancy on chemical composition fluctuations and degradation of InAlN layer

Centre de Recherche sur les Ions, les Matériaux et la Photonique UMR 6252, CNRS ENSICAEN UCBN CEA, 6 Boulevard du Maréchal Juin, 14050 Caen Cedex, France
Institute of Physics, Polish Academy of Sciences, 32/46 al. Lotników, 02-668 Warsaw, Poland
III-V Lab, Campus Polytechnique, 1 Avenue Augustin Fresnel, 91767 Palaiseau, France

Journal of Applied Physics
https://doi.org/10.1063/1.5088109

Due to its intrinsic properties and the possible lattice match to GaN, InAlN is expected to allow the fabrication of optimal high electron mobility transistors for high power and high frequency applications. However, the crystal quality of InAlN nearly lattice-matched to GaN degrades when the layer thickness is increased, and this is a strong

limitation for the fabrication of devices in which thick barriers need to be used. In this work, we have carried out a detailed theoretical investigation of the behavior of indium atoms in the alloy. It is clearly shown that in the presence of nitrogen vacancies, which are common defects in these materials, indium nitride clusters will present excess formation energy up to diameters around 1.4 nm. In parallel, Z-contrast TEM observations close to the InAlN/GaN interface show that 2–5 nm size indium rich areas form and are systematically connected to the vertical degradation channels. This is at variance with published results, which concluded that the observed degradation was exclusively either due to the underlying threading dislocations or due to a characteristic three-dimensional growth mode.

Achieving high electron mobility in AlInGaN/GaN heterostructures: The correlation between thermodynamic stability and electron transport properties

Department of Electrical Engineering, National Central University, Jhongli 32001, Taiwan
Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan

Applied Physics Letters
https://doi.org/10.1063/1.5090874

A significant improvement in electron mobility has been achieved by several authors on AlInGaN/GaN heterostructures by adding a small amount of Ga to the AlInN alloy. In this study, we propose that thermodynamic stability plays an important role in controlling the electron transport properties of these heterostructures. A quantitative investigation of the thermodynamic stability of the AlInGaN barrier has been carried out analytically, for a wide range of compositions ($0.5 \leq Al \leq 0.8$; In = 0.2, 0.15, 0.1). A slow change in the thermodynamic stability is observed when the Ga atoms replace only the Al atoms. In contrast, a significant improvement in thermodynamic stability is observed when the indium atoms are replaced by the Ga atoms in the same Al0.83In0.17N layer. It is found that the Al content in the range of 65%–70% with 10% In exhibits the highest thermodynamic stability within the calculated composition range owing to the significant reduction in total elastic strain in the barrier. Thereby, it leads to the highest electron mobility, as evidenced by the experimental observations in this work, i.e., electron mobility of 2090 cm2/V s with a sheet carrier density of 1.09×1013 cm−2. Therefore, the thermodynamic stability apart from commonly observed scattering mechanisms may at least be partially held to be responsible for the consistent improvement in electron mobility in AlInGaN/GaN heterostructures.

2D materials as semiconducting gate for field-effect transistors with inherent over-voltage protection and boosted ON-current

Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong SAR, China

npj 2D Materials and Applications
https://doi.org/10.1038/s41699-019-0106-6

Various 2D/3D heterostructures can be created by harnessing the advantages of both the layered two-dimensional semiconductors and bulk materials. A semiconducting gate field-effect transistor (SG-FET) structure based on 2D/3D heterostructures is proposed here. The SG-FET is demonstrated on an AlGaN/GaN high-electron mobility transistor (HEMT) by adopting single-layer MoS2 as the gate electrode. The MoS2 semiconducting gate can effectively turn on and turn off the HEMT without sacrificing the subthreshold swing and breakdown voltage. Most importantly, the proposed semiconducting gate can deliver inherent over-voltage protection for field-effect transistors (FETs). Furthermore, the self-adjustable semiconducting gate potential with drain bias can even boost the ON-current while guaranteeing the safe operation of FET. In implementing the semiconducting gate, the layered two-dimensional materials such as the adopted MoS2 have several important benefits such as the feasibility of high-quality crystals on different gate dielectrics and the good controllability of semiconducting gate depletion threshold voltage by the layer thickness. The demonstrated semiconducting gate as over-voltage protection for HEMT can be extended to other FETs, which can become another advantageous arena for the possible applications of the layered two-dimensional materials.

First Observations on the Trap-Induced Avalanche Instability and Safe Operating Area Concerns in AlGaN/GaN HEMTs

Department of Electronic Systems Engineering, Indian Institute of Science, Bangalore 560012, India

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2919491

This paper reports the very first systematic study on the physics of avalanche instability and safe operating area (SOA) reliability in AlGaN/GaN high-electron-mobility transistor (HEMT) using submicroseconds pulse characterization, poststress degradation analysis, well-calibrated TCAD simulations, and failure analysis by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Impacts of electrical and thermal effects on SOA boundary and avalanche instability are investigated. Trap-induced cumulative nature of degradation is studied in detail. The root cause for avalanche instability in AlGaN/GaN HEMTs is investigated. Postfailure SEM, energy dispersive X-ray (EDX), and TEM analysis reveal distinct failure modes in the presence and absence of carrier trapping.

Identifying the Traps in the Channel Region in GaN-based HEMTs Using a Nonmonotone Drain Current Transient

College of Microelectronics, Beijing University of Technology, Beijing, 100124, China

IEEE Transactions on Device and Materials Reliability
https://doi.org/10.1109/TDMR.2019.2923107

The reliability of GaN-based HEMTs is still hindered by trapping effects. Current transient spectroscopy provides an effective way to characterize traps. In this paper, we revealed a trapping behavior hidden in the recovery transients caused by the measuring voltage, and for the first time, we took advantage of it to demonstrate the Ids-related traps in these devices. We applied this method to three different HEMTs and demonstrated traps' energy levels using Arrhenius plots. In particular, we found that the Ids-related traps in different HEMTs had different temperature dependences. A perfect exponential relationship between the degradation rate and the channel current in the linear region was identified. This method provides an effective and easy way to localize traps that capture electrons from the 2DEG directly.

Nitrogen-Polar Polarization-Doped Field-Effect Transistor based on Al0.8Ga0.2N/AlN on SiC with drain current over 100 mA/mm

Aalto University, Department of Electronics and Nanoengineering, Espoo, 02150 Finland
Microsystems Technology Laboratories, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA 02139 USA
Faculty of Pure and Applied Science, University of Tsukuba, Tsukuba 305-8573 Japan

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2923902

This letter reports the demonstration of N-polar Al0.8Ga0.2N/AlN continuously-graded-channel polarization-doped field-effect transistors (PolFETs) on SiC. A PolFET with a source to drain distance of 12 µm exhibited a maximum drain current of 62.8 mA/mm and an on/off current-ratio of 1.1 × 10.4. The maximum drain current was stable between 20 °C and 250 °C operating temperatures. With the addition of 30-nm-thick Al2O3 gate insulator the maximum drain current increased to 126 mA/ mm.

Electronic and optical properties of van der Waals heterostructures of g-GaN and transition metal dichalcogenides

School of Automation and Information Engineering, Xi'an University of Technology, Xi'an, Shaanxi 710048, China
School of Mechanical Engineering, Southeast University, Nanjing, Jiangsu 211189, China
Materials Science Program, University of Rochester, Rochester, NY 14627, USA
Department of Radiology, Affiliated Hospital of Yan'an University, Yan'an, Shaanxi 716000, China
School of Science, Jiangsu University of Science and Technology, Zhenjiang, Jiangsu 212001, China

Applied Surface Science
https://doi.org/10.1016/j.apsusc.2019.06.207

Based on first-principles calculations, we systematically investigate the electronic and optical

properties of van der Waals (vdW) heterostructures composed of graphene-like gallium nitride (g-GaN) and transition metal dichalcogenides (TMDs). The investigated vdW heterostructures (g-GaN/MoS2, g-GaN/WS2, g-GaN/MoSe2, and g-GaN/WSe2) are all semiconductors with direct bandgap. In particular, both the g-GaN/MoS2 and g-GaN/WS2 vdW heterostructures possess type-II band alignment, which will facilitate the separation of photogenerated carriers, and enhance their lifetime. Furthermore, band edge positions of these two heterostructures satisfied both water oxidation and reduction energy requirements, suggesting the potential in photocatalysts for water splitting. In addition, both g-GaN/MoS2 and g-GaN/WS2 vdW heterostructures exhibit a high electron mobility, which ensure that the redox reactions for water splitting will be effectively proceeded. More importantly, they show significant absorption peaks in the visible light region, leading to highly efficient utilization of the solar energy. These fascinating properties render the g-GaN/MoS2 and g-GaN/WS2 vdW heterostructures high-efficiency photocatalysts for water splitting.

Type-II band alignment of low-boron-content BGaN/GaN heterostructures

Institute of Photonics and Nanotechnology, Vilnius University, Saulėtekio al. 3, LT-10257 Vilnius, Lithuania
Institute of Materials Science, Kaunas University of Technology, K.Baršausko st. 59, LT-51423 Kaunas, Lithuania
National Institute for Research and Development in Microtechnologies, Erou Iancu Nicolae 126A, 077190 Voluntari, Romania
Faculty of Exact Sciences and Engineering, Hyperion University, Calea Călăraşilor 169, 030615 Bucharest, Romania

Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/ab2337

The band offset parameters of low-boron-content BGaN/GaN heterojunctions have been studied using x-ray photoelectron spectroscopy (XPS) and photoluminescence (PL) in BxGa1−xN epilayers ($x \leq 0.043$) grown on GaN/sapphire and AlN/sapphire templates. A staggered-gap (type-II) band alignment has been identified at the BGaN/GaN heterojunction by XPS. A study of the red shift of deep-level-related yellow PL band and the band gap shrinkage of BGaN epilayers with increasing boron content confirmed the type-II band alignment and enabled us to estimate that the ratio of the conduction-to-valence band discontinuity is 57:43. It is also shown that the band gap bowing of the BGaN alloy system is accommodated in the conduction band.

Properties of N-polar InGaN/GaN quantum wells grown with triethyl gallium and triethyl indium as precursors

Electrical & Computer Engineering Department, University of California Santa Barbara, Santa Barbara, CA 93106, United States of America
Materials Department, University of California Santa Barbara, Santa Barbara, CA 93106, United States of America

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab1204

N-polar InGaN/GaN multi quantum wells (MQWs) were grown by metal organic chemical vapor deposition (MOCVD) using a methyl-free process with triethyl gallium (TEGa) and triethyl indium (TEIn) as precursors allowing the demonstration of N-polar (In,Ga)N layers with residual carbon impurity concentrations as low as 2 × 1016 cm−3, which was about one order of magnitude lower compared to samples grown with trimethyl indium (TMIn) as the indium precursor. The residual oxygen concentration in the samples ranged between 3 and 5 × 1016 cm−3. Interestingly the significantly lower carbon content in the samples grown with TEIn resulted only in a slight increase of the quantum well luminescence compared to the samples grown with TMIn. Independent of the indium precursor used, the luminescence of the N-polar MQWs was significantly less intense compared to complimentary Ga-polar samples, which were also grown for comparison.

Suppressing the compositional nonuniformity of AlGaN grown on HVPE-AlN template with large macro-steps

State Key Laboratory of Luminescence and Applications, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China
Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049 , China

CrystEngComm
https://doi.org/10.1039/C9CE00608G

AlGaN is a promising material for ultraviolet optoelectronic and microelectronic devices. In this report, we investigated the influences of metallization pretreatment on the strain, morphology and optical properties of AlGaN grown on HVPE-AlN. The results indicated the pretreatment could effectively alleviate the compressive strain from HVPE-AlN and thus lower the Al-content in AlGaN. The composition pulling effect was considered to be responsible for the Al-content reduction. On the other hand, the pretreatment could help to improve the surface morphology of AlGaN, which was attributed to the growth mode transition as the introduction of the pretreatment. Besides, the optical measurements revealed the AlGaN directly grown on HVPE-AlN exhibited distinct compositional nonuniformity and the reasons were the macro-steps in the surface of HVPE-AlN and the mobility discrepancy of Al and Ga atoms. The pretreatment could eliminate such nonuniformity efficaciously. The carbon-clusters formed by metal-organics decomposition during the pretreatment was believed to be responsible for the improvement. The localized excitonic characteristics were also studied. It was found the localized excitonic states were abundant and energy transport processes were complex in AlGaN directly grown on HVPE-AlN, which would result in undesired light emissions. The pretreatment was proved to be effective to optimize the localized excitonic characteristics, which may be attributed to the alleviation of Al-content fluctuation by the pretreatment. These results can not only provide deeper understanding of AlGaN epitaxy, but also offer an approach to optimize the properties of the AlGaN materials.

Growth of AlN Epilayers on Sapphire Substrates by Using the Mixed-Source Hydride Vapor Phase Epitaxy Method

Department of Nano Fusion Technology, Pusan National University, Busan, Korea
Department of Electronic Materials Engineering, Korea Maritime and Ocean University, Busan, Korea
Power Semiconductor Commercialization Center, Busan, Korea
Department of Nanoenergy Engineering and Department of Nano Fusion Technology, Pusan National University, Busan, Korea
Department of PhysicsAndong National University, Andong, Korea

Journal of the Korean Physical Society
https://doi.org/10.3938/jkps.74.1160

AlN epilayers of different thicknesses were grown directly on sapphire substrates without a buffer layer by using a mixed (Al+Ga) source containing 95 at% Al and a mixed-source hydride vapor phase epitaxy (HVPE) method at a temperature of around 1120°C. The grown epilayers consisted of an AlN alloy in the upper region and an AlGaN alloy in the nucleation region just above the sapphire substrate. The upper part of the epilayer gradually transformed from AlGaN into AlN owing to a decrease in the Ga content of the AlGaN alloy grown on the sapphire substrate with increasing growth thickness. The role of Ga in the mixed (Al+Ga) source in the growth of the epilayer directly on the sapphire substrate and the dependence of the growth mechanism of the epilayer with varying Ga contents on the growth thickness were investigated. We found that Ga in the mixed (Al+Ga) source only acted as an activation material that generated gaseous precursors rather than directly contributing to the growth of the epilayers. The mixed-source HVPE method appears suitable for the growth of thick AlN epilayers.

