GANEX

Newsletter No. 84

January 2020

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

Sources

10+ scientific journal editors

Elsevier, IOP, IEEE, Wiley, Springer,
APS, AIP, AVS, ECS, Nature, Science …

10+ specialist magazines

Semiconductor Today, ElectoIQ, i-micronews,
Compound Semiconductor, Solid State Technology …

5+ open access database: *FreeFulPDF, DOAJ …*

Patent database: *Questel-Orbit*

Each month

150+ new scientific publications
200+ new patent applications
30+ new press releases

Selection by III-N French experts

GANEX

monthly newsletter

TABLE OF CONTENTS

(clickable links to chapters)

SCIENTIFIC PUBLICATIONS

Selection of new scientific articles

GROUP 1 - LEDs and Lighting

Group leader: Benjamin Damilano (CRHEA-CNRS)

Information selected by Benjamin Damilano (CRHEA-CNRS)

Regulating the circular polarization in nitride-based light-emitting diodes through the spin injection

Department of Physics, OSED, Fujian Provincial Key Laboratory of Semiconductor Materials and Applications, Jiujiang Research Insitute, Xiamen University, Xiamen, 361005, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab54a1

Circular polarization in nitride-based light-emitting diodes is investigated and regulated through the spin injection. Ferromagnet/dielectric are grown on n-type GaN as electron injector. Ultrathin quantum wells with quantum confinement effect are designed for enhancement of the circular polarizations in electroluminescence. By modulating the tunneling layer thickness and injection polarizer material, the preferred spin injection structure is determined. Room temperature circular polarization for surface-emission is optimized to 9.0% at most under a vertical magnetic field for the spin injecting contact. Spin relaxation time and diffusion length of about 34.9 ps and 134.5 nm, respectively, are revealed through the non-local three-terminal spin valve measurements.

Enhancing the light extraction of AlGaN-based vertical type deep-ultraviolet light-emitting-diodes with an internal reflector

Department of LED Business, Chip development group, LG Innotek, Paju, 10842, Republic of Korea
School of Advanced Materials Science and Engineering, Sungkyunkwan University, Suwon 16419, Republic of Korea
SKKU Advanced Institute of Nano Technology (SAINT), Sungkyunkwan University, Suwon 16419, Republic of Korea

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab52b6

AlGaN-based UV-C vertical LEDs comprising Ga-face n-contact and an internal reflector are reported here. Inside the chip, the internal reflector is designed as a hexagonal shape surrounding a circular n-electrode. The use of SiO2/Al reflectors on the etched plane improves the local reflectivity. Forming the internal reflector has been shown to lead to a significant improvement in light output power (LOP). The LOP of the vertical LED with an internal reflector is 1.27 times higher than that of the vertical LED without an internal reflector.

Improved efficiency of InGaN/GaN light-emitting diodes with perpendicular magnetic field gradients

School of Materials Science and Engineering, Gwangju Institute of Science and Technology, Gwangju 61005, South Korea
Department of Nanobio Materials and Electronics, Gwangju Institute of Science and Technology, Gwangju 61005, South Korea
School of Electrical Engineering and Computer Science, Gwangju Institute of Science and Technology, Gwangju 61005, South Korea
Research Institute for Solar and Sustainable Energies, Gwangju 61005, South Korea

Optics Express
https://doi.org/10.1364/OE.27.036708

The effect of magnetic fields on the optical output power of flip-chip light-emitting diodes (LEDs) with InGaN/GaN multiple quantum wells (MQWs) was investigated. Films and circular disks comprising ferromagnetic cobalt/platinum (Co/Pt) multilayers were deposited on a p-ohmic reflector to apply magnetic fields in the direction perpendicular to the MQWs of the LEDs. At an injection current of 20 mA, the ferromagnetic Co/Pt multilayer film increased the optical output power of the LED by 20% compared to an LED without a ferromagnetic Co/Pt multilayer. Furthermore, the optical output power of the LED with circular disks was 40% higher at 20 mA than the output of the LED with a film. The increase of the optical output power of the LEDs featuring ferromagnetic Co/Pt multilayers is attributed to the

magnetic field gradient in the MQWs, which increases the carrier path in the MQWs. The time-resolved photoluminescence measurement indicates that the improvement of optical output power is owing to an enhanced radiative recombination rate of the carriers in the MQWs as a result of the magnetic field gradient from the ferromagnetic Co/Pt multilayer.

Nitride LEDs and Lasers with Buried Tunnel Junctions

Institute of High Pressure Physics, Polish Academy of Sciences, 01-142 Warsaw, Poland
Cornell University, Ithaca, New York 14850, USA

ECS J. Solid State Sci. Technol.
https://doi.org/10.1149/2.0412001JSS

Traditionally, Nitride semiconductors have suffered from poor p-type conductivity, requiring Mg activation by removing hydrogen from grown layers either through thermal annealing or electron irradiation. This requirement restricts the growth of buried p-type layers. Here, we report structures obtained using a Hydrogen-free growth technique – plasma assisted molecular beam epitaxy. Using this method, top and bottom tunnel junctions are realized for top and bottom contacts to traditional Ga-polar devices. Advantages of using both constructions are discussed. The efficiency of the bottom-tunnel junction design is presented through realization of a stable laser diode operating at room temperature. Further work needed to improve tunnel junction performance as well as optical mode confinement to fully benefit from this design is outlined.

Ge doped GaN and Al0.5Ga0.5N-based tunnel junctions on top of visible and UV light emitting diodes

CNRS, Université Côte d'Azur, CRHEA, Rue Bernard Grégory, 06560 Valbonne, France
CEA—LETI, MINATEC Campus, 17 Rue des Martyrs, 38054 Grenoble, France

Journal of Applied Physics
https://doi.org/10.1063/1.5121379

The use of tunnel junctions (TJs) is a potential solution in blue light-emitting diodes (LEDs) to poor p-contacts, replacing it with another n-contact. TJs are even more advantageous for UV-emitting structures, which suffer from considerably low injection efficiency in high Al concentration UV LEDs. In this article, we report our work on Ge n-doped GaN and AlGaN TJs grown on top of blue and UV LEDs, respectively, by a hybrid growth method. We have achieved state-of-the-art mobility (67 cm2/V s) and resistivity ($1.7 \times 10{-}4\ \Omega\,\mathrm{cm}$) at a free electron concentration of $5.5 \times 1020\ \mathrm{cm}{-}3$ in Ge-doped GaN. With an emission wavelength of 436 nm, the GaN TJ slightly increased the optical power of the blue LED. The AlGaN TJs, on the other hand, improved the optical power of the UV LED (304 nm) by at least a factor of 3, suggesting the enhancement of the hole injection efficiency by the use of TJs in UV-emitting structures.

Two-dimensional analysis of the nonuniform quantum yields of multiple quantum wells for AlGaN-based deep-ultraviolet LEDs grown on AlN templates with dense macrosteps using cathodoluminescence spectroscopy

UV Craftory Co., Ltd., Bldg. D, 2-98 Yashirodai, Nagoya 465-0092, Japan
Toray Research Center, Inc., Otsu 520-8567, Japan
Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai 980-8577, Japan
Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya 464-8603, Japan
Venture Business Laboratory, Nagoya University, Nagoya 464-8601, Japan
Akasaki Research Center, Nagoya University, Nagoya 464-8601, Japan
Department of Materials Science and Engineering, Faculty of Science and Technology, Meijo University, Nagoya 464-8502, Japan

Journal of Applied Physics
https://doi.org/10.1063/1.5125623

AlGaN-based deep-ultraviolet light-emitting diodes (LEDs) incorporating uneven multiple quantum wells (MQWs) with inclined and terrace zones, which were fabricated on an AlN template with dense macrosteps, have exhibited a high internal quantum efficiency (IQE). To investigate the microscopic structure of uneven MQWs, cathodoluminescence (CL) mapping characterization was carried out, and the maps of the CL intensity at 300 K relative to that

at 38 K were obtained for uneven MQWs that targeted 265 and 285 nm LEDs. At an electron beam current of less than 1.0 nA, the signals from inclined and terrace zones of the uneven MQWs were confirmed to satisfy the nonsaturated excitation condition at 300 K. Nonradiative recombination (NR) was insufficiently frozen even at 38 K, specifically on the terraces in the 265 nm MQW, suggesting high concentrations of NR centers due to point defects (PDs). In contrast, NR in the 285 nm MQW at 38 K was closer to freeze-out. The concentration of PDs in the 285 nm MQW was likely to be lower than that in the 265 nm MQW. Finally, the ratios of the CL intensity at 300 K to those at 38 K were mapped, demonstrating an approach to creating an approximate map of IQE. The values in the CL intensity ratio maps are discussed by considering the analytical error factors. The results support the model of localized current injection through Ga-rich stripe zones in the n-AlGaN cladding layer.

Recombination rates in green-yellow InGaN-based multiple quantum wells with AlGaN interlayers

Center for Photonics and Nanoelectronics, Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, Pennsylvania 18015, USA

Journal of Applied Physics
https://doi.org/10.1063/1.5126965

The recombination rates in InGaN/AlGaN/GaN multiple quantum wells (MQWs) emitting in the green-yellow and grown with different Al compositions in the AlGaN interlayer (IL) are shown. By transforming measurements on radiative efficiency, absorption, and differential carrier lifetime, the radiative and nonradiative rates are determined. The IL Al composition controls lattice relaxation of the MQWs, as determined by X-ray reciprocal space mapping, and, therefore, defect formation. For the most pseudomorphic MQWs, the Shockley-Read-Hall (SRH) A coefficient is minimized and is similar to reports at shorter (blue and green) wavelengths. It is an order of magnitude smaller than a conventional InGaN/GaN MQW and is the most significant factor behind the improvement in radiative efficiency using the IL. The radiative B coefficient is also reduced and a minimum for the most pseudomorphic MQWs due to a reduction in the electron-hole wavefunction overlap. However, the decrease in A is more significant and leads to an overall improvement in the radiative efficiency. These recombination rate measurements confirm that if the SRH recombination is controlled, then the severe reduction of radiative recombination with an increased emitting wavelength is one of the main challenges in realizing high efficiency, long-wavelength InGaN-based MQW emitters operating at low to moderate current densities.

BAlGaN alloys nearly lattice-matched to AlN for efficient UV LEDs

Department of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan 48109, USA

Applied Physics Letters
https://doi.org/10.1063/1.5129387

The lattice mismatch between AlGaN and AlN substrates limits the design and efficiency of UV light-emitting diodes, but it can be mitigated by the coincorporation of boron. We employ hybrid density functional theory to investigate the thermodynamic, structural, and electronic properties of BAlGaN alloys. We show that BAlGaN can lattice match AlN with bandgaps that match AlGaN of the same gallium content. We predict that BAlGaN emits transverse-electric polarization for a gallium content of ∼45% or more. Our results indicate that BAlGaN alloys are promising materials for higher efficiency UV optoelectronic devices on bulk AlN substrates.

Strongly Confined Excitons in GaN/AlN Nanostructures with Atomically Thin GaN Layers for Efficient Light Emission in Deep-Ultraviolet

Ioffe Institute, St. Petersburg 194021, Russia
University of Notre Dame, Notre Dame, Indiana 46556, USA
Université Montpellier, L2C, UMR 5221, 34095 Montpellier Cedex 5, France

NanoLetters
https://doi.org/10.1021/acs.nanolett.9b03517

Fascinating optical properties governed by extremely confined excitons have been so far observed in 2D crystals like monolayers of transition metal dichalcogenides. These materials, however, are

limited for production by epitaxial methods. Besides, they are not suitable for the development of optoelectronics for the challenging deep-ultraviolet spectral range. Here, we present a single monolayer of GaN in AlN as a heterostructure fabricated by molecular beam epitaxy, which provides extreme 2D confinement of excitons, being ideally suited for light generation in the deep-ultraviolet. Optical studies in the samples, supplemented by a group-theory analysis and first-principle calculations, make evident a giant enhancement of the splitting between the dark and bright excitons due to short-range electron–hole exchange interaction that is a fingerprint of the strongly confined excitons. The practical significance of our results is in the observation of the internal quantum yield of the room-temperature excitonic emission as high as ∼75% at 235 nm.

p-GaN/n-ZnO Nanorod/CsPbBr3 Quantum Dots Decorated with ZnO Nanoseeds for Light-Emitting Diodes

Department of Physics, College of Science, Jiangsu University of Science and Technology, Zhenjiang, 212003, China
College of Materials Science and Engineering, Jiangsu University, Zhenjiang 212013, China
College of Telecommunication and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China

ACS Appl. Nano Mater.
https://doi.org/10.1021/acsanm.9b01744

In this paper, we report the dual-wavelength green-light emission from zinc oxide (ZnO)-nanoseed-decorated p-GaN (gallium nitride)/n-ZnO nanorod/CsPbBr3 quantum dots (QDs) light-emitting diodes (LEDs). At the same time, the effect of ZnO nanoseeds on the p-GaN/n-ZnO nanorod/CsPbBr3 QDs LED performance is deeply studied. ZnO nanoseeds were fabricated by magnetron sputtering and the sol–gel method; then ZnO nanorods were obtained on GaN by hydrothermal treatment to form the p-GaN/n-ZnO nanorod heterojunction, and green CsPbBr3 QDs were further deposited on ZnO nanorod arrays to realize LEDs. The results show that magnetron-sputtering ZnO nanoseeds can induce regular vertical ZnO nanorod arrays, and the corresponding device presents a better electroluminescence (EL) performance. The X-ray diffraction, atomic force microscopy, and EL mechanisms indicate that the p-GaN/n-ZnO nanorod with magnetron-sputtering ZnO nanoseeds has a better crystalline interface. Our results indicate that the p-GaN/n-ZnO nanorod/CsPbBr3 QDs heterojunction structure can be served as dual-wavelength LEDs, and magnetron-sputtering ZnO nanoseeds can give rise to a better EL performance.