Indium concentration fluctuations in InGaN/GaN quantum wells

Łukasiewicz
Research Network-Institute of Electronic Materials Technology, Wól-
czy ́nska 133, 01-919 Warsaw, Poland
Institute of High Pressure Physics, Polish Academy of Sciences, Sokolowska 29/37, 01-142, Warsaw, Poland
TopGaN Ltd., Sokolowska 29/37, 01-142, Warsaw, Poland
National Centre for Nuclear Research, Soltana 7, 05-400 Otwock, Poland

Journal of Analytical Atomic Spectrometry
https://doi.org/10.1039/C9JA00122K

InGaN/GaN quantum wells grown by Metalorganic Chemical Vapor Phase Epitaxy (MOVPE) were initially studied by optical measurements and the X-ray Diffraction measurements. The comparison of these two techniques indicated that indium is not distributed homogeneously what was confirmed by transmission electron microscopy in nanometer scale. Experimental results of Secondary Ion Mass Spectrometry (SIMS) measurements showed that this analytic method can provide specific information on In spatial distributions not accessible by other methods. SIMS data revealed that In fluctuations occur only in the lower part of 2 nm thick InGaN quantum wells, whereas the QW composition is quite uniform in the upper parts. From the experimental data, one may estimate SIMS depth resolution of about 0.2 nm and of about 1 µm in lateral directions.

Preparation and optimization of freestanding GaN using low-temperature GaN layer

State Key Lab of Crystal Materials, Shandong University, Jinan, China
Key Lab of Advanced Transducers and Intelligent Control System (Ministry of Education), Taiyuan University of Technology, Taiyuan, China
College of Physics and Optoelectronics, Taiyuan University of Technology, Taiyuan, China

Frontiers of Materials Science
https://doi.org/10.1007/s11706-019-0466-z

In this work, a method to acquire freestanding GaN by using low temperature (LT)-GaN layer was put forward. To obtain porous structure and increase the crystallinity, LT-GaN layers were annealed at high temperature. The morphology of LT-GaN layers with different thickness and annealing temperature before and after annealing was analyzed. Comparison of GaN films using different LT-GaN layers was made to acquire optimal LT-GaN process. According to HRXRD and Raman results, GaN grown on 800 nm LT-GaN layer which was annealed at 1090 °C has good crystal quality and small stress. The GaN film was successfully separated from the substrate after cooling down. The self-separation mechanism of this method was discussed. Cross-sectional EBSD mapping measurements were carried out to investigate the effect of LT-buffer layer on improvement of crystal quality and stress relief. The optical property of the obtained freestanding GaN film was also determined by PL measurement.

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

Sanan IC adds 150mm 650V GaN-on-Si E-HEMT process to wafer foundry portfolio for power electronics

SemiconductorToday

Sanan Integrated Circuit Co Ltd (Sanan IC) of Xiamen City, Fujian province (China's first 6-inch pure-play compound semiconductor wafer foundry) has announced the commercial release of its 150mm gallium nitride on silicon (GaN-on-Si) wafer foundry services, intended for the latest high-voltage AC/DC and DC/AC power electronics applications.

G06P111 is a 650V enhanced-mode high-electron-mobility transistor (E-HEMT) GaN process that adds to the firm's power electronics wafer foundry portfolio of wide-bandgap (WBG) compound semiconductors, which includes 100mm and 150mm silicon carbide (SiC) for high-voltage Schottky barrier diodes (SBD). Leveraging years of high-volume GaN manufacturing experience gained by parent company Sanan Optoelectronics for the LED market, Sanan IC is able to complement its foundry services with in-house metal-organic chemical vapor deposition (MOCVD) growth capabilities of high-voltage, low-leakage GaN-on-Si epitaxial wafers with high uniformity.

"The launch of our 650V GaN E-HEMT process technology exemplifies our commitment to advanced compound semiconductor manufacturing for serving the global market," says Sanan IC's assistant general manager Jasson Chen. "We view GaN-on-silicon as a complimentary technology to silicon carbide as key wide-bandgap semiconductors of choice for today's high-voltage, high-power electronics industry," he adds. "Component suppliers and system designers are migrating to wide-bandgap semiconductors over traditional silicon for enhanced performance, efficiency and reliability in high-power analog designs. Sanan IC is well positioned for success in serving this high-growth, large-scale power electronics market," he believes.

Having passed the JEDEC standard for process reliability qualification, the G06P11 GaN-on-Si process offers device structures for 650V E-mode FETs that support a drain-to-source on-state resistance (RDS(on)) range of 50-400mΩ. Engineered for low leakage, low gate charge, high current density and low dynamic specific on resistance (Rsp), it enables ultra-fast-switching compact designs for high-temperature operation. Following later this year will be the launch of a 200V GaN E-HEMT process as well as a second-generation SiC SBD process with a merged PiN Schottky (MPS) diode structure.

Sanan IC says that GaN-on-Si as a process technology is suitable for the latest wave of consumer and server applications such as power adapters, USB-PD (power delivery), portable chargers and power factor correction (PFC) for AC/DC uninterrupted power supplies (UPS). The technology is also getting traction in other markets such as EV/HEV (hybrid/electric vehicles), LiDAR, and wireless charging. The GaN power device market is rising at a compound annual growth rate (CAGR) of 93% to $423m in 2023, according to the bull-case scenario of market research firm Yole Développement's report 'Power GaN 2018: Epitaxial, Devices, Applications, and Technology Trends report, December 2018'. Sanan IC says that it is dedicated to serving this emerging technology for these multiple market segments in the power electronics industry.

Conductive penetration of aluminium nitride buffers on silicon substrates

SemiconductorToday

Noriko Kurose and Yoshinobu Aoyagi of Ritsumeikan University in Japan claim the first successful fabrication of fully vertical n-type aluminium gallium nitride (n-AlGaN) Schottky diodes on silicon (Si) substrate [J. Appl. Phys., vol125, p205110, 2019]. The device was achieved by creating a conducting path through the normally insulating AlN buffer layer that is needed to grow III-nitride materials on (111)-oriented Si. The conduction was enabled by filling spontaneously formed via holes in the AlN (v-AlN) with n-AlGaN.

Kurose and Aoyagi suggest that the technique could also lead to other vertical high-power devices on silicon, such as vertical n-AlGaN field-effect transistors (FETs), bipolar devices, light-emitting diodes (LEDs), and sensors. Vertical structures push peak electric fields away from the surface of devices where failure often occurs. Production on silicon substrates would substantially reduce manufacturing costs. Further benefit could arise from monolithic integration of III-nitride power structures and silicon control circuitry.

Kurose and Aoyagi used horizontal metal-organic chemical vapor deposition (MOCVD) with trimethyl-gallium (TMG), trimethyl-aluminium (TMA), tetraethyl-silicon (TESi) and ammonia (NH3) precursors in hydrogen carrier gas. The silicon substrates were (111) crystal oriented and doped n-type with antimony.

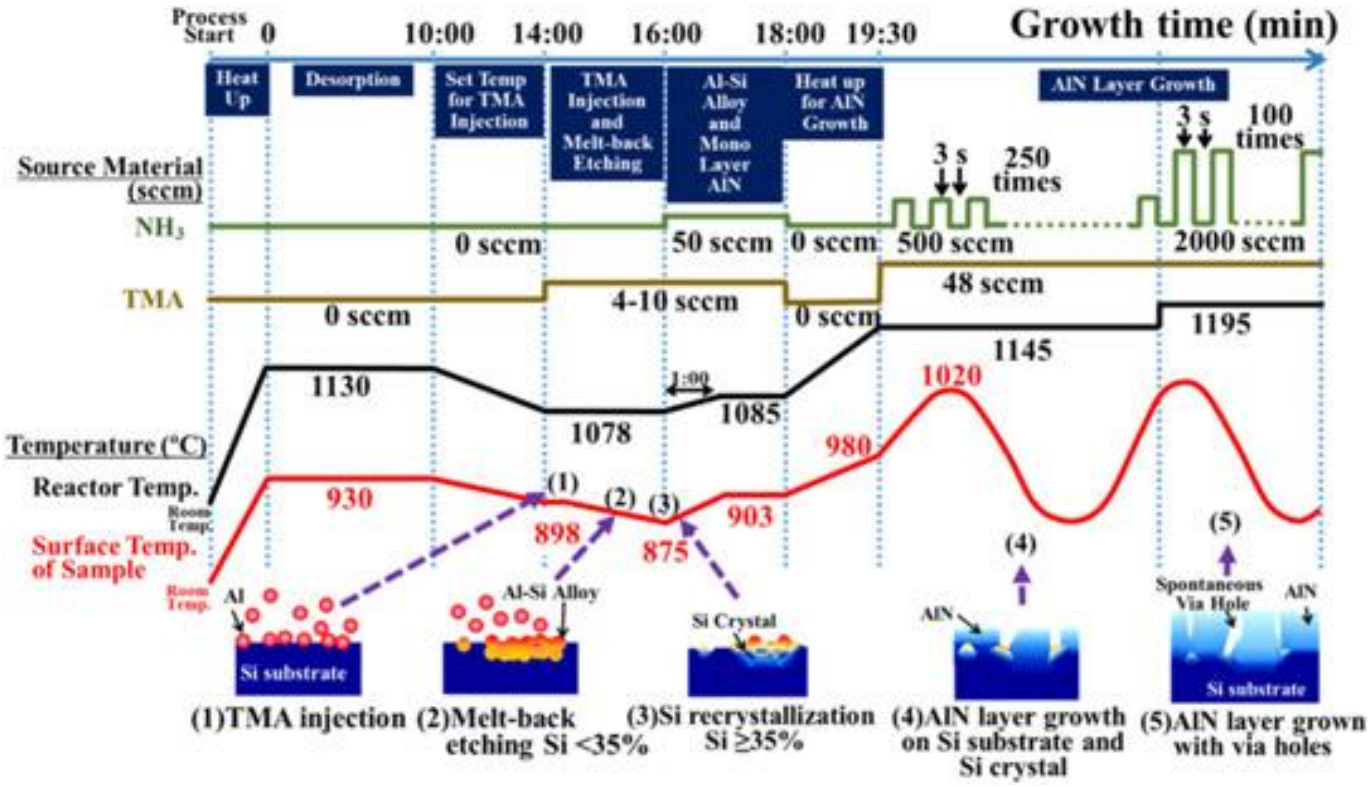


Figure 1: Epitaxial-growth chart and schematic views of cross section of grown layer.

The initial MOCVD growth (Figure 1) generated spontaneous via holes in the AlN nucleation layer. The hole density was (2.5-3.0)x107/cm2, according to optical microscope inspection on samples grown at TMA flow rates of 7 and 8 standard cubic centimeters per minute (sccm). The hole sizes came in the ranges 400-800nm and 500-1000nm, respectively. The depth of the holes were about 80nm, according to atomic force microscopy.

These via holes in the insulating AlN buffer were filled with conductive n-AlGaN using alternate-growth-mode MOCVD where the source materials are fed in in-sequence. The method enhances lateral migration of surface atoms as the growth proceeds.

Scanning electron microscope cross sections of the material showed filling of the via holes with n-AlGaN. Above the via holes, voids tended to form in the overlying n-AlGaN material. A further n-AlGaN layer with somewhat different growth conditions closed the voids and gave a flat surface on which quantum wells and GaN contact layers could be grown.

The voids are seen as being helpful in "reducing the bowing of the epitaxial layer on the Si substrate" and for avoiding cracks in the device layers. Measurements of curvature showed an increase during the AlN growth to 70/km and a decrease to negative values when the n-AlGaN with voids is grown. After cooling, the curvature returned to +70/km. This contrasts with n-AlGaN grown on n-AlN without via holes: the curvature continued increasing to a total of +190/km. This final value was unaffected by cooling.

Vertical conduction structures were made from n-AlGaN layers on v-AlN and non-v-AlN buffers. Ohmic contact metals were applied to both the top n-AlGaN (titanium/aluminium/titanium/gold) and bottom silicon (silver/gold) substrate, followed by sintering. The v-AlN structure demonstrated a low resistance of 33Ω, while the non-v-AlN resistance was 7200Ω. The electrode area was 0.75mm2.

The researchers extracted the specific resistivity of the v-AlN buffer as 100mΩ-cm2, which compares with the non-v-AlN's 54,000mΩ-cm2.

Schottky diodes were also produced with the n-AlGaN electrode replaced with nickel/gold. The layers between the electrodes consisted of 500µm silicon substrate, 300nm v-AlN, and 1µm n-Al0.3Ga0.7N. The forward/reverse current ratio for +/-20V bias was ~104 (Figure 2). The extracted ideality factor of the Schottky diode was 60 while the barrier height was 0.44eV. The series resistance was estimated to be 900Ω. The forward current density at 20V bias was 4.9A/cm2.

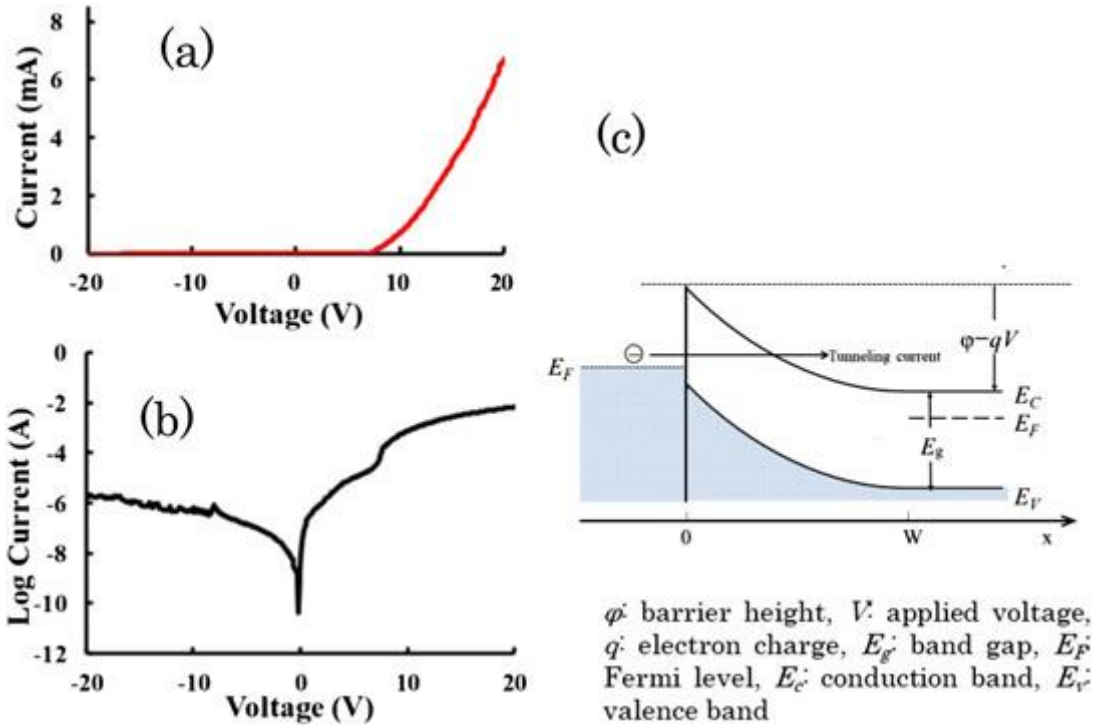


Figure 2: Current-voltage (I–V) characteristics of vertical Schottky diode fabricated on v-AlN: (a) linear plot, (b) logarithmic plot, and (c) band diagram.