Band engineering of III-nitride-based deep-ultraviolet light-emitting diodes: a review

School of Microelectronics, University of Science and Technology of China, Hefei, Anhui 230026, People's Republic of China
Jacobs School of Engineering, University of California San Diego, San Diego, CA 92093, United States of America

Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/ab4d7b

III-nitride deep ultraviolet (DUV) light-emitting diodes (LEDs) have been identified as promising candidates for energy-efficient, environment-friendly and robust UV lighting sources with potential applications in water/air purification, sterilization, and bio-sensing. However, the performance of state-of-art DUV LEDs is far from satisfactory for commercialization due to their low internal quantum efficiency, large current leakage and efficiency droop at high current injection, etc. Extensive efforts have been devoted to properly designing the band structures of such luminescent devices to enhance their output power. In this review, we summarize the recent progress of various energy band designs and of the engineering of DUV LEDs, with particular attention paid to the various approaches in band engineering of electron-blocking layers, quantum wells, quantum barriers and the implementation of many novel structures such as tunnel junctions and ultrathin quantum heterostructures utilized to enhance their efficiency. These inspirational approaches pave the way towards the next generation of greener and more efficient UV sources suitable for practical applications.

Temperature-Dependent Carrier Recombination and Efficiency Droop of AlGaN Deep Ultraviolet Light-Emitting Diodes

Department of Electronic Science,Xiamen University, Xiamen, China, Xiamen University, Xiamen, China, Xiamen, Fujian China

IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2019.2958311

We investigate temperature-dependent carrier transfer and efficiency droop on AlGaN-based deep ultraviolet light-emitting diodes. The Shockley-Read-Hall (SRH) recombination and carrier leakage are highly associated with the poor thermal stability. The existence of Auger recombination and carrier leakage is identified by the m-power method. A modified ABC model with an additional term f(n) related to carrier leakage is employed to analyze the evolution of multiple recombination mechanisms. The SRH process strongly suppresses both Auger recombination and carrier leakage at low currents. At high currents, the latter two processes are responsible for the efficiency droop and exhibit an anti-correlation upon temperature.

Effect of oxygen plasma modification on Pd/Al/Au Ohmic contacts on undoped AlN

Department of Physics, College of Science, Beijing University of Chemical Technology, 15 East Road, Beisanhuan, Beijing 100029, People's Republic of China
Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Science, Beijing 100083, People's Republic of China

Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/ab407a

The influence of surface modification of undoped AlN by oxygen plasma on the Pd/Al/Au Ohmic contacts was studied. Pd/Al/Au alloys were deposited on undoped AlN films by electron beam evaporation and annealed from 750 °C to 900 °C for 30 s to form metal–semiconductor contacts. All the samples without oxygen plasma treatment were Schottky contacts. After oxygen plasma treatment, the contacts below annealing temperature of 850 °C were Schottky type. However, the contacts changed to be Ohmic type with specific contact resistivity of 3.01 Ω centerdot cm2 when the annealing temperature was 900 °C. The samples were characterized by scanning electron microscopy and x-ray diffraction, which indicated that the formation of AlPd alloy was believed to play a key role for the formation of low Ohmic contacts. The first-principle calculation indicated that the surface modification by oxygen plasma could increase the work function of AlN and therefore benefit the formation of Ohmic contacts. This result can promote the application prospects of AlN in deep ultraviolet optoelectronic devices and high frequency and high power RF devices.

The Physics of Recombinations in III-Nitride Emitters

Soraa Inc., Fremont California 94555, USA

ECS J. Solid State Sci. Technol.
https://doi.org/10.1149/2.0372001JSS

The physics of carrier recombinations in III-nitride light emitters are reviewed, with an emphasis on experimental investigations. After a discussion of various methods of measuring recombination dynamics, important results on recombination physics are examined. The radiative rate displays a complex behavior, influenced by Coulomb interaction and carrier screening. Non-radiative recombinations at low and high current are shown to scale with the overlap of electron-hole wavefunctions, similarly to the radiative rate, leading to a compensation effect which explains the high efficiency of III-nitride emitters. Finally, the droop current is decomposed into two contributions: the well-known Auger scattering, and a defect-assisted droop process, which is shown to play an important role in the green gap.

Integrated ray-wave optics modeling for macroscopic diffractive lighting devices

Department of Applied Physics, Kyung Hee University, Gyeonggi-do 17104, South Korea
Department of Applied Chemistry, Kyung Hee University, Gyeonggi-do 17104, South Korea

Optics Express
https://doi.org/10.1364/OE.27.037910

We studied a high-accuracy hybrid optics modeling for macroscopic lighting devices containing highly

diffractive elements. For a two-dimensional (2D) grating, we achieved forward and backward diffraction distributions at omnidirectional incidence by conducting rigorous coupled-wave analysis and then assigned the diffuse information to a virtual, planar surface in a ray-optics model. By using the integrated ray-wave optics simulation, we obtained extraction efficiencies and far-field distributions of millimeter-scale ($0.5 \times 0.5 \times 0.1$ mm3) flip-chip GaN-based light-emitting diodes (LEDs) with embedded 2D gratings. The increased index contrast of 2D gratings progressively improved the extraction of light via the top face of the substrates, thus inducing a vertical beaming effect that strongly supported measured data. The outcoupling features related to the index contrast of gratings were understood by performing Fourier analysis; a high-index-contrast grating preferred to excite high-order diffraction modes, thereby effectively converting tightly bound waveguide modes into leaky light through the top escape route. The simulation strategy developed herein will be essential for designing directional illuminations and micro-LED displays.

Broadened Bandwidth Amplified Spontaneous Emission from Blue GaN-Based Short-Cavity Superluminescent Light-Emitting Diodes

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

ECS J. Solid State Sci. Technol.
https://doi.org/10.1149/2.0432001JSS

We report broad bandwidth blue superluminescent light-emitting diodes (SLEDs) based on a short-cavity active region. The dependencies of amplified spontaneous emission (ASE) output power and gain bandwidth on cavity length were investigated in devices whose gain medium consists of a ridge waveguide with embedded InGaN/GaN quantum wells sandwiched between one etched facet coated with a high reflectivity distributed Bragg mirror and one cleaved facet with an anti-reflection coating. 250 µm-long blue SLEDs exhibit a spectral bandwidth up to 7.5 nm at 1.72 mW output power at a wavelength of 427 nm. As cavity length decreases, the bandwidth gradually broadens up to 15 nm for the shortest, 40 µm-long, SLED devices. ASE is confirmed by current-dependent electroluminescence spectra and polarization-dependent emission intensity measurements. The optical features of those short-cavity devices could be helpful for designing broad bandwidth SLEDs aiming for various applications such as optical coherence tomography, next generation displays, on-chip biosensing and imaging.

Size-dependent optoelectrical properties of 365 nm ultraviolet light-emitting diodes

Department of Electrical and Computer Engineering, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada
Waterloo Institute of Nanotechnology, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada

Nanotechnology
https://doi.org/10.1088/1361-6528/ab4201

In this paper, the size-dependent optical and electrical properties of 365 nm InGaN/AlGaN ultraviolet micron-size light-emitting diodes (µLEDs) on c-plane sapphire substrates is investigated. The series resistance of the µLED increased from 20 Ω to 15 kΩ when the diameter of the device decreased from 150 to 3 µm. The ideality factor increased from 4 to 4.6 over the same range of diameters due to the increase in the defect density for the smaller µLEDs. Moreover, electroluminescence characterization showed a fixed and red-spectral-shift emission for the µLEDs with diameters smaller than 10 µm and larger than 15 µm, respectively. The red-shift was due to band-gap narrowing in InGaN/AlGaN multi-quantum wells as a result of self-heating at higher current densities in the larger diameter µLEDs. Due to an increase in the heat dissipation of devices with a high surface to volume ratio, the smaller diameter devices were found to have higher light extraction efficiency and no measurable emission spectrum shift.

Toyoda Gosei's History of R&D on Blue LEDs with Professor Isamu Akasaki

Toyoda Gosei Co., Ltd, Optpelectronics, Aichi 490-1207, Japan

ECS J. Solid State Sci. Technol.
https://doi.org/10.1149/2.0442001JSS

Toyoda Gosei (TG) started joint R&D with Prof. Akasaki and Prof. Amano (collectively, the Akasaki

Group) in 1986, immediately after the Akasaki Group succeeded in the growth of high-quality GaN single crystals for the first time in the world. Then, the Akasaki Group and TG concluded an entrustment R&D agreement with Japan Science and Technology Agency (JST) in 1987 to promote R&D through the investment of JST. Under these circumstances, the Akasaki Group achieved the growth of high-quality p-type GaN and n-type GaN, believed impossible at that time. These breakthrough technologies were of fundamental importance for developing blue light-emitting diodes (LEDs). Namely, (1) high-quality GaN single crystals, (2) p-type GaN, and (3) n-type GaN were found to be applicable to industrial products. Thanks to the Akasaki Group, TG started the mass production of blue LEDs in 1995. However, at that time, these LEDs were not particularly bright, and no one believed that they would be used in general lighting. In spite of this prediction, the brightness of blue LEDs was improved markedly by industry-based developments, leading to their widespread adoption in many applications.

Improvement of The Light Output of Blue InGaN-Based Light Emitting Diodes by Using a Buried Stripe-Type n-Contact and Reflective Bonding Pad

Department of Materials Science and Engineering, Korea University, Seoul 02841, South Korea
Department of Nanophotonics, Korea University, Seoul 02841, South Korea
Department of Electronics and Communication Engineering, Hanyang University, Ansan, Gyeonggi 15588, Korea
LED Division, LG Innotek Co., Ltd., Paju, Gyeonggi 10842, Korea
Center for Integrated Research of Future Electronics, and Institute of Materials and Systems for Sustainability, Nagoya University, Nagoya 464-8603, Japan

ECS J. Solid State Sci. Technol.
https://doi.org/10.1149/2.0462001JSS

To enhance the light output of blue InGaN-based light emitting diodes (LEDs), a buried stripe-type n-electrode, expanded stripe-type p-electrode, and reflective p-bonding pad were employed. Flip-chip (FC) LEDs with the expanded p-electrode gave forward voltages of 2.99–3.11 V at 100 mA and series resistances of 3.28–3.94 Ω. The expanded p-electrode FCLED fabricated with 375 nm-thick window and TiO2 adhesion layers produced 22.7% higher light output at 21 A/cm2 than conventional FCLEDs. The expanded p-electrode FCLEDs revealed better current spreading efficiency than the c-FCLED, indicating the importance of the use of an optimised window and TiO2 adhesion layers.

Beyond solid-state lighting: Miniaturization, hybrid integration, and applications of GaN nano- and micro-LEDs

Institute of Semiconductor Technology (IHT), Technische Universität Braunschweig, Hans-Sommer-Straße 66, D-38106 Braunschweig, Germany
Laboratory for Emerging Nanometrology (LENA), Technische Universität Braunschweig, Langer Kamp 6a, D-38106 Braunschweig, Germany
MIND-IN2UB, Department of Electronic and Biomedical Engineering, Universitat de Barcelona, C/Martí i Franquès 1, E-08028 Barcelona, Spain

Applied Physics Reviews
https://doi.org/10.1063/1.5096322

Gallium nitride (GaN) light-emitting-diode (LED) technology has been the revolution in modern lighting. In the last decade, a huge global market of efficient, long-lasting, and ubiquitous white light sources has developed around the inception of the Nobel-prize-winning blue GaN LEDs. Today, GaN optoelectronics is developing beyond solid-state lighting, leading to new and innovative devices, e.g., for microdisplays, being the core technology for future augmented reality and visualization, as well as point light sources for optical excitation in communications, imaging, and sensing. This explosion of applications is driven by two main directions: the ability to produce very small GaN LEDs (micro-LEDs and nano-LEDs) with high efficiency and across large areas, in combination with the possibility to merge optoelectronic-grade GaN micro-LEDs with silicon microelectronics in a hybrid approach. GaN LED technology is now even spreading into the realm of display technology, which has been occupied by organic LEDs and liquid crystal displays for decades. In this review, the technological transition toward GaN micro- and nanodevices beyond lighting is discussed including an up-to-date overview on the state of the art.

Suppressing the Initial Growth of Sidewall GaN by Modifying AlN-Coated Patterned Sapphire with KOH-Based Etchant

Department of Materials Science and Engineering, National Chaio Tung University
Department of Photonics, National Cheng Kung University, Tainan City 701, Taiwan
Taiwan Semiconductor Research Institute, Hsinchu, Taiwan

ECS Journal of Solid State Science and Technology
https://doi.org/10.1149/2.0182001JSS

Micron-sized patterned sapphire substrates (PSSs) with an ex situ sputtered AlN nucleation layer (NL) have been used to improve the performance of GaN-based light-emitting diodes (LEDs). The growth of GaN was enhanced not only from bottom c-plane, but also from the sidewall of the micron-sized patterns. In this study, KOH solution was used to etch AlN (especially sidewall AlN) for the first time. The additional etching process is very simple. It was found that KOH etching 1 min did enhance the light output power (LOP) of LED. However, with the increase of etching time to 4 min, the LOP decreased. Besides, the effect of remained AlN on GaN growth mechanism was investigated in detail.

On The Search for Efficient Solid State Light Emitters: Past, Present, Future

Materials Department, University of California, Santa Barbara, California 93106-5050, USA
Laboratoire de Physique de la Matière Condensée, CNRS, Ecole Polytechnique, IP Paris, Palaiseau, 91128, France

ECS Journal of Solid State Science and Technology
https://doi.org/10.1149/2.0392001JSS

The emergence of efficient solid state light emitters was the result of the remarkable breakthroughs in the late 1980s and early 1990s in GaN-based materials and light emitting diodes. Over the past two decades, the continued progress in blue LED efficiency resulted in a revolution in lighting. While the basic physics of nitrides LEDs operation are well understood, nitride LEDs have still open questions, and their reaching physical limits at all wavelengths still raises major challenges.