The researchers comment: “These values do not indicate a very good Schottky diode performance. This may result from leakage current and/or a high series resistance from our state-of-the-art phase of development of the fully vertical Schottky diode on the Si substrate using v-AlN.”

Comparing the performance of the Schottky and Ohmic devices, the team says that the series resistance mainly originated in the Schottky contact. The thinness of the n-AlGaN layer with unterminated threading dislocations, giving a high leakage current, was blamed for the poor performance. A further effect reducing performance was a high current arising from high fields at the Schottky-electrode edge.

Transphorm adds second 900V GaN FET, targeting three-phase industrial power supplies and automotive converters

SemiconductorToday

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has launched its second 900V FET, the Gen III TP90H050WS (sampling now), enhancing what is claimed to be the industry’s only 900V GaN product line. The devices now enable three-phase industrial systems and higher-voltage automotive electronics to leverage GaN’s speed, efficiency and power density. Further, the new FET’s platform is based on Transphorm’s 650V predecessor, the only JEDEC- and AEC-Q101-qualified HV GaN technology.

The TP90H050WS has a typical on-resistance of 50mΩ with a 1000V transient rating, offered in a standard TO-247 package. It can reach power levels of 8kW in a typical half bridge while maintaining greater than 99% efficiencies. Its figures of merit for Ron*Qoss (resonant switching topologies) and R on*Qrr (hard switching bridge topologies) are 2-5 times less than those of common superjunction technologies in production — indicating highly reduced switching losses. While a JEDEC-qualified version is slated for first-quarter 2020, customers can design 900V GaN power systems today.

Transphorm’s first 900V device, the TP90H180PS (with a typical on-resistance of 170mΩ in a TO-220 package) is JEDEC qualified and has been available through Digi-Key since 2017. It can reach a peak efficiency of 99%, demonstrating its suitability for 3.5kW single-phase inverters.

“Transphorm’s latest 900V GaN product represents a major milestone for commercial GaN power transistors as it reaches the 1kV mark, an industry first,” claims co-founder & chief operating officer Primit Parikh. “This paves the way for GaN to be a viable choice at these higher voltage nodes,” he adds. “With partial funding from ARPA-E for early risk reduction and Power America for initial product qualification, this effort represents successful public-private partnership that accelerates GaN’s market adoption.”

Transphorm says that its 900V platform provides higher breakdown levels for systems already targeted by its 650V FETs, such as renewables, automotive and various broad industrial applications. It is designed to be deployed in bridgeless totem-pole power factor correction (PFC), half-bridge configurations used in DC-to-DC converters and inverters. The ability to support these topologies at a higher voltage expands Transphorm’s target applications to now include a broad list of three-phase industrial applications, such as uninterruptible power supplies (UPS) and automotive chargers/converters at higher battery voltage nodes.

“900V GaN power devices eliminate barriers to access applications not presently supported with GaN semiconductors,” notes Victor Veliadis, deputy executive director & chief technology officer of PowerAmerica, which partially funded the project. “With innovations like this 900V platform, Transphorm is advancing the industry, creating new customer opportunities,” he comments.

Navitas earns Frost & Sullivan's 2019 Global Technology Innovation Award for GaNFast Power Ics

SemiconductorToday

Based on its recent analysis of the global gallium nitride (GaN) integrated circuit (IC) market, Frost & Sullivan has recognized Navitas Semiconductor Inc of El Segundo, CA, USA with the 2019 Global Technology Innovation Award for its unique GaNFast power ICs.

Frost & Sullivan presents the award annually to the firm that has developed a product with innovative features and functionalities that is gaining rapid acceptance in the market. The award recognizes the quality of the solution and the customer-value enhancements it enables.

Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs. The firm says that its proprietary 'AllGaN' process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with GaN logic and analog circuits, enabling faster charging, higher power density and greater energy savings for mobile, consumer, enterprise, eMobility and new energy markets.

The firm leverages its proprietary GaN technology to address challenges such as integration and packaging, manufacturing capability, and voltage and switching issues, which are inherent in the legacy, silicon-dominated semiconductor industry.

"Navitas' power ICs address system- and application-level concerns relating to power electronic circuits incorporated with GaN," comments senior research analyst Sushrutha Katta Sadashiva. "Instead of delivering a stand-alone discrete product, Navitas developed GaN into a system-based solution; this vision resulted in the unique GaNFast power ICs," he adds. "By leveraging its proprietary platform, Navitas achieved monolithic integration of GaN FETs with GaN drivers and other mixed-signal circuits. Navitas has embedded analog, logic and power circuits into a single package, thereby enabling the entire system to be faster, simpler, smaller and more energy efficient than existing offerings."

Through its R&D, Navitas says it has achieved the ability to cater to the technical, size and performance requirements of various power electronic systems such as mobile chargers & adapters, solar inverters, chargers for electric vehicles (EVs), and switch-mode power supplies (SMPS). Its GaNFast power ICs are fabricated on 6-inch enhancement mode (E-mode) GaN-on-silicon wafers. The firm follows a fabless model for developing its products, which encourages third-party semiconductor manufacturers to venture into the GaN domain. Through manufacturing partnerships with Taiwan Semiconductor Manufacturing Company Ltd (TSMC) and Amkor, Navitas has been able to scale to high-volume production. In addition, it has partnered with component manufacturers such as TDK and Hitachi to create miniaturized transformers that can work along with GaNFast power ICs.

Navitas reckons that its GaN power ICs will have a significant impact on consumer electronics, communication, automobiles, energy and other industries where power electronics are widely used. Leveraging the relevance of GaN in power electronic applications with voltages of 200-1200V, the firm has developed power ICs in half-bridge topologies suitable for this range. In renewable energy, GaNFast power ICs can be embedded in solar micro-inverters to reduce operating costs and increase productivity.

"GaN ICs that integrate power, analog and digital circuits are enabling dramatic improvements to next-generation power systems, and we're pleased that Navitas and this exciting technology has been recognized for its industry impact," says CEO & co-founder Gene Sheridan.

"Navitas sets the benchmark for companies planning to venture into the GaN power IC semiconductor market, and will significantly influence the growth of power-efficient and compact electronic devices in the near future," comments Frost & Sullivan's Sushrutha Katta Sadashiva. "Navitas' thought leadership will accelerate the market penetration of GaN through the company's pioneering GaNFast power ICs, which aligns with its vision to lead the high-speed revolution in power electronics."

Lockheed Martin demos LTAMDS radar technology during US Army's Sense-Off

SemiconductorToday

Lockheed Martin (LMT) completed a demonstration of its radar solution for the US Army's Lower Tier Air and Missile Defense Sensor (LTAMDS) program during a 'Sense-Off' at White Sands Missile Range, New Mexico.

During the two-week demonstration period, the Lockheed Martin team completed a series of exercises showcasing its radar solution and how it will meet the Army's requirements for the LTAMDS system, while providing additional deployment strategies for the air & missile defense mission.

The firm's radar will incorporate a balance of mature production radar technology in a scalable, next-generation architecture designed to evolve as mission needs change. Both Lockheed Martin and its strategic partner ELTA Systems Ltd say they are prepared to conduct the testing it takes to meet the Army's timeline.

"The LTAMDS program requires mature technology specifically designed to address the threat, which Lockheed Martin and ELTA both bring to the program. We are demonstrating and proposing an innovative approach," says Dr Rob Smith, VP & general manager of Radar and Sensor Systems at Lockheed Martin. "We will leverage technology that is production-ready and proven in the field, allowing us to meet the Army's requirements quickly and provide qualified systems within 24 months after the initial contract award," he adds. "We have a proven track record of performing on programs with aggressive development and delivery needs, such as the Q-53 radar, where both capability and schedule commitments are extremely important."

Lockheed Martin and ELTA have several recent development and production radar programs that offer active electronically scanned array (AESA) technology, which does not require modifications. Lockheed Martin has already fielded tactical operational radars with gallium nitride (GaN) technology, beginning with its delivery of a TPS-77 Multi Role Radar system to Latvia and a TPS-77 system to Romania (both in 2018). The firm is also on contract to deliver GaN in the Army's Q-53 system.

ELTA is in active production and fielding of the GaN-based ELM-2084 Multi Mission Radar that detects and tracks both aircraft and ballistic targets, while providing fire control guidance for missile interception or artillery air defense. The Army is actively procuring Iron Dome systems that include battle-proven ELM-2084 radars.

The Lockheed Martin team is built around the strength of its global organization and supply base, including strategic partnerships with ELTA and the radar systems engineering expertise of deciBel Research in Huntsville, AL.

Northrop Grumman awarded $958m contract to provide US Marines full-rate production of GaN-based G/ATOR radar systems

SemiconductorToday

The US Marine Corps has awarded Northrop Grumman Corp a $958m contract for Lot 6 full-rate production of an additional 30 units of gallium nitride (GaN)-based AN/TPS-80 Ground/Air Task-Oriented Radar (G/ATOR) systems. The program is managed by Program Executive Officer Land Systems.

"Northrop Grumman and the Marine Corps have successfully partnered to create a best of ground and airborne radar solution that exceeds the current threat on the modern battlefield," says Christine Harbison, VP, land and avionics C4ISR, Northrop Grumman. "G/ATOR is a crucial capability that protects our warfighters and defends against today's threat environment and the threat environment of the future," she adds. "We are excited to reach the full-rate production decision and continue providing advanced multi-mission functionality that meets our customer's mission needs, protects the warfighter in a rapidly changing threat environment, and has significant margin for capability growth."

G/ATOR replaces five legacy systems operated by the Marine Corps with a single system, providing significant improvements in performance compared with the legacy radar families in each of its modes. This results in reduced training, logistics and maintenance costs.

The AN/TPS-80 G/ATOR is an active electronically scanned array (AESA) multi-mission radar that leverages GaN to provide comprehensive real-time, full-sector, 360° situational awareness against a broad array of threats. The highly expeditionary, three-dimensional, short-to-medium-range multi-role radar system is designed to detect, identify and track cruise missiles, manned aircraft and unmanned aerial vehicles (UAVs) as well as rockets, mortars and artillery fire.

UK's CSC-led GaNTT consortium awarded £1.3m via the Office for Low Emission Vehicles

SemiconductorToday

A consortium led by the Compound Semiconductor Centre Ltd (CSC) - a joint venture founded in 2015 between Cardiff University and epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK - has been awarded £1.3m in funding through 'The road to zero emission vehicles' competition sponsored by OLEV (the Office for Low Emission Vehicles). CSC leads a consortium of partners across the power electronics supply chain: SPTS Technologies Ltd of Newport, Wales; Newport Wafer Fab Ltd; Turbo Power Systems Ltd of Gateshead, UK; and the South Wales-based Compound Semiconductor Applications (CSA) Catapult, supplemented with academic expertise in power systems and devices at Swansea University and Coventry University.

The project GaNTT (Realisation of a mass-manufacturable Vertical GaN Trench FET architecture) will develop a voltage-scalable, vertical gallium nitride process platform (200-600V) suitable for electric vehicle (EV) applications and integrate the resulting device into an on-vehicle demonstrator for bi-directional battery charging. Vertical GaN architectures are a viable future technology for low- to medium-voltage and power applications, e.g. on-board charging (OBC) and DC-DC applications where higher switching speed is desirable. It also has the potential to meet the cost challenges related to existing silicon cabide (SiC) field-effect transistor (FET) technologies, although significant challenges in epitaxial material layer quality and device thermal management require de-risking.

The project will focus on the development of large-diameter substrate solutions that provide high-quality, thick GaN layers and address the challenges of lattice mismatch and wafer bow by employing novel epitaxial substrate solutions for future foundry products. Vertical GaN devices architectures enable FET operation at high electric fields and thus facilitate a significant reduction in chip area compared with lateral power devices. The breakdown voltage can be increased by increasing the thickness of the epitaxial drift region supporting the electric field, enabling the voltage to be scaled independently of chip area. The device approach also incorporates an innovative source-metal/P-body Schottky contact approach, patented by researchers at Swansea and Coventry Universities, to provide better control and stability of the channel threshold voltage.

Crucially, the project will evaluate prototype devices at the packaged device and sub-system level, with Turbo Power Systems providing a tier-1 automotive testing environment. The activity aims to establish a 'materials to

system' UK supply chain in wide-bandgap materials and enhance exploitation opportunities for all partners by ensuring that device development is driven by automotive requirements. The performance benefits of the new platform technology are not limited to automotive applications, but are also suitable for use in other harsh environments (e.g. space applications, where the combination of improved power density and radiation-hardness would reduce payload and improve system reliability).

"Vertical GaN Power Technology will deliver emerging opportunities across a broad applications space, currently growing at >50% CAGR [compound annual growth rate] and forecast to be worth >$150-300m by 2023," says CSC's GaN programme manager Robert Harper. "This activity will build on UK strengths in compound semiconductor materials and device technology to energize a new supply chain in automotive power component supply," he adds.

Transphorm awarded $15.9m contract modification to develop US-based production of GaN epi for high-performance RF and mmW electronics

SemiconductorToday

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has been awarded $15,869,322 for a modification (P00002) to a previously awarded cost-plus-fixed-price contract (N68335-19-C-0107) to exercise an option.

The option modification procures the continued services and materials necessary to conduct R&D for a US-based dedicated production source of gallium nitride (GaN) epitaxy for high-performance radio-frequency and millimeter-wave (mmW) electronics.