GaN/AlN quantum-disk nanorod 280 nm deep ultraviolet light emitting diodes by molecular beam epitaxy

Semiconductor Lighting R&D center, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China
Deparment of Electrical and Computer Engineering, Cornell University, Ithaca, New York 14853, USA
Paul-Drude-Institut fürFestköperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

Optics Letters
https://doi.org/10.1364/OL.45.000121

We report optically and electrically pumped ~280nm deep ultraviolet (DUV) light emitting diodes (LEDs) with ultra-thin GaN/AlN quantum disks (QDs) inserted into AlGaN nanorods by selective epitaxial regrowth using molecular beam epitaxy. The GaN/AlN QD LED has shown strong DUV emission distribution on the ordered nanorods and high internal quantum efficiency of 81.2%, as a result of strain release and reduced density of threading dislocations revealed by transmission electron microscopy. Nanorod assembly suppresses the lateral guiding mode of light, and light extraction efficiency can be increased from 14.9% for planar DUV LEDs to 49.6% for nanorod DUV LEDs estimated by finite difference time domain simulations. Presented results offer the potential to solve the issue of external quantum efficiency limitation of DUV LED devices.

Photonic crystal tunnel junction deep ultraviolet light emitting diodes with enhanced light extraction efficiency

Department of Electrical and Computer Engineering, University of Michigan, 1301 Beal Avenue, Ann Arbor, MI 48105, USA

Optics Express
https://doi.org/10.1364/OE.380739

We report on the demonstration of top emitting AlGaN tunnel junction deep ultraviolet (UV) light emitting didoes (LEDs) operating at ~267 nm. We show, both theoretically and experimentally, that the light extraction efficiency can be enhanced by nearly a factor of two with the incorporation of AlGaN nanowire photonic crystal structures. A peak wall-

plug efficiency (WPE) ~3.5% and external quantum efficiency (EQE) ~5.4% were measured for AlGaN LEDs directly on-wafer without any packaging. This work demonstrates a viable path for achieving high efficiency deep UV LEDs through the integration of AlGaN planar and nanoscale structures.

Feasibility study of nanopillar LED array for color-tunable lighting and beyond

Department of Electrical Engineering and Computer Science, University of Michigan, 1301 Beal Ave, Ann Arbor, MI 48109, USA

Optics Express
https://doi.org/10.1364/OE.382287

An LED chip containing monolithically integrated red, green, and blue channels was fabricated and characterized. Using local strain engineering in gallium nitride p-i-n nanopillar structures, each color channel emits a distinct color with emission wavelength determined entirely by the diameter of the nanopillar. The crosstalk between color channels is negligible. As a result, individually addressable color channels can be integrated on the same substrate which will be suitable for color-tunable lighting applications. Optical and electrical properties were measured and discussed. Fabrication challenges which degraded power efficiency of the shorter-wavelength channel were analyzed. Potential strategies for improvements were proposed.

Symmetrical bi-heterojunction alternating current ultraviolet light-emitting diode

State Key Laboratory of Bioelectronics, School of Biological Sciences & Medical Engineering, Southeast University, 2 Sipailou, Nanjing 210096, People's Republic of China

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2960816

The development of bidirectional light emitting diodes (LEDs) is significant to avoid stroboscopic effects and save energy for illumination and display applications. However, the existing bidirectional LEDs present different electroluminescent (EL) emission spectra and intensity at forward and reverse bias conditions which causes stroboscopic effects. Herein, A symmetrical bi-heterojunctional n-ZnO/n-GaN/n-ZnO LED was fabricated by bonding n-ZnO microwires on a n-GaN layer. The LEDs generate a stable UV light output under both forward and reverse bias conditions. The EL intensities of LEDs under forward and reverse bias conditions are approximately equal because of symmetrical characters between two heterojunctions. Our results provide a bi-directionbiased bi-heterojunction ultraviolet LED avoiding stroboscopic effects.

High-Performance Semi-polar InGaN/GaN Green Micro Light-emitting Diodes

Nanjing University, 12581 Nanjing, Jiangsu China
College of Electronic and Optical Engineering & College of Microelectronics, Nanjing University of Posts and Telecommunications, 12577 Nanjing, Jiangsu China
Nanjing University, Research Institute of Superconductor Electronics (RISE), Nanjing, Jiangsu China

IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2019.2962184

Semi-polar micro-LEDs have gain increasing interests due to the advantages of polarization control and quantum efficiency improvement. In this work, a novel semi-polar (20-21)-plane micro-LEDs array has been designed and manufactured. In comparison with c-plane micro-LEDs, semi-polar micro-LEDs indicate better electrical and optical performance. The relative EQE of semi-polar micro-LEDs remains at 62% under the injected current density of 775.6 A/cm2, which indicates a reduced efficiency droop due to less polarization in MQWs. It has been further proved by a significant reduction of 55% in emission peak blue-shift under the injected current density from 11.1 A/cm2 to 775.6 A/cm2. In addition, the carrier recombination dynamics and spatial light distribution of semi-polar micro-LEDs with different pixel sizes have been studied. Fast recombination lifetime in smaller size semi-polar micro-LEDs indicates a promising way to be used as a high modulation bandwidth light source. Stable and uniform light distribution in a wider range of spatial azimuths further supports for the semi-polar micro-LEDs as a strong candidate for the applications of high-resolution display and high-speed visible light communication.

Boosted ultraviolet electroluminescence of InGaN/AlGaN quantum structures grown on high-index contrast patterned sapphire with silica array

Center for Photonics and Semiconductors, School of Power and Mechanical Engineering, Wuhan University, Wuhan, 430072, China
HC SemiTek Corporation, Wuhan, 430072, China
The Institute of Technological Sciences, Wuhan University, Wuhan, 430072, China
School of Microelectronics, University of Science and Technology of China, Hefei, 230026, China
Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, 430074, China
Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI, 48109, USA

Nano Energy
https://doi.org/10.1016/j.nanoen.2019.104427

Epitaxially grown high crystalline quality InGaN/AlGaN multiple quantum structures on patterned sapphire with silica array (PSSA) have been successfully demonstrated. In comparison to conventional epilayers grown on patterned sapphire substrate (PSS), we observed a reduced threading dislocation density in the films grown on PSSA, attributing to the preferable vertical growth mode and reduced misfit at the coalescence boundary. Furthermore, a significant enhancement in light extraction efficiency can be achieved from InGaN/AlGaN-based ultraviolet light-emitting diodes (UVLEDs) built on PSSA owing to the large refractive index contrast between the epilayers and PSSA. More photons can escape from the top and bottom of the device, which was confirmed by numerically modeling light propagation within such device architecture. Benefiting from the reduced threading dislocation density and enhanced light extraction efficiency, the external quantum efficiency (EQE) of the fabricated UVLEDs on PSSA was more than two times higher than that of devices on the conventional flat sapphire substrate and it was additionally enhanced by 26.1% in comparison to the devices fabricated on PSS under an injection current of 150 mA. Therefore, the successful demonstration of UVLED on PSSA provides an unprecedented opportunity in achieving higher electroluminescence performance in future solid-state UV light sources.