Work will be performed in Goleta, and is expected to be completed in June 2022. Fiscal 2019 Department of Defense funds of $10m for research, development, test and evaluation will be obligated at the time of award, none of which will expire at the end of the current fiscal year. The Naval Air Warfare Center Aircraft Division in Lakehurst, NJ (NAWCAD Lakehurst) is the contracting activity.

EPC and Spirit to provide lot-specific data services for eGaN power devices

SemiconductorToday

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 partnered with Spirit Electronics of Phoenix, AZ, USA (appointed distributor for the defense & aerospace markets in May 2018) to provide an expanded range of manufacturing-lot-specific data services for its enhancement-mode gallium nitride (eGaN)-based power devices. EPC is offering a variety of data pack services for its eGaN FETs and ICs.

"Our partnership with Spirit Electronics provides the opportunity for EPC to complement Spirit's extensive history and proven successful track record in working with defense and aerospace customers," says CEO & co-founder Alex Lidow. "Offering lot-specific data services related to our eGaN power semiconductor products will enable us to bring additional value to these demanding applications," he adds.

"Our partnership with EPC has been an exciting addition to our portfolio of products, and this new offering of lot-specific data services will further help us bring the superior performance of eGaN power transistors and ICs to defense and aerospace customers, so they can design leading-edge power system solutions," states Spirit Electronics' CEO Marti McCurdy.

Integra Technologies wins US Air Force contract to accelerate thermally enhanced GaN/SiC readiness

SemiconductorToday

Integra Technologies Inc (ITI) of El Segundo, CA, USA (which makes high-power RF and microwave transistors and power amplifier modules for mission-critical applications including radar, electronic warfare and advanced communications systems) has been awarded a two-year contract by the US Air Force to accelerate technology and manufacturing readiness of its patented Thermally Enhanced GaN/SiC technology.

Integra says that its GaN/SiC technology is suitable for high-efficiency, solid-state RF power applications including high-power radar systems requiring improved performance, increased range and reduced operating costs.

The firm has developed its Thermally Enhanced GaN/SiC to deliver superior power and efficiency while operating at lower temperatures, which is a key enabler of next-generation high-performance radar platforms. Integra is leveraging its domestic R&D and manufacturing platform to optimize the GaN epitaxial wafer, device design and package design. Additionally, the US Air Force contract will enable robust qualification of Integra's Thermally Enhanced GaN/SiC for production.

"Through this effort, we have the opportunity to commercialize our leap-ahead GaN/SiC technology to meet the high-efficiency performance and production readiness requirements of the US Department of Defense," says president & CEO Suja Ramnath.

GaN And SiC Require A New Approach To Packaging

CompoundSemiconductor

A generational shift is taking place in power electronics. New semiconductor technologies such as SiC and GaN are enabling smaller and more integrated devices capable of handling higher power density levels. With these, the bottleneck against higher temperature operation is not the semiconductor device but the packaging material.

A critical packaging material is the die (and to a lesser extent substrate) attach. The push towards higher temperatures has, in some cases, already pushed solder, the incumbent, to or beyond its performance limit, creating the need for an alternative. The need to sustain the roadmap towards higher temperature will only aggravate the challenge.

Sintered metal pastes have emerged as a compelling proposition. They increase the thermal conductivity and the melting temperature, allowing devices to reliability operate at higher temperatures. This technology is already in commercial use after some seven years of development and its markets will expand as the shift towards new semiconductor technologies further accelerates.

Sintered metal paste technology is improving. The development targets are to achieve rapid low (or zero) pressure sintering of ever larger surface areas and to narrow the significant price differential versus SAC solder. There is innovation in the material system.

Ag is dominant but promising Cu alternatives have also emerged with friendlier sintering conditions. Nano or hybrid (nano + micron) are positioning themselves as alternatives to traditional solutions based on micron-sized particles. The short-term promise is to lower the sintering temperature whilst the long-term one is to eliminate it altogether. Suppliers are also diversifying the product form factor, moving beyond just screen or stencil printing, to make the product more of a drop-in replacement. Machines makers are now offering turn-key solutions, integrating the pick-and-place, the drying, the pressure sintering units.

OPTOELECTRONICS

Chromium/aluminium n-electrode for reflection boost of deep-ultraviolet LEDs

SemiconductorToday

Researchers based in China have been applying reflective n-type electrode metal structures to boost light extraction in 280nm-wavelength deep-ultraviolet light-emitting diodes (DUV-LEDs) [Yang Gao et al, IEEE Transactions on Electron Devices, published online 21 May 2019]. One of the big challenges for sub-300nm DUV devices is pushing the efficiency above 10%.

The work by Huazhong University of Science and Technology and University of Science and Technology of China used a chromium/aluminium combination to enhance reflection of the electrodes on the n-type aluminium gallium nitride (AlGaN) contact layer of the LEDs. While the chromium absorbs DUV radiation, aluminium is highly reflective.

The researchers explain the need for chromium in the electrode: "If we only adopt the Al layer as the n-type electrode, it is almost impossible to form an ohmic contact with the Al-rich n-AlGaN. Therefore, a Cr metal layer must be introduced before the deposition of the Al layer to form an ohmic contact and improve the electrical performance."

The researchers see DUV applications in sterilization, water/air purification, medical and bio-related equipment. Competing mercury-lamp devices have drawbacks such as system fragility and bulk, along with short lifetime and low efficiency. And, of course, mercury is highly toxic.

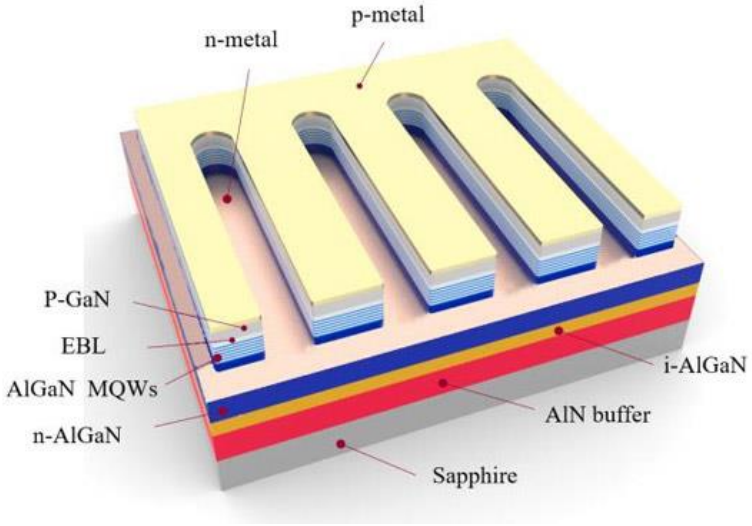


Figure 1: Schematic of flip-chip DUV-LED device.

The DUV-LED material was grown by metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire. The buffer consisted of 2µm of AlN. Undoped Al0.55Ga0.45N was used for strain release before a silicon-doped n-Al0.55Ga0.45N contact layer. The light-emitting active region contained five 2.5nm Al0.37Ga0.63N quantum wells separated by 12.5nm Al0.51Ga0.49N barriers. The p-side of the device consisted of magnesium-doped p-Al0.7Ga0.3N and p-GaN contact layers.

The fabrication process was designed to create flip-chips with the DUV light emerging mainly through the sapphire substrate since the bandgap of p-GaN is less than that of the photon energy (Figure 1). The relatively

narrow p-GaN gap makes it highly absorbing of the DUV. Unfortunately, magnesium-doping of high-Al-content AlGaN results in very low enhancement of the hole concentration at room temperature due to a high activation energy.

DUV-LED fabrication began with inductively coupled plasma etch to expose the n-AlGaN contact layer. The reflective n-electrode consisted of chromium/aluminium/titanium/gold (Cr/Al/Ti/Au) deposited by electron-beam evaporation. The thicknesses of the aluminium, titanium and gold layers were 120nm, 40nm and 60nm, respectively. The chromium thickness varied between 1nm and 20nm. The n-electrode was annealed at 850°C for 30 seconds in nitrogen. The p-electrode consisted of nickel/gold/nickel/gold.

An LED with 2.5nm chromium in the n-contact had the lowest turn-on voltage of 4.7V (LED-2). The same device also had the lowest contact resistance. The ideality factor of the devices was around 5.31.

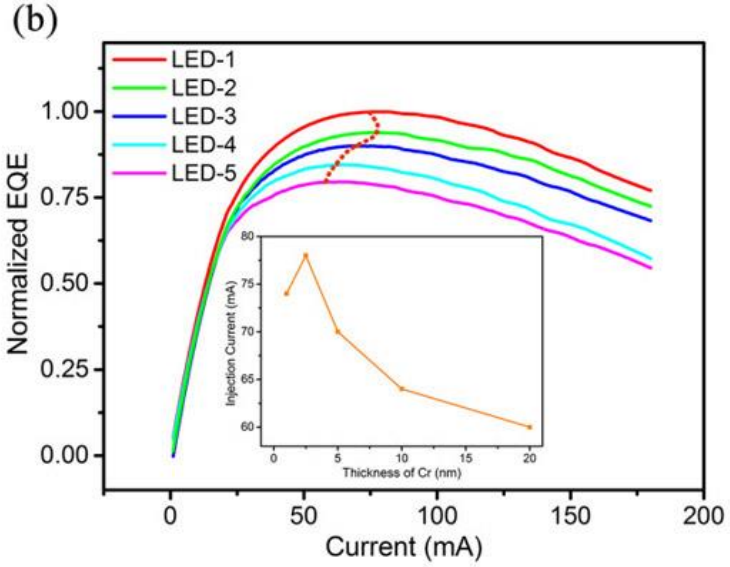


Figure 2: (a) LOP versus injected current for five fabricated DUV-LED devices. (b) EQE in terms of current. Inset: corresponding injection current to achieve peak EQE. LED-3 and LED-4 had 5nm and 10nm Cr, respectively.

In terms of light output power (LOP) at a given current injection, the device with 1nm chromium in the reflector (LED-1) gave the highest value (Figure 2). At 180mA injection, the output power was 40.9% higher than that for the LED with the thickest chromium layer – LED-5 with 20nm Cr. The researchers suggest that the higher turn-on voltage and contact resistance of LED-1 versus LED-2 could be due to the chromium layer being too thin to form the high-quality Al-Cr and Cr-N alloys needed for ohmic contact. The higher light output is attributed to the high reflectivity of the aluminium layer.

The peak external quantum efficiency (EQE) for LED-1 was 25.4% greater than that of LED-5. The corresponding figure for LED-2 was 17.9%. The current injection point of the peak efficiency varied with device: 74mA for LED-1, 78mA for LED-2, and 60mA for LED-5. The researchers explain the higher current injection for LED-2 as being due to its superior ohmic contact and electrical behavior. “Normally, a lower contact resistance or better ohmic contact can definitely improve current spreading and thus higher current injection efficiency,” the team writes.

The reflectivity of Cr/Al metal stacks on sapphire was measured at 280nm center wavelength and compared with the results from an unalloyed Al layer. The relative reflection for 1nm Cr was 93.1%, and that for 2.5nm Cr was 82.2%.

Achieving nitrogen-polar performance from gallium-polar growth

SemiconductorToday

Cornell University in the USA has been using plasma-assisted molecular beam epitaxy (PAMBE) to realize bottom- and top-tunnel junction (TJ) vertical III-nitride blue and green light-emitting diodes (LEDs) [Henryk Turski et al, J. Appl. Phys., vol125, p203104, 2019]. This enabled the team to explore the advantages of reversing the orientation of the charge-polarization-induced electric fields relative to the forward bias direction.

Turski, the lead author, was visiting Cornell from the Institute of High Pressure Physics in Poland, supported partially by the Polish National Centre for Research and Development and the Foundation for Polish Science co-financed by the European Union.

The charge polarization induction of electric fields in III-nitrides arises from the lack of inversion symmetry of the wurtzite crystal structure. Fixed sheet charges arise at heterostructure junctions, giving rise to electric fields of ~1MV/cm. These fields can pull apart electrons and holes, inhibiting recombination into photons (the 'quantum-confined Stark effect').

In addition to these problems, the conductivity of n-type III-nitrides tends to be much higher than for p-type material. The gallium nitride substrates used for indium gallium nitride (InGaN) vertical LEDs therefore are n-type in conduction character. Conventional LEDs then have the p-GaN contact at the top of the device (p-side up). The direction of the polarization fields then depends on whether the epitaxy is performed with gallium- or nitrogen-polar growth.

Although it is expected that N-polar LEDs should perform better, growth in that orientation seems to result in material with low internal quantum efficiency (IQE), as found from photoluminescence experiments.

The researchers comment: "The reason for this remains a mystery and is unsolved to date. It is likely related to the difference in defect formation mechanics, e.g. higher layer contamination for growths in the N-polar orientation by metal-organic vapor phase epitaxy (MOVPE) and molecular beam epitaxy (MBE), due to the drastically different growth dynamics and the chemistry of the N-polar and Ga-polar structures."

The Cornell researchers used tunnel junctions to enable placement of the p-side of the device above or below the active region, avoiding the need for N-polar growth. The tunnel junctions consisted of n- and p-type material.

For effective p-GaN one needs to avoid passivation with hydrogen. For MOVPE growth this is achieved with activation annealing. However, the out-diffusion of hydrogen is blocked when there are overlying layers, restricting devices to top p-GaN contact layers. MBE growth can be arranged to avoid the presence of hydrogen, using nitrogen plasma rather than ammonia (NH3) as precursor, allowing the creation of buried p-type layers.

Another advantage of tunnel junction structures is that the outside contact to metal electrodes can be through thick n-GaN layers, which enable more effective current spreading than p-GaN. Tunnel-junction devices could also realize new geometries for integrating and stacking multiple light emitters. The team also hopes that such "fresh ideas" could eventually lead to lower threshold currents in laser diodes.

The researchers used plasma-assisted molecular beam epitaxy on commercial bulk n-GaN substrates to grow various tunnel-junction/LED combinations (Figure 1). The threading dislocation density of the Ga-polar substrate was ~5x107/cm2. The devices were aimed at blue and green emissions with the tunnel junction variously on top and below the active layers. The GaN layers were grown at 740°C. A lower temperature of 650°C was used for

InGaN layers. The 'quantum wells' (QWs) in the blue devices were 20nm thick, giving them more the character of double heterostructures. The resulting materials were smooth, with atomic force microscopy (AFM) of 5µmx5µm fields giving roughness values less than 0.5nm.

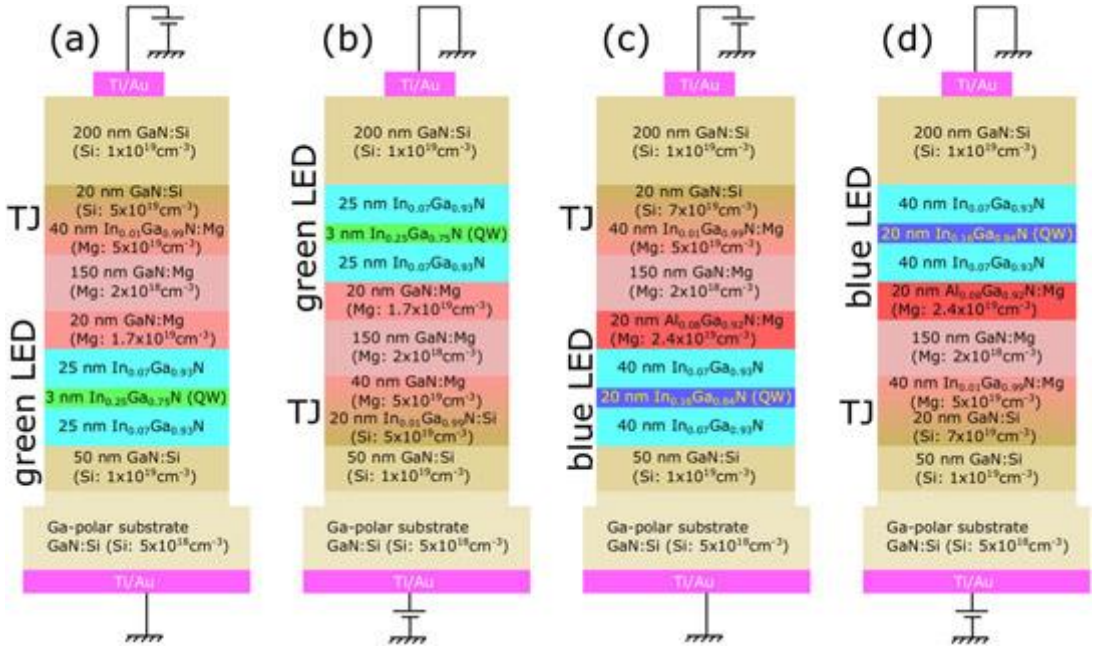


Figure 1: Layer and doping details of quantum well heterostructures with top (a, c) and bottom (b, d) tunnel junctions aimed at blue (c, d) and green (a, b) emission. Researchers referred to structures presented in (a), (b), (c), and (d) as A, B, C, and D, respectively.

Fabrication involved device isolation by inductively coupled plasma etch and deposition of titanium/gold electrodes. The bottom electrode consisted of a common contact on the back-side of the substrate. The top electrodes were circular, placed in the center of the mesa. Titanium/gold has a low contact resistance on n-GaN.

The researchers suggest that in future the bottom tunnel-junction contact resistance could be lowered by exploiting a larger cross-section area than for the LED mesa itself. This is not possible for top tunnel-junction devices.

Bottom-TJ devices with 80µmx80µm mesas had higher current flow near the turn-on voltage. This effect was greater in the green-emitters. The researchers say that low leakage levels in all the devices show that the density of extended defects propagating through the LEDs is similar.

The team also suggests that lower tunnel-junction resistance could be achieved by increased doping and polarization-induced effects from InGaN or AlN interlayers. However, such techniques carry the risk of degraded crystal quality in the active region.

The top-TJ LEDs had electroluminescence spectra with two peaks (Figure 2). The high photon energy (shorter wavelength) peak was attributed to parasitic recombination in lower-indium-content layers around the wells. In fact, the parasitic recombination dominated at low current injection levels. The parasitic peaks were not observed for bottom-TJ structures.

The bottom-TJ LED also had higher peaks: ~2.5x for green-emission at 20A/cm2, and ~13x for blue. The researchers comment: "The quantitative differences between the enhancement for green and blue emitters can

be attributed to differences in active regions and the electron-blocking layer (EBL) design but, irrespective of the details, the bottom-TJ structures for both wavelengths demonstrate the important advantages offered by this conceptual change in the LED design."

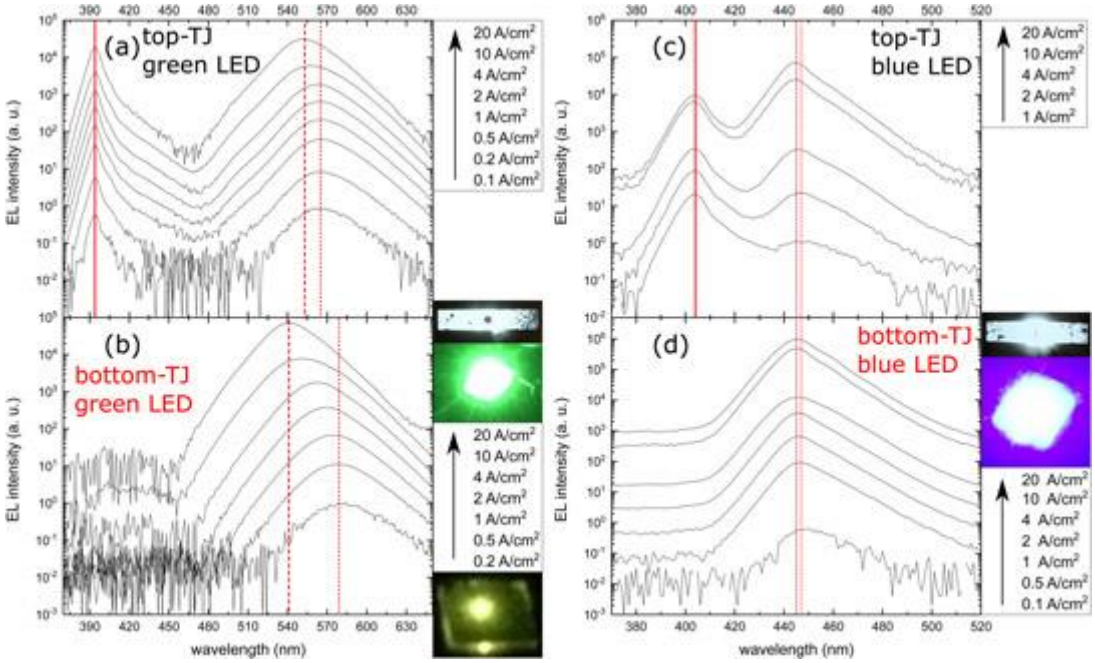


Figure 2: (a)–(d) Electroluminescence spectra in log scale measured on-chip for indicated current densities for 80µmx80µm device. Real-color pictures next to (b) and (d) is whole 1cmx1cm wafer. Above real-color images are monochromatic images collected under microscope for 100µmx500µm Bottom-TJ devices under 100mA injection, showing excellent current spreading.

The high-indium-content green LED saw some yellow-to-green shift in the spectral output with increasing injection: from 565nm/580nm for top-/bottom-TJ LEDs to 552nm/541nm, respectively. This was attributed to localized state filling and screening of the internal polarization electric field as injection increased. The researchers see the more pronounced shift in the bottom-TJ device as being evidence of more efficient injection at higher currents. The increased carrier concentration in the quantum well is thought to lead to the higher light output in the bottom-TJ LED.

Simulations of the devices suggested to the researchers that bottom-TJ LEDs suffered less from carrier overshoot effects that can result in efficiency droop at high currents. Overshooting carriers (mostly electrons) recombine non-radiatively in the doped contact layers.

In the presented devices the overshooting carriers could also recombine in the barrier layers, leading to higher-energy photon emission in some cases. The inverted polarization field in the bottom-TJ devices retains the electrons and holes in the quantum well, it is thought. The researchers add: "Because of the separation of electrons and holes outside the QWs, the recombination in the barrier surrounding the QW is significantly reduced for the bottom-TJ LEDs compared to the top-TJ case."

Capacitance-voltage measurements at 5MHz showed significant hysteresis between up and down sweeps in blue LEDs with top junctions, attributed to charge trapping in the active region. Energy-band simulations suggest that a deep triangular well forms, trapping electrons near the p-side and holes near the n-side of the quantum well. "The hysteresis is caused by charging/discharging of this local, triangular minimum of the potential due to carriers injected or extracted from this region," the researchers write.

Developing III-nitride-on-silicon optoelectronic platform

SemiconductorToday

China's Nanjing University of Posts and Telecommunications continues to develop III-nitride optoelectronic systems with light-emitting diodes (LEDs) and photodiodes (PDs) connected with waveguides [Yongjin Wang et al, Semicond. Sci. Technol., vol34, 065017, 2019]. The new work used a metal-bonded III-nitride-on-silicon platform "for the first time", according to the researchers.

The platform was also used in the group's recent work on enhancing LED extraction by eliminating waveguide modes in the LED itself by the thinning of epitaxial layers [link]. Previously, the Nanjing researchers constructed LED/PD systems that were transferred to glass [link].

In the latest work, III-nitride thin-film material was metal-bonded to (100) silicon. The film was flipped so that the 125nm p-GaN side was down. The other layers consisted of a 50nm multiple quantum well, a 70nm InGaN spacer, and a 2800nm top n-GaN contact. On top of the n-GaN there was also 800nm undoped GaN and 700nm from the AlN/AlGaN buffer layers from the epitaxial growth process. The metal bonding included a silver reflector.

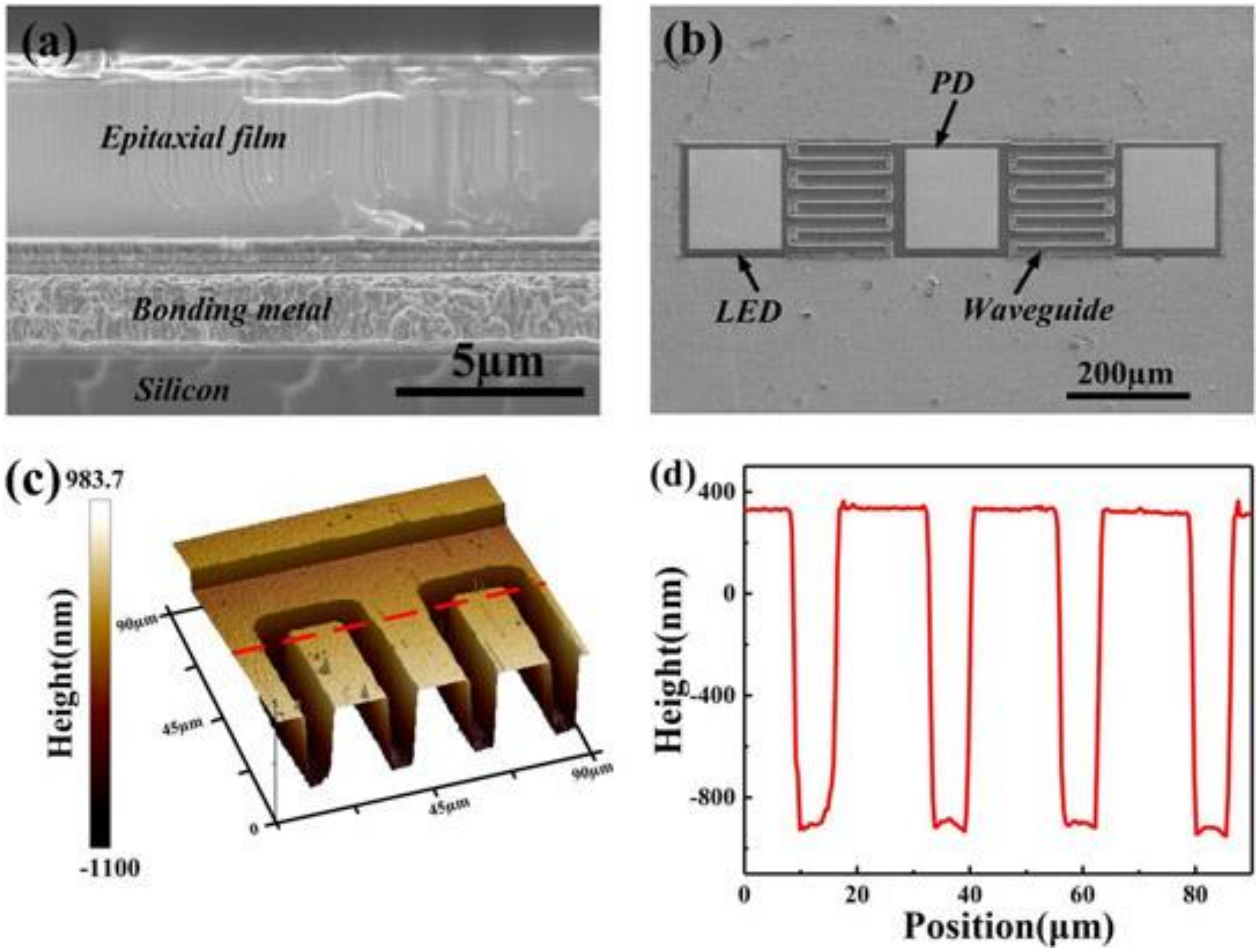


Figure 1: (a) Cross-sectional scanning electron microscope (SEM) image of III-nitride films on Si (100) substrate. (b) SEM image of on-chip power monitoring system. (c) Three-dimensional atomic force microscope image of waveguides. (d) Device height profile.

The device structure (Figure 1) was created using mesa and waveguide etching down to the silver-bonding layer, isolating the components electrically. The etch plasma consisted of a mix of chlorine and boron trichloride gases. Further patterned etching defined the p- and n-contact areas. Contact electrodes consisted of nickel/gold.

The device incorporated two LEDs and a central photodiode. The different sections were connected with waveguides consisting of 155µm-long fingers. The width and height of the waveguides were 18µm and 1253nm, respectively.

The light from the LEDs was transmitted along the waveguides and then across a 12µm air gap into the photodiode. The researchers see such structures as having potential for liquid and gas analysis, where fluids would flow through isolation trenches and channels, modulating light propagation.

The LED emission peak was at ~452nm, which was in the range of detection of the photodiode. By imposing different signals on the left and right LEDs, the researchers were able to distinguish the responses in the superposed photodiode output signal (Figure 2).