High performance electron blocking layer-free InGaN/GaN nanowire white-light-emitting diodes

Department of Electrical and Computer Engineering, New Jersey Institute of Technology, 323 Dr Martin Luther King Jr. Boulevard, Newark, New Jersey 07102, USA
Institute of Chemical Technology, Vietnam Academy of Science and Technology, 1 Mac Dinh Chi Street, District 1, Ho Chi Minh City 700000, Vietnam
Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Assam 788010, India
Division of Computational Physics, Institute for Computational Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Optics Express
https://doi.org/10.1364/OE.28.000665

We investigated the effect of coupled quantum wells to reduce electron overflow in InGaN/GaN dot-in-a-wire phosphor-free white color light-emitting diodes (white LEDs) and to improve the device performance. The light output power and external quantum efficiency (EQE) of the white LEDs with coupled quantum wells were increased and indicated that the efficiency droop was reduced. The improved output power and EQE of LEDs with the coupled quantum wells were attributed to the significant reduction of electron overflow primarily responsible for efficiency degradation through the near-surface GaN region. Compared to the commonly used AlGaN electron blocking layer between the device active region and p-GaN, the incorporation of a suitable InGaN quantum well between the n-GaN and the active region does not adversely affect the hole injection process. Moreover, the electron transport to the device active region can be further controlled by optimizing the thickness and bandgap energy of this InGaN quantum well. In addition, a blue-emitting InGaN quantum well is incorporated between the quantum dot active region and the p-GaN, wherein electrons escaping from the device active region can recombine with holes and contribute to white-light emission. The resulting device exhibits high internal quantum efficiency of 58.5% with highly stable emission characteristics and virtually no efficiency droop.

Monolayer GaN excitonic deep ultraviolet light emitting diodes

Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan 48109, USA
Department of Materials Science and Engineering, University of Michigan, Ann Arbor, Michigan 48109, USA

Applied Physics Letters
https://doi.org/10.1063/1.5124828

We report on the molecular beam epitaxy and characterization of monolayer GaN embedded in N-polar AlN nanowire structures. Deep ultraviolet emission from 4.85 to 5.25 eV is measured by varying the AlN barrier thickness. Detailed optical measurements and direct correlation with first-principles calculations based on density functional and many-body perturbation theory suggest that charge carrier recombination occurs predominantly via excitons in the extremely confined monolayer GaN/AlN heterostructures, with exciton binding energy exceeding 200 meV. We have further demonstrated deep ultraviolet light-emitting diodes (LEDs) with the incorporation of single and double monolayer GaN, which operate at 238 and 270 nm, respectively. These unique deep ultraviolet LEDs exhibit highly stable emission and a small turn-on voltage around 5 V.

Thermal and efficiency droop in InGaN/GaN light-emitting diodes: decoupling multiphysics effects using temperature-dependent RF measurements

Center for High Technology Materials (CHTM), University of New Mexico, Albuquerque, New Mexico, 87106, USA

Scientific Reports
https://doi.org/10.1038/s41598-019-56390-2

Multiphysics processes such as recombination dynamics in the active region, carrier injection and transport, and internal heating may contribute to thermal and efficiency droop in InGaN/GaN light-emitting diodes (LEDs). However, an unambiguous methodology and characterization technique to decouple these processes under electrical injection and determine their individual roles in droop phenomena is lacking. In this work, we investigate thermal and efficiency droop in electrically injected single-quantum-well InGaN/GaN LEDs by decoupling the inherent radiative efficiency, injection efficiency, carrier transport, and thermal effects using a comprehensive rate equation approach and a temperature-dependent pulsed-RF measurement technique. Determination of the inherent recombination rates in the quantum well confirms efficiency droop at high current densities is caused by a combination of strong non-radiative recombination (with temperature dependence consistent with indirect Auger) and saturation of the radiative rate. The overall reduction of efficiency at elevated temperatures (thermal droop) results from carriers shifting from the radiative process to the non-radiative processes. The rate equation approach and temperature-dependent pulsed-RF measurement technique unambiguously gives access to the true recombination dynamics in the QW and is a useful methodology to study efficiency issues in III-nitride LEDs.

Improving AlN Crystal Quality and Strain Management on Nano-Patterned Sapphire Substrates by High Temperature Annealing for UVC-LEDs

Ferdinand-Braun-Institut, Leibniz-Institut fuer Hoechstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany
Institute of Solid State Physics, Technische Universitaet Berlin, Hardenbergstr. 36, 10623 Berlin, Germany
Osram Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany
Institute of Semiconductor Technology, Technische Universitaet Braunschweig, Hans-Sommer-Straße 66, 38106 Braunschweig, Germany
Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Straße 16, 12489 Berlin, Germany

physica status solidi a
https://doi.org/10.1002/pssa.201900796

In this study, AlN growth by metalorganic vapor phase epitaxy on hole-type nano-patterned sapphire substrates is investigated. Cracking occurs for an unexpectedly thin layer thickness which is associated to altered nucleation conditions caused by the sapphire pattern. To overcome the obstacle of cracking and at the same time to decrease the threading dislocation density by an order of

magnitude high temperature annealing of a 300 nm thick AlN starting layer is successfully introduced. By this method, we end up with 800 nm thick, fully coalesced and crack-free AlN on 2-inch nano-patterned sapphire wafers. The usability of such templates as basis for UVC light emitting diodes is furthermore proved by subsequent growth of an UVC-LED heterostructure with single peak emission at 265 nm. Prerequisites for the enhancement of the light extraction efficiency by hole-type nano-patterned sapphire substrates are discussed.

An Initial Study of UVC Optical Losses for Monolithically Integrated AlGaN Heterojunction Optoelectronic Devices

Department of Electrical Engineering, University of South Carolina, Columbia, 301 Main St., Columbia, SC 29208, USA

physica status solidi a
https://doi.org/10.1002/pssa.201900801

An initial study of losses in n-AlxGa1−xN planar waveguides at λemission∼280 nm using monolithically integrated AlxGa1−xN multiple quantum wells (MQWs) based light-emitting diodes and detectors is presented. The epilayer structure for the integrated devices was grown on an AlN (3.5 µm thick) template over sapphire substrates. Emitter-detector optical coupling and the directional independence of radiation within the epi-structure were experimentally established. A model for estimating the attenuation coefficient under these conditions was developed. The attenuation coefficient for a planar n-Al0.65Ga0.35N waveguide was measured to be 5–6 cm−1 and it primarily arises from the free carrier absorption rather than surface roughness dependent Rayleigh scattering.