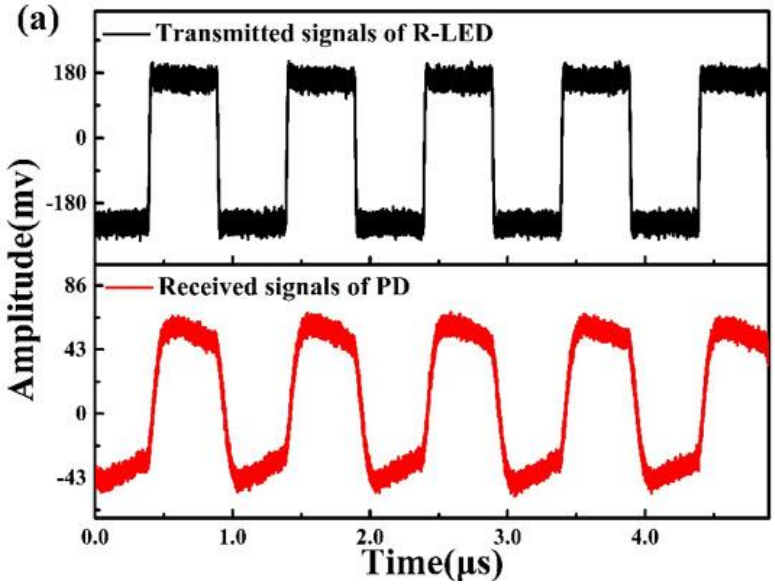


Figure 2: Transmitted signals of LEDs versus induced photocurrent temporal traces of photodiode: (a) R-LED and (b) L-LED. (c) Measured superimposed signals versus calculated signals.

The filling factor of the right LED was found to be 0.5 under 1MHz pulses with 0.4V peak-to-peak voltage and 5.0V offset. The left LED had a filling factor of 0.3. The researchers comment: "The filling factor of signals constitutes the codes used by the LEDs to modulate light for information transfer in the system."

The team adds: "If the received signals from one LED is measured, the received signals from another LED can be obtained by subtracting the known signals using the superimposed signals. According to the difference in the filling factor, the mixed signals can be extracted to identify the individual LED."

The researchers see the system being used as an on-chip monitor, enabling one photodiode to check dynamic emission power fluctuations from multiple LEDs.

Reflectivity studies suggested that thinning the epitaxial layer - confining the Fabry-Perot modes of the waveguide - could enhance light extraction in the systems.

Plessey's GaN-on-Si micro-LED emissive display wins two Electronics Industry Awards

SemiconductorToday

At the 2019 Electronics Industry Awards at London's Tower Hotel, UK-based Plessey received the Display Product of the Year and the Embedded Solution Product of the Year for its micro-LED Emissive Display.

Plessey provides full-field emissive micro-LED displays combine very high-density RGB pixel arrays with high-performance CMOS backplanes to produce high-brightness, low-power and high-frame-rate image sources for head-mounted displays (HMDs) and augmented reality (AR) and virtual reality (VR) systems. The firm has 150mm and 200mm wafer processing facilities (to undertake design, test and assembly of LED products) as well as a suite of photonic characterization and applications laboratories.



"As demand for micro-LED displays is accelerating, Plessey's GaN-on-silicon is recognized as the only technology platform capable of addressing all of the challenges involved with manufacturing micro-LED displays in high volumes cost-effectively," comments Niamh Marriot, editor of CIE magazine. "It is also one of the only viable solutions that can enable products that are not only compact enough to be worn without restricting the overall experience for AR [augmented reality] applications and in HUDs [head-up displays], but also provide the size, weight, power and luminance needed… With its integrated components and excellent thermal performance, it is a standout display," she adds.

"As the only provider of GaN-on-silicon monolithic micro-LEDs, Plessey is disrupting the display market with a technology that delivers a tangibly better consumer experience," says Mike Lee, Plessey's president of corporate & business development.

SLD Laser demos high-power blue laser modules for materials processing applications

SemiconductorToday

SLD Laser of Goleta, CA, USA (a spin-off from LED lighting firm Soraa Inc that is commercializing visible laser-based light sources and blue laser products for automotive, industrial, specialty lighting and display applications) has demonstrated compact, high-power, high-brightness, fiber-coupled blue laser modules for materials processing applications including copper welding for battery production for electric vehicles (EVs) and consumer electronic devices, as well as 3D printing. At Laser World of Photonics 2019 in Munich, Germany (24–27 June), the firm is debuting the blue laser module technology, and also demonstrating its UL and IEC safety-certified high-luminance LaserLight-SMD and LaserLight-Fiber products.

"SLD's blue laser light modules feature up to 12 times the absorption, processing quality and speed compared to infrared laser technology," reckons says president, chief operating officer & co-founder Dr James Raring. "This technology produces superior results in copper, aluminum, stainless steel, as well as other metals such as nickel, gold, titanium and silver that are commonly used for plating, other thin metal processes and 3D printing," he adds.

SLD's blue laser light output is also highly absorptive in non-metals and organics, and therefore is suitable for marking, engraving and cutting of these materials. Moreover, for biomedical applications, it exhibits more than ten times absorption in blood hemoglobin and melanin in skin than infrared lasers, enabling next-generation solutions in dermatology and surgery.

SLD says that its blue laser module is ultra-compact (with a form factor roughly the size of a credit card) and delivers over 20W from a 100µm transport fiber. The technology is modular and can be power scaled and aggregated with optical fibers into higher-power systems to deliver hundreds of watts from high-brightness delivery fibers less than 600µm diameter. The modules feature the firm's proprietary and patented Semipolar GaN laser diode technology, with highly efficient and reliable operation to enable system integrators and application development teams to configure solutions for a wide variety of applications, and to get to market quickly.

Also at Laser World of Photonics, SLD is showcasing its LaserLight product line. The firm has recently initiated production of the UL and IEC safety-certified LaserLight-SMD and LaserLight-Fiber products, including the recently demonstrated fiber-coupled SMD and SkyBeam (the first 12,000 lumen LaserLight spotlight for outdoor lighting applications based on the SMD). LaserLight products won the Technical Innovation Award at May's LightFair International trade fair in Philadelphia, PA.

"We have recently entered production for our two first LaserLight product lines into the automotive and specialty lighting markets, delivering up to 10 times higher visibility and safety than can be achieved with LEDs, and replacing older legacy lighting that contains mercury," says chief marketing officer & co-founder Dr Paul Rudy. "LaserLight products serve a myriad of applications such as automotive headlights, portable handheld flashlights, drones, off-road light bars, and professional applications in search and rescue, marine, avionics, architecture, and entertainment," he adds. "We are thrilled to now take the next step, and introduce the blue laser module technology for emerging industrial materials processing and biomedical applications."

Aixtron Provides MOCVD System To Nagoya University

CompoundSemiconductor

Deposition firm Aixtron has delivered a Close Coupled Showerhead (CCS) system to Nagoya University (Japan). Aixtron's 3x2-inch Flip Top CCS MOCVD platform is intended for research in the field of GaN-based deep ultra-violet (DUV) optoelectronic devices and has been installed at the University's Institute of Materials and Systems for Sustainability (IMaSS).

Nagoya University is one of the leading Japanese research institutions for semiconductor materials, especially in the field of GaN-based structures. By focusing on the development of DUV devices with Aixtrons 3x2-inch Flip Top CCS MOCVD tool, IMaSS takes into account their benefit for a wide range of future-oriented applications in areas such as agriculture, health or water purification.

Specially designed for research and small series production, the proven Aixtron system enables real scaling from R&D to large series production. The unique Close Coupled Showerhead concept inherently allows an extremely

uniform and reproducible deposition of various complex, mostly single crystal materials. The high flexibility of the exceptional reactor design enables not only further developments of existing materials and their application in future devices, but also permits extensive research into completely materials, their properties and potential applications.

"In addition to its excellent technical performance, our Closed Coupled Showerhead Flip Top Reactor is characterised by its easy maintenance and lowest running cost. The system is one of the most successful Aixtron products as proven by numerous orders from universities, laboratories and other research institutions worldwide. We are looking forward to closely cooperate with Nagoya University and its renowned IMaSS," comments Bernd Schulte, president of Aixtron SE.

OTHER

Aixtron partners in UltimateGaN project to make power semiconductors available for broad applications at competitive cost

SemiconductorToday

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says that it is a partner in the European research project UltimateGaN (research for GaN technologies, devices and applications to address the challenges of the futureGaN roadmap). In addition to Aixtron, 25 other companies and institutions from nine countries have come together to research the next generation of energy-saving chips based on gallium nitride (GaN) over the next three years. The aim is to make these power semiconductors available for a wide range of applications at globally competitive costs.

UltimateGaN is one of the largest existing European research projects in semiconductor development. The €48m in funding consists of investment by industry, subsidies from the individual participating countries and the Electronic Components and Systems for European Leadership (ECSEL) Joint Undertaking (JU).

Efficient use of energy for climate protection

“By developing intelligent technologies, we are making a key contribution to the global challenge of climate change,” says Aixtron president Dr Felix Grawert. “New materials and efficient chip solutions play a key role here. With this research project, we are creating the conditions for making innovative energy-saving chips available for many future-oriented everyday applications,” he adds.

“Gallium nitride semiconductor devices are revolutionizing energy use on many levels,” says professor Michael Heuken, Aixtron’s VP Research & Development. “The research project opens up an enormous global market potential,” he adds. “It enables better performance and efficiency in a wide range of applications and significantly improves user comfort. Efficient operation of servers and data centers, fast and wireless charging of smartphones, data exchange between machines in real time, or lightning-fast video streaming become reality.”

UltimateGaN - smaller, energy-efficient chips at marketable costs

UltimateGaN’s objective is to develop innovative power and high-frequency electronics from gallium nitride. Aixtron is contributing its expertise as a supplier to the semiconductor industry and in the production of gallium nitride to the research project: The production of high-quality wafers using metal-organic chemical vapor deposition (MOCVD) technology is carried out on Aixtron equipment at the Infineon plant in Villach, Austria.

In terms of materials and processes, research is now going one step further to develop the next generation of these highly efficient energy-saving chips for the mass market: The focus is on further miniaturization and provision of the chips in high quality and at globally competitive costs. The unique material structure of GaN enables higher current densities to be achieved, which allows smaller and lighter designs that switch the current much more efficiently and can transmit higher data rates more quickly. The result is a significant reduction in energy consumption: current losses are reduced by up to 50%.

Profit from renewable energy, e-mobility and faster data transfer

Many applications in which low energy consumption, compact designs and faster data exchange are key will benefit from the use of the chips. The energy efficiency of high-performance servers and other IT infrastructure devices will gain a further boost with the research project: power dissipation can be significantly reduced by the higher switching efficiency of GaN power devices. The new 5G mobile communication standard and ultra-fast video loading are also supported, for example, as is real-time traffic flow control for autonomous driving or, in the context of Industry 4.0, easy communication between machines.

Research focuses along the entire value chain

When seeking to miniaturize GaN chips, the small and compact design as well as the complex technology required for the connections and packaging present special challenges. High current densities, the effect of electrical fields, and material stresses and stabilities must be taken into account. As a result, the research will take a holistic approach with the entire value chain in focus – from process development, design, assembly and packaging technologies to integrated system solutions. The consortium of partners from academia and business is therefore equally broadly based.

UltimateGaN project partners

UltimateGaN's 26 partners from nine countries include: Austria Technologie & Systemtechnik AG, Infineon Technologies Austria AG, Fronius International GmbH, CTR Carinthian Tech Research AG, and Graz University of Technology (of Austria); IMEC (in Belgium); Aixtron SE, Infineon Technologies AG, Siltronic AG, Max-Planck-Institut für Eisenforschung GmbH, Fraunhofer Society for the Promotion of Applied Research e.V., Chemnitz University of Technology, and NaMLab GmbH (of Germany); Università degli studi di Padova, Infineon Technologies Italia, and Universita di Milano Bicocca (of Italy); Eltek AS (in Norway); Slovak University of Technology in Bratislava, and Nano Design SRO (of Slovakia); Ecole Polytechnique Fédérale de Lausanne (EPFL) and Attolight SA (of Switzerland); IKERLAN, For Optimal Renewable Energy, and LEAR (of Spain); and RISE Research Institutes of Sweden AB and SweGaN AB (of Sweden).

The project has received funding from the ECSEL Joint Undertaking (JU) under grant agreement No 826392. The JU receives support from the European Union's Horizon 2020 research and innovation program and Austria, Belgium, Germany, Italy, Slovakia, Spain, Sweden, Norway, Switzerland.

MACOM cuts June-quarter revenue guidance from $120-124m to $107-109m

SemiconductorToday

In response to (1) reduced shipments to certain distribution channel partners and (2) the US Department of Commerce's Bureau of Industry and Security (BIS) on 15 May adding Huawei Technologies Co Ltd and 68 of its subsidiaries and affiliates to its 'Entity List' prohibiting the sale to Huawei of products covered by the Export Administration Regulations (EAR) without obtaining an appropriate export license, for its fiscal third-quarter 2019 (to end-June) MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes

semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) has reduced its guidance for revenue from $120-124m to $107-109m.

Non-GAAP gross margin guidance has been reduced from 53-55% to 39-41%, which includes about $14m in inventory reserves (1300 basis points of gross margin impact) associated primarily with data-center products and products that would otherwise have been shipped to Huawei.

Guidance for adjusted earnings per share has been revised from a loss of $0.08-0.04 to a loss of $0.41-0.45 (not include any restructuring- or impairment-related charges).

To save about $50m in annual expenses (once fully implemented), MACOM has implemented a restructuring plan that includes the following:

- A permanent reduction in MACOM's hourly, salaried and management workforce of about 250 (20% of the total), including personnel in R&D, Production, Sales & Marketing and General & Administrative functions. Substantially all affected staff have been notified and customary transition assistance will be provided.
- The closure of seven product development facilities, including locations in France, Japan, The Netherlands, Florida, Massachusetts, New Jersey and Rhode Island.

The firm also says it will no longer invest in the design and development of optical modules and subsystems for data-center applications. Going forward, MACOM will be a merchant supplier of integrated circuits and photonic devices and will support optical module manufacturers at the component level.

"These actions are necessary in order to strengthen our strategic plan," says president & CEO Stephen Daly.

The firm expects about $14m in restructuring charges including $7m for employee severance obligations, most of which are expected to be incurred during fiscal third-quarter 2019. In addition, it is performing a recoverability assessment for its long-lived assets, most specifically intangible assets (which had a carrying value of $472m as of 29 March) that may be impacted. To date, MACOM has also identified about $15m of non-cash impairment charges associated with these restructuring actions.