High-Temperature Optical Characterization of GaN-Based Light-Emitting Diodes for Future Power Electronic Modules

Department of Electrical Engineering, University of Arkansas, Fayetteville, Arkansas 72701, USA

physica status solidi a
https://doi.org/10.1002/pssa.201900792

High-temperature optical analysis of three different InGaN/GaN multiple quantum well (MQW) light-emitting diode (LED) structures (peak wavelength λp = 448, 467, and 515 nm) is conducted for possible integration as an optocoupler emitter in high-density power electronic modules. The commercially available LEDs, primarily used in the display (λp = 467 and 515 nm) and lighting (λp = 448 nm) applications, are studied and compared to evaluate if they can satisfy the light output requirements in the optocouplers at high temperatures. The temperature- and intensity-dependent electroluminescence (T-IDEL) measurement technique is used to study the internal quantum efficiency (IQE) of the LEDs. All three LEDs exhibit above 70% IQE at 500 K and stable operation at 800 K without flickering or failure. At 800 K, a promising IQE of above 40% is observed for blue for display (BD) (λp = 467 nm) and green for display (GD) (λp = 515 nm) samples. The blue for light (BL) (λp = 448 nm) sample shows 24% IQE at 800 K.

Red-Emitting InGaN-Based Nanocolumn Light-Emitting Diodes with Highly Directional Beam Profiles

Sophia University, 7-1, Kioi-cho, Chiyoda, Tokyo 102-8554, Japan

physica status solidi a
https://doi.org/10.1002/pssa.201900771

Various InGaN/GaN pn-junction nanocolumn arrays arranged in a triangle lattice are grown on the same substrate while changing the nanocolumn diameters (Dn-GaN) of the underlying n-side GaN region under the lattice constant (L) of 340 nm. The nanocolumn diameter increases during the growth of the active InGaN and p-side GaN regions. The periodic arrangement of nanocolumns leads to a photonic crystal effect. Redshift of the band edge wavelength, from 573 to 629 nm, is observed as Dn-GaN increases from 159 to 282 nm. This phenomenon can be explained by the fact that the larger filling factor increases the effective refractive index of the nanocolumn system, resulting in a redshift of the band edge. The light diffraction at the photonic band edge induces the directional radiation beam from the surface of the nanocolumn system. Using the nanocolumn array with Dn-GaN = 260 nm, the red-emitting (λ = 637 nm) nanocolumn light-emitting

diodes with the radiation angle of ±30° are demonstrated.

Impact of alloy disorder on Auger recombination in single InGaN/GaN core-shell microrods

Institute of Physics, École polytechnique fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
OSRAM Opto Semiconductors GmbH, 93055 Regensburg, Germany
Department of Microsystems Engineering (IMTEK), University of Freiburg, 79110 Freiburg, Germany
Institute of Physics, Technische Universität Chemnitz, 09126 Chemnitz, Germany
École polytechnique, 91128 Palaiseau, France
Univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France

PHYSICAL REVIEW B
https://doi.org/10.1103/PhysRevB.100.235301

We study the influence of local inhomogeneities on carrier recombination dynamics in single InGaN/GaN core-shell microrods (MRs) by means of time-resolved microphotoluminescence (TRPL) at 10 K. At low carrier density (∼1011cm−2), the carrier recombination in the m-plane quantum well is dominated by radiative processes and the recorded decay times along the MR equally amount to about 400 ps, corresponding to a bimolecular coefficient of 1.1±0.2×10−2cm2s−1. When the excited carrier density exceeds 1012cm−2, both the efficiency and the decay time of the PL in the quantum well drop significantly, which indicates the onset of Auger recombination. Based on a modified ABC model, we estimate a C coefficient varying from 0.5±0.2 to 2.2±0.9×10−16cm4s−1 from the lower to the upper part of the MR. This increase is accompanied by a rise of PL linewidth in the low excitation regime, indicating an increase of alloy disorder. Relaxation of the k-selection rule by alloy disorder is expected to play an important role in the observed increase of Auger coefficient. These results confirm that Auger recombination is sensitive to disorder and can be significantly enhanced in strongly disordered systems. We conclude that it is therefore crucial to minimize the degree of disorder in the active layer for high power LEDs based on core-shell MRs.

Radiative and Auger Recombination Constants and Internal Quantum Efficiency of (0001) AlGaN Deep-UV Light-Emitting Diode Structures

STR Group –Soft-Impact, Ltd., 64 Bolshoi Sampsonievskii ave.,Bld.'E', St. Petersburg, 194044, Russia

physica status solidi a
https://doi.org/10.1002/pssa.201900878

A semiempirical model accounting for hole localization by composition fluctuations is applied to estimate the radiative and Auger recombination constants in (0001) AlGaN quantum wells serving as active regions of deep-ultraviolet (UV) light-emitting diodes (LEDs). The model is preliminarily calibrated using the directly measured hole localization lengths in Al0.25Ga0.75N alloys and quantum wells. The recombination constants are found to vary nonmonotonously with the alloy composition/emission wavelength. Device simulations combined with the estimated recombination constants enable identification of major factors limiting the internal quantum efficiency of the LED structures: competition of various recombination channels and electron leakage through the electron-blocking layer at wavelengths longer and shorter than ≈240 nm, respectively. Comparison of the predicted recombination constants with the data available for bulk AlGaN alloys and Al0.45Ga0.55N/AlN quantum wells is done.

High-efficiency near-UV light-emitting diodes on Si substrates with InGaN/GaN/AlGaN/GaN multiple quantum wells

State Key Laboratory of Luminescent Materials and Devices, South China University of Technology, Guangzhou 510641, China.
Guangdong Choicore Optoelectronics Co., Ltd., Heyuan 517003, China

Journal of Materials Chemistry C
https://doi.org/10.1039/C9TC06138J

Both the weak carrier confinement in InGaN/GaN multiple quantum wells (MQWs) and the severe quantum-confined Stark effect in InGaN/AlGaN MQWs limit the improvement of quantum efficiency for near-ultraviolet (UV) light-emitting diodes (LEDs). In this regard, we have demonstrated the high

quantum efficiency LEDs grown on 4-inch Si substrates with well-designed InGaN/GaN/AlGaN/GaN MQWs. On the one hand, the proposed GaN interlayer barrier can increase the concentration and the spatial overlap of carriers in MQWs for modulating the energy band and polarization theoretically. On the other hand, the GaN interlayer barrier grown by a two-step temperature control can effectively improve the quality of MQWs. The as-fabricated 395 nm near-UV LEDs chips with InGaN/GaN/AlGaN/GaN MQWs reveal an external quantum efficiency of 60% and a light output power of 659 mW at an injection current of 350 mA. This work provides a valuable solution to obtain high quantum efficiency and high power near-UV LEDs.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowmade

Absorption and emission modulation in a MoS2–GaN (0001) heterostructure by interface phonon–exciton coupling

Department of Physics, University of North Texas, Denton, Texas 76203, USA
Department of Chemistry, University of North Texas, Denton, Texas 76203, USA
Department of Physics, Northeastern University, Boston, Massachusetts 02115, USA