Riber licenses LAAS-CNRS' reflective surface defect and curvature measurement technology

SemiconductorToday

Riber S.A. of Bezons, France – which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells – has signed an operational licensing agreement with Toulouse Tech Transfer (TTT, a regional operator for creating value and transferring technology from public research to businesses in France's Occitanie region) for the exclusive marketing of a reflective surface defect and curvature measurement technology, developed by the Laboratory for Analysis and Architecture of Systems (LAAS-CNRS), one of the largest in-house units of the French National Centre for Scientific Research (CNRS).

Dedicated high-precision metrology technology for semiconductor manufacturing

Research engineer Alexandre Arnoult and post-doctoral researcher Jonathan Colin of LAAS-CNRS have developed an optical device that is easy to implement and helps to improve control over operations to deposit thin films. The device can be used in any type of environment.

This makes is possible to measure curvature and defects on all types of surfaces in real time and over significant production times. For example, it helps to avoid dislocations, produce perfectly even wafers or control deposit

consistency. The device will also be equipped with machine learning algorithms that will be specially developed to optimize analysis and control for the materials growth process.

EZ-Curve: new technological component for Riber's strategic development

The know-how based on this research - marketed under the new EZ-Curve brand - will enable Riber to extend its range of solutions and services, providing research laboratories and semiconductor manufacturers with added value in line with their needs, the firm says.

For industrial users, ensuring the traceability and reliability of their measurements is key to effectively managing their manufacturing processes and guarantee product quality and performance, Riber adds. For researchers, analyzing and understanding materials growth-related behavior makes it possible to expand fundamental knowledge.

In addition to controlling the epitaxial growth process with high-precision 3D reflectance metrics, EZ-Curve also offers wider possibilities by supporting the implementation of automated advanced control processes and, over the longer term, the development of smart MBE systems.

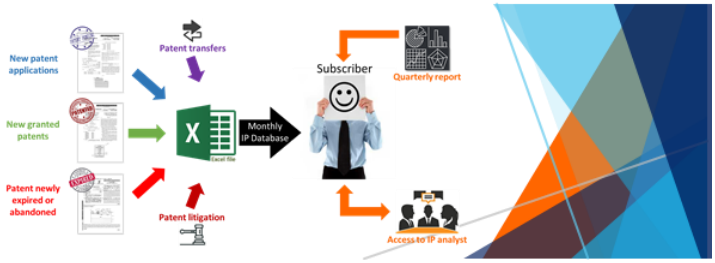
"EZ-Curve is a significant technological innovation compared with the measurement instruments currently available on the market," reckons Riber's CEO Philippe Ley. "Our ambition is to provide our clients with the very precise levers needed to considerably improve their processes and the results of their developments, whether they are academic or industrial," he adds. "This new technological component and its industrialization will make it possible to further strengthen MBE performance capabilities".

The new device is said to offer a range of benefits: being non-invasive, cost-effective, portable, lightweight, easy to install and use, EZ-Curve is adapted for in-situ epitaxial process analysis.

"Monitoring a wafer's deformations during the vacuum growth or processing of a thin film represents an unrivalled source of information on the atomistic processes involved, and quality control for industrial processes," says Arnoult. "Until now, this monitoring was reserved for specialists using tools that were complex to master," he adds. "Our new technology successfully makes it possible to achieve this combination of increased sensitivity with outstanding robustness and simple implementation, which enables [the user] to deploy it across a large number of advanced and/or production systems. For example, we can now continuously monitor molecular beam epitaxy growth for complex semiconductor structures with low constraints, opening up possibilities for in-situ feedback control during processes, and therefore optimization and automation of processes."

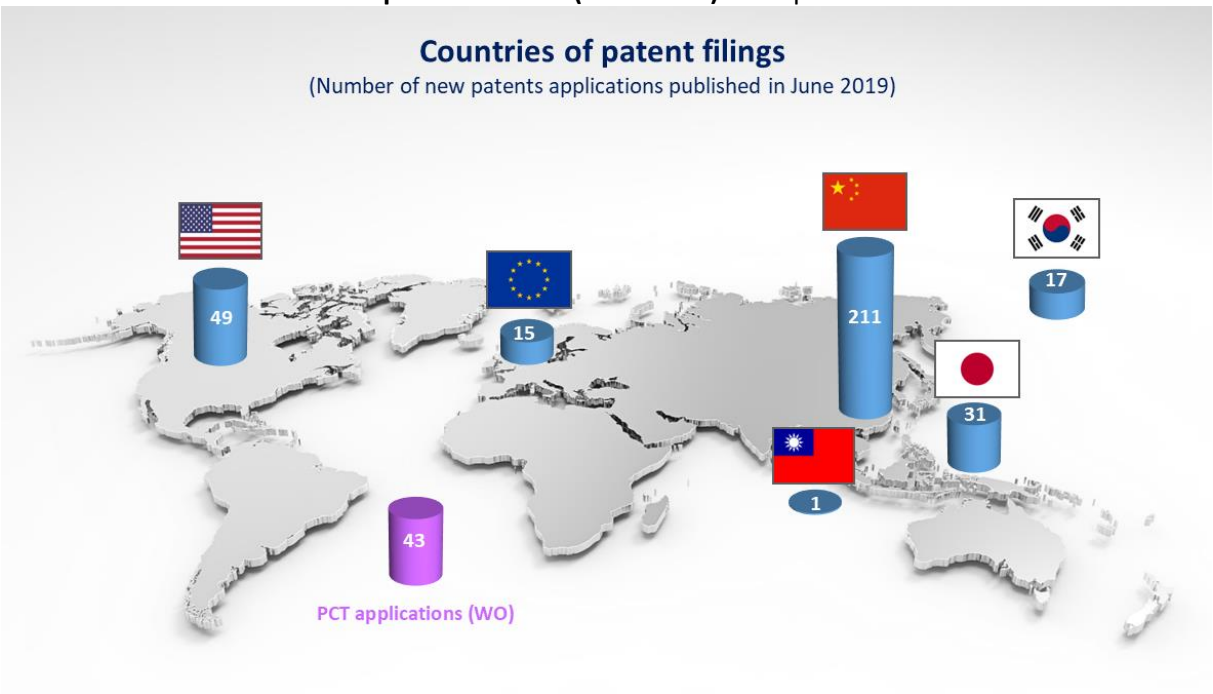
Following maturation and market release phases, Riber, LAAS-CNRS and TTT intend to continue sharing their knowledge in order to support the product's development worldwide.

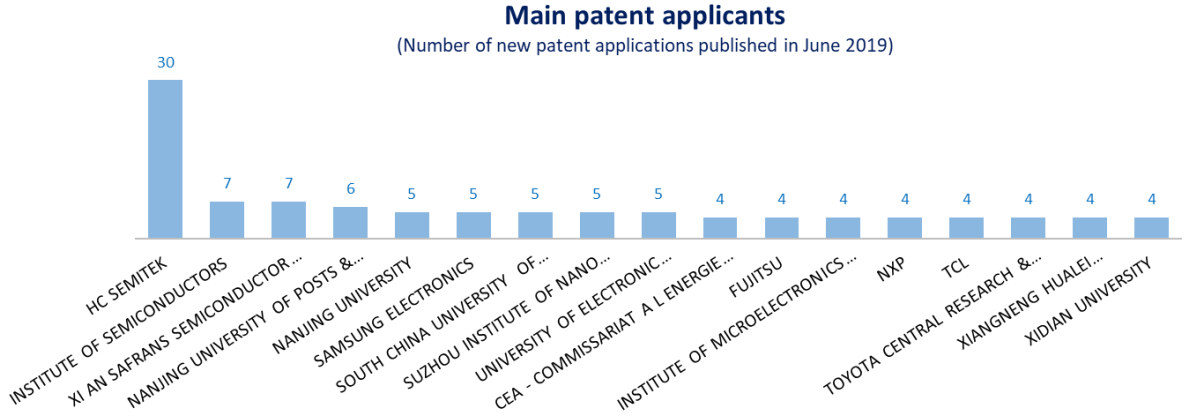
GaN Patent Monitors
Take advantage of periodic updates on IP activities
KnowMade IP & Technology Intelligence
Click here



PATENT APPLICATIONS

More than 290 **new patent families (inventions)** were published in **June 2019**.





Other patent applicants Baoding Zhongchuang Yanyuan Semiconductor Technology, BOE Technology, Guangdong Midea, Huangshan Qimen Xinfei Electronic Technology Development, Jiangxi Zhaochi Semiconductor, King Abdullah University of Science & Technology, Lumileds, Meijo University, Rohm, Shenzhen Third Generation Semiconductor Research Institute, Shindengen Electric Manufacturing, Toyota Motor, University of Chinese Academy of Sciences, 13th Research Institute of China Electronics Technology, Abb Schweiz, Beijing BOE Display Technology, Beijing University of Posts &Telecommunications, Changchun Institute of Optics Fine Mechanics & Physics Chinese Academy of Sciences, Enraytek Optoelectronics, Facebook Technologies, Fraunhofer, Institute of Physics Chinese Academy of Sciences, Lumens, Nagoya Institute of Technology, National Center For Nanoscience & Technology China, Nikkiso, Nippon Telegraph & Telephone, Nissan Motor, Northrop Grumman Systems, Panasonic, Peking University Shenzhen Graduate School, Saphlux, Seoul Viosys, Shandong University, Shenzhen Qianhai Xiaoyou Technology, Shenzhen Sitan Technology, Shenzhen UVEI Silicon, Stanley Electric, Sumitomo Electric Industries, Sun Yat Sen University, TGO

Technology, Tokuyama, University South Science & Technology China, Vanguard International Semiconductor, Xi'an Jiaotong University, Xiamen Changelight, 3 D Matrix, Advanced Healthtech Biopetide Laboratories, Advanced Optoelectronic Technology, Air Water, Akoustis, Aledia, Ampleon Netherlands, Anhui Sanlian University, Anhui University of Technology, Binzhou Medical University Hospital, Chengdu Jiachen Technology, Cheongju University Industry & Academy Cooperation Foundation, Chongqing HKC Optoelectronics Technology, Chongqing University, Chuzhou Cigarette Materials Factory, CNRS - Centre National De La Recherche Scientifique, Commscope Technologies, Dena, Doshisha University, East China Institute of Technology, Eggtronic Engineering, Enkris Semiconductor, Federal State Budgetary Institution of Higher Professional Education Bauman Moscow State Technical University, Fujian Green Gold Biotechnology, Fujian Nan An Qingxin Stone, Furukawa, Gansu Wushanchi Yellow Wine, Guangdong Litai Big Health Industry, Guangxi Nannan Aluminum Processing, Guangzhou Biting Cosmetics, Guizhou Aerospace Electronic Technology, Guizhou Evergreen Pharmaceutical, Hangzhou Haicun Information Technology, Hangzhou Silan Azure, Huangshan University, Hubei Deep Purple Technology.

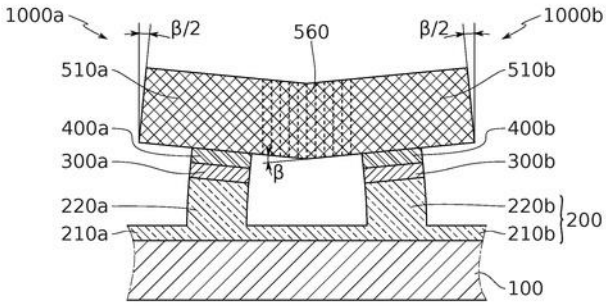
Notable new patent applications

Process for obtaining a nitride layer

Publication Number: WO2019/122461, FR3075833

Patent Applicant: Cea, CNRS

One subject of the invention relates to a process for obtaining a nitride (N) layer (550) preferably obtained using at least one from among gallium (Ga), indium (In) and aluminium (Al), the process comprising the following steps: - providing a stack comprising a substrate (100) and at least the following layers successively positioned from the substrate (100): ■ a flow layer (220) having a glass transition temperature Glass transition ■ a crystalline layer (300), - forming pads (1000a-1000e) by etching of the stack so that each pad (1000a-1000e) comprises at least: ■ a flow section (220a, 220b) formed by one portion at least of the flow layer (200), ■ a crystalline section (300a, 300b) formed by the crystalline layer (300), - epitaxially growing a crystallite (510a-510e) on each of the pads (1000a-1000e) and continuing the epitaxial growth of the crystallites (510a-510e) so as to form said nitride layer (550). The epitaxial growth being carried out at a temperature Tepitaxy, such that: Tepitaxy ≥k1. Glass transition > with k1=0.8.

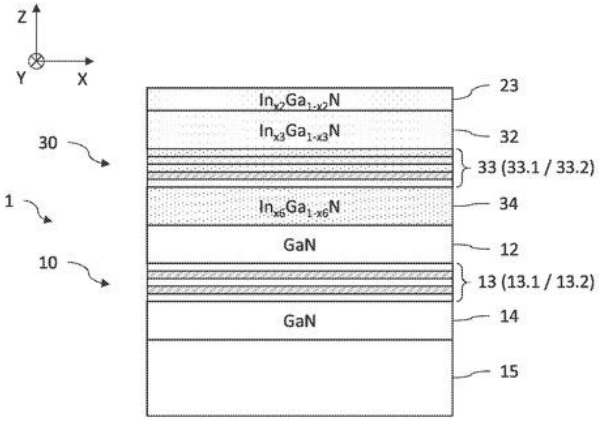


Method for manufacturing an optoelectronic device by transferring a conversion structure onto an emission structure

Publication Number: EP3503222, FR3075468, US20190189835

Patent Applicant: Cea, Thales

The invention relates to a method of manufacturing an optoelectronic device (1) made based on GaN, comprising a transmission (10) structure adapted to emit a first light radiation at a first wavelength (λ 1), the method comprising the following steps: i. production of a growth structure comprising a seed layer (23) made of Inx2 Ga1-x2 N at least partially relaxed; II. performing a conversion structure (30), including an emission layer (33) adapted to emit light radiation at a second wavelength (λ 2), and an absorption layer (34) made on the basis of InGaN; III. transfer of the conversion structure (30) on the emission (10) structure such that the absorption layer is (34) located between the emission (10) structure and the emission layer (33) of the conversion structure.

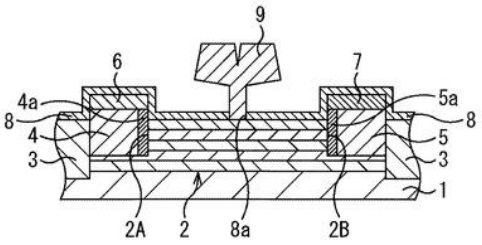


Compound semiconductor device and method

Publication Number: US20190189746

Patent Applicant: Fujitsu

A compound semiconductor device includes: a compound semiconductor area in which a compound semiconductor plug is embedded and formed; and an ohmic electrode provided on the compound semiconductor plug, wherein the compound semiconductor plug includes, in a side surface portion that is as an interface with the compound semiconductor area, a high concentration dopant layer containing a dopant whose concentration is higher than that of other portions.

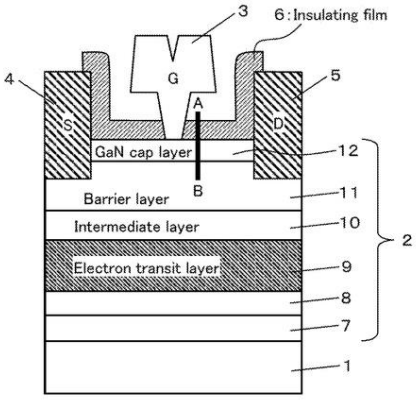


Semiconductor device and fabrication method therefor, and high-frequency amplifier

Publication Number: US20190189757

Patent Applicant: Fujitsu

A semiconductor device includes a nitride semiconductor stacked structure that includes a channel layer containing GaN and a barrier layer containing In and further includes a cap layer that contains GaN on the outermost surface but does not contain Al. The cap layer has a Ga/N ratio that varies along a thicknesswise direction.

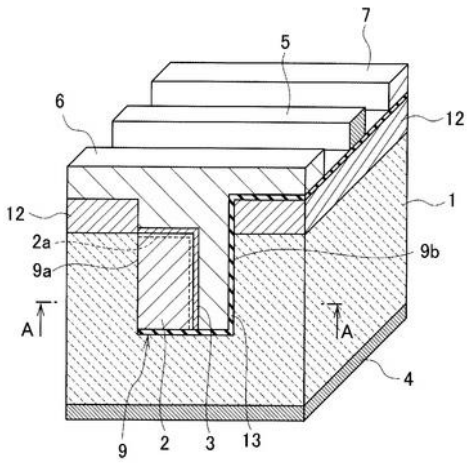


Semiconductor device and semiconductor device production method

Publication Number: WO2019/116464

Patent Applicant: Nissan motor

This semiconductor device comprises: a substrate (1) having a first main surface and a second main surface facing each other, a groove (9) being formed on the first main surface; a semiconductor region (2) formed so as to be in contact with the surface of the groove (9); and an electron supply region (3) which is formed so as to be in contact with the surface of the semiconductor region (2) and causes the semiconductor region (2) to generate a two-dimensional electron gas layer (2a). In addition, this semiconductor device comprises a first electrode (6) which electrically connects to the two-dimensional electron gas layer (2a) and a second electrode (7) which electrically connects to the two-dimensional electron gas layer (2a) at a position that is separated from the first electrode (6). Among a first side-surface (9a) and a second side-surface (9b) facing one another in the groove (9), the semiconductor region (2) is formed only on the first side-surface (9a).

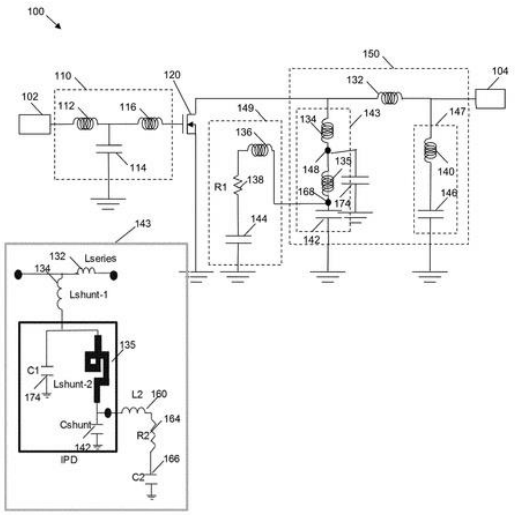


Rf power transistors with impedance matching circuits, and methods of manufacture thereof

Publication Number: US20190190464, EP3503387, CN109861654

Patent Applicant: NXP

Embodiments of an RF amplifier include a transistor with a control terminal and first and second current carrying terminals, and a shunt circuit coupled between the first current carrying terminal and a ground reference node. The shunt circuit is an output pre-match impedance conditioning shunt circuit, which includes a first shunt inductance, a second shunt inductance, and a shunt capacitor coupled in series. The first shunt inductance comprises a plurality of bondwires coupled between the first current carrying terminal and the second shunt inductance, and the second shunt inductance comprises an integrated inductor coupled between the first shunt inductance and a first terminal of the shunt capacitor. The shunt capacitor is configured to provide capacitive harmonic control of an output of the transistor.

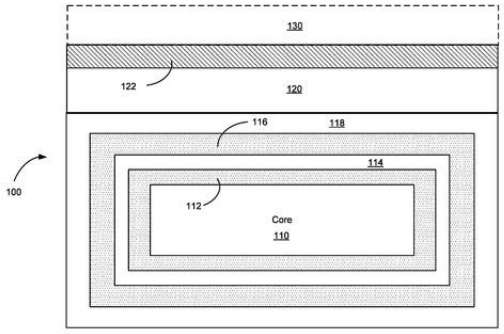


Systems and method for integrated devices on engineered substrate

Publication Number: WO2019/113045, US20190172709

Patent Applicant: Qromis

A method of forming a plurality of devices on an engineered substrate structure includes forming an engineered substrate by providing a polycrystalline ceramic core, encapsulating the polycrystalline ceramic core with a first adhesion shell, encapsulating the first adhesion shell with a barrier layer, forming a bonding layer on the barrier layer, and forming a substantially single crystal layer coupled to the bonding layer. The method further comprises forming a buffer layer coupled to the substantially single crystal layer, forming one or more epitaxial III-V layers on the buffer layer according to requirements associated with the plurality of devices, and forming the plurality of devices on the substrate by removing a portion of the one or more epitaxial III-V layers disposed between the plurality of devices and removing a portion of the buffer layer disposed between the plurality of devices.

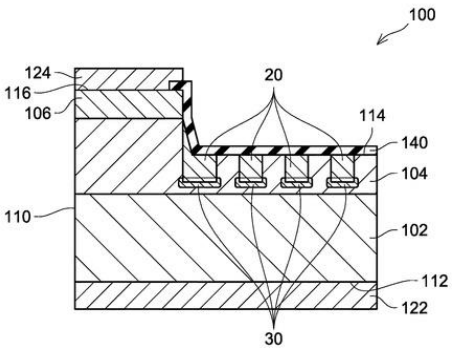


Group iii nitride semiconductor substrate

Publication Number: US20190181230, JP2019106456

Patent Applicant: Toyota Central Research & Development Labs

A group III nitride semiconductor substrate may include: a p-type conduction region into which a group II element has been implanted in a depth direction of the group III nitride semiconductor substrate from a surface of the group III nitride semiconductor substrate, the p-type conduction region having p-type conductivity, wherein hydrogen has been implanted from the p-type conduction region across an n-type conduction region adjacent to the p-type conduction region in the depth direction of the group III nitride semiconductor substrate.

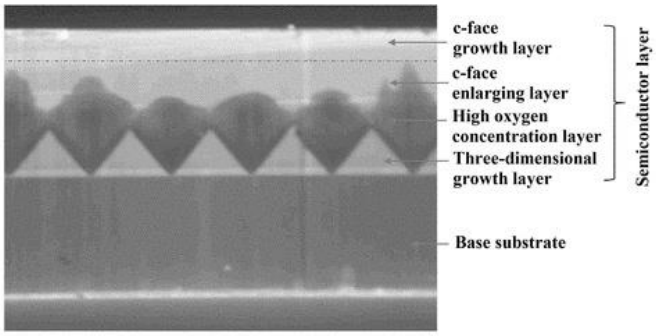


Nitride semiconductor substrate, semiconductor laminate, laminated structure, method for manufacturing nitride semiconductor substrate and method for manufacturing semiconductor laminate

Publication Number: US20190198312

Patent Applicant: SCIOCS, Sumitomo Chemical

To provide a technique of increasing a radius of curvature of (0001) plane, and narrowing an off-angle distribution, there is provided a nitride semiconductor substrate containing a group III nitride semiconductor crystal and having a main surface in which a nearest low index crystal plane is (0001) plane, wherein (0001) plane in one of a direction along <1-100> axis and a direction along <11-20> axis orthogonal to the <1-100> axis, is curved in a concave spherical shape with respect to the main surface, and a radius of curvature of the (0001) plane in one of the direction along the <1-100> axis and the direction along the <11-20> axis orthogonal to the <1-100> axis is different from a radius of curvature of at least a part of the (0001) plane in the other direction.

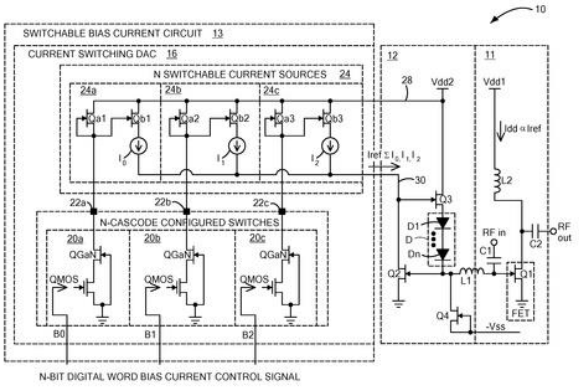


Amplifier having a switchable current bias circuit

Publication Number: WO2019/118199, US20190190456

Patent Applicant: Raytheon

A circuit having (A) a transistor; (B) a bias circuit for providing setting a bias current for the transistor, the bias current having a current level in accordance with a reference current fed to the bias circuit; and (C) a bias current level controller, comprising: (i) a plurality of switches, each one of the switches comprises: a MOS FET and a GaN FET connected in a cascode configuration; and (ii) current source circuitry, comprising a plurality of current sources, each one of the current sources being connected between a voltage source and a corresponding one of the plurality of switches, the current source circuit combining currents produced by the current source in response a binary control signal fed to a gate of the MOS FET, the combined current providing the reference current fed to the bias circuit.

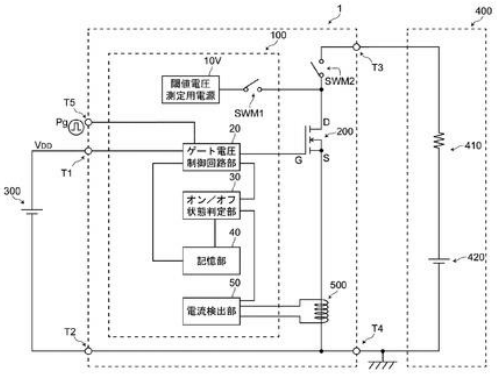


Semiconductor module

Publication Number: WO2019/123551

Patent Applicant: Shindengen Electric Manufacturing

This semiconductor module is characterized by being provided with: a semiconductor base body; a switching element, which has a first electrode, a second electrode, and a gate electrode, and which performs turning on/off between the first electrode and the second electrode by applying a predetermined gate voltage to the gate electrode; a control circuit unit that controls the gate voltage; and a current detection element that detects a current flowing between the first electrode and the second electrode of the switching element. The semiconductor module is also characterized in that: the switching element, the control circuit, and the current detection element are mounted on the semiconductor base body; and the current detection element is a Rogowski coil. The semiconductor module has effects, such as enabling to acquire a suitable gate voltage threshold value for each switching element, and perform a suitable on/off control for each switching element, even if the threshold value varies by each switching element due to manufacturing variance.



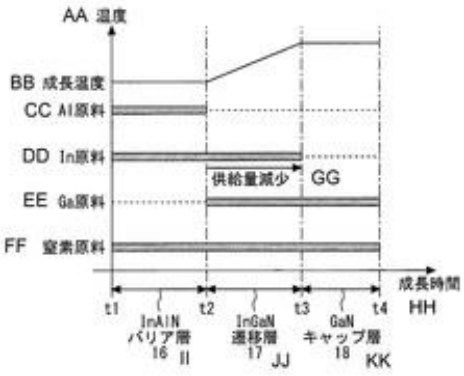
10V Threshold voltage measurement power supply
20 Gate voltage control circuit unit
30 On/off state determining unit
40 Storage unit
50 Current detection unit

Method for producing semiconductor device and semiconductor device

Publication Number: WO2019/106843

Patent Applicant: Mitsubishi Electric

The present invention is characterized in comprising: forming a barrier layer from InAlN or InAlGaN on a channel layer; forming a transition layer from InGaN on the barrier layer while raising the growth temperature; and forming a cap layer from GaN on the transition layer.

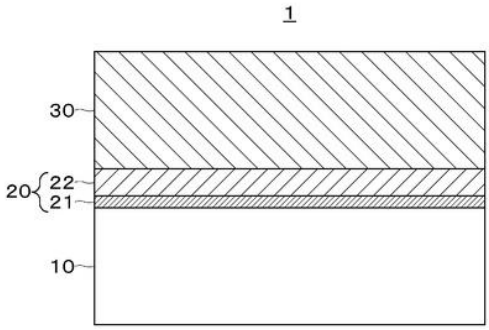


AA Temperature
BB Growth temperature
CC Al starting material
DD In starting material
EE Ga starting material
FF Nitrogen starting material
GG Reduction in amount fed
HH Growth time
II InAlN barrier layer 16
JJ InGaN transition layer 17
KK GaN cap layer 18

Method for producing group iii nitride semiconductor substrate

Publication Number: WO2019/123763
Patent Applicant: Sumco

[Problem] To suppress diffusion of a group III material into a Si substrate during the time when a group III nitride semiconductor layer is grown on the Si substrate, with an AlN buffer layer being interposed therebetween. [Solution] A method for producing a group III nitride semiconductor substrate according to the present invention comprises: a step (S12A) for growing a first AlN buffer layer 21 on an Si substrate 10; a step (S12B) for growing a second AlN buffer layer 22 on the first AlN buffer layer 21 at a temperature that is higher than the growth temperature of the first AlN buffer layer 21; and a step (S13) for growing a group III nitride semiconductor layer 30 on the second AlN buffer layer 22. The growth temperature of the first AlN buffer layer 21 is 400-600°C.



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