Photonics Research
https://doi.org/10.1364/PRJ.7.001511

Semiconductor heterostructures based on layered two-dimensional transition metal dichalcogenides (TMDs) interfaced to gallium nitride (GaN) are excellent material systems to realize broadband light absorbers and emitters due to their close proximity in the lattice constants. The surface properties of a polar semiconductor such as GaN are dominated by interface phonons, and thus the optical properties of the vertical heterostructure are influenced by the coupling of these carriers with phonons. The activation of different Raman modes in the heterostructure caused by the coupling between interfacial phonons and optically generated carriers in a monolayer MoS2–GaN (0001) heterostructure is observed. Different excitonic states in MoS2 are close to the interband energy state of intraband defect state of GaN. Density functional theory (DFT) calculations are performed to determine the band alignment of the interface and revealed a type-I heterostructure. The close proximity of the energy levels and the excitonic states in the semiconductors and the coupling of the electronic states with phonons result in the modification of carrier relaxation rates. Modulation of the excitonic absorption states in MoS2 is measured by transient optical pump-probe spectroscopy and the change in emission properties of both semiconductors is measured by steady-state photoluminescence (PL) emission spectroscopy. There is significant red-shift of the C excitonic band and faster dephasing of carriers in MoS2. However, optical excitation at energy higher than the bandgap of both semiconductors slows down the dephasing of carriers and energy exchange at the interface. Enhanced and blue-shifted PL emission is observed in MoS2. GaN band-edge emission is reduced in intensity at room temperature due to increased phonon-induced scattering of carriers in the GaN layer. Our results demonstrate the relevance of interface coupling between the semiconductors for the development of optical and electronic applications.

Structural characterization of porous GaN distributed Bragg reflectors using x-ray diffraction

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

Journal of Applied Physics
https://doi.org/10.1063/1.5134143

Porous GaN distributed Bragg reflectors (DBRs) provide strain-free, high-reflectivity structures with a wide range of applications across nitride optoelectronics. Structural characterization of porous DBRs is currently predominantly achieved by cross-sectional scanning electron microscopy (SEM), which is a destructive process that produces local data and has accuracy limited to around 3% by instrument calibration uncertainty. Here, we show that high-resolution x-ray diffraction (XRD) offers an alternative, nondestructive method for characterizing porous nitride structures. XRD scans of porous GaN DBRs show that despite the constant lattice parameter across the DBR layers, characteristic satellite peaks still arise, which are due to the interference between x-rays reflected from the porous and nonporous layers. By comparing the intensities and positions of the satellite peaks through diffraction patterns simulated from a kinematic model, the structural properties of the porous GaN DBRs can be analyzed. Using our method, we have measured a series of DBRs with stop bands from the blue wavelength region to the IR and compared their structural values with those from

SEM data. Our results show that the XRD method offers improvements in the accuracy of determining layer thickness, although uncertainty for the value of porosity remains high. To verify the results gained from the XRD and SEM analysis, we modeled the optical reflectivity using the structural values of both methods. We found that the XRD method offered a better fit to the optical data. XRD, therefore, offers accurate, nondestructive characterization of porous DBR structures based on macroscale measurements and is suitable for full wafer analysis.

Subliming GaN into Ordered Nanowire Arrays for Ultraviolet and Visible Nanophotonics

Nanophotonics Center, NTT Corp., 3-1, Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan
NTT Basic Research Laboratories, NTT Corp., 3-1, Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Université Côte d'Azur, CNRS, CRHEA, Rue B. Grégory, 06560 Valbonne, France
NTT Device Technology Laboratory, NTT Corp., 3-1, Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan

ACS Photonics
https://doi.org/10.1021/acsphotonics.9b01435

We report on the fabrication of ordered arrays of InGaN/GaN nanowire quantum disks by a top-down selective-area sublimation method. Using a combination of two-dimensional molecular beam epitaxy of InGaN/GaN quantum wells, electron beam lithography, and ultra-high-vacuum sublimation techniques, we demonstrate that the position, geometry, and dimensions of nanowires can be finely controlled at nano-, micro-, and macroscales. Relying on structural data, we evaluate in particular the relative sublimation rates of GaN crystal planes that drive the nanowire formation, we assess the intrinsic limits of selective area sublimation for the fabrication of NW arrays, and we evaluate the homogeneity of the process across the wafer. Because the sublimation method preserves the crystal quality of the NW material, we show that InGaN/GaN NWs present good optical properties, which can be leveraged for photonic applications in the ultraviolet and the visible range. In particular, we demonstrate that it is possible to realize on the same wafer not only arrays of nanowires that individually support room-temperature lasing based on Fabry–Pérot resonances, but also subwavelength nanowires that we integrate in photonic crystals for the realization of nanowire-induced nanocavities.

Design of AlGaN-based quantum structures for low threshold UVC lasers

Department of Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina 27695, USA
Adroit Materials, 2054 Kildaire Farm Rd, Suite 205, Cary, North Carolina 27518, USA

Journal of Applied Physics
https://doi.org/10.1063/1.5125256

The influence of the polarization field on the emission properties of the AlGaN-based quantum structures grown on AlN substrates was investigated as a function of well width, barrier width, and barrier height. A thin AlGaN well and a thin AlN barrier design reduced the polarization field to ∼0.5 MV/cm, resulting in an ultralow laser threshold of 3 kW/cm2 in an optically pumped configuration. These experimental results were used to validate the simulation. In the next step, a structure with Al0.7Ga0.3N barriers was designed to support carrier injection with a minimal loss in optical performance. This structure showed a threshold of 7 kW/cm2 under optical pumping and an estimated threshold current of 8 kA/cm2 for the electric injection.

Demonstration of critical coupling in an active III-nitride microdisk photonic circuit on silicon

Centre de Nanosciences et de Nanotechnologies, CNRS, University Paris-Sud, Université Paris-Saclay, F-91120, Palaiseau, France
University Grenoble Alpes, CEA, INAC-Pheliqs, 38000, Grenoble, France
Laboratoire Charles Coulomb (L2C), Université de Montpellier, CNRS, Montpellier, France
Université Côte d'Azur, CNRS, CRHEA, F-06560, Valbonne, France

Scientific Reports
https://doi.org/10.1038/s41598-019-54416-3

On-chip microlaser sources in the blue constitute an important building block for complex integrated photonic circuits on silicon. We have developed photonic circuits operating in the blue spectral range

based on microdisks and bus waveguides in III-nitride on silicon. We report on the interplay between microdisk-waveguide coupling and its optical properties. We observe critical coupling and phase matching, i.e. the most efficient energy transfer scheme, for very short gap sizes and thin waveguides (g = 45 nm and w = 170 nm) in the spontaneous emission regime. Whispering gallery mode lasing is demonstrated for a wide range of parameters with a strong dependence of the threshold on the loaded quality factor. We show the dependence and high sensitivity of the output signal on the coupling. Lastly, we observe the impact of processing on the tuning of mode resonances due to the very short coupling distances. Such small footprint on-chip integrated microlasers providing maximum energy transfer into a photonic circuit have important potential applications for visible-light communication and lab-on-chip bio-sensors.

Improving Output Power of InGaN Laser Diode Using Asymmetric In0.15Ga0.85N/In0.02Ga0.98N Multiple Quantum Wells

Microsystem & Terahertz Research Center, China Academy of Engineering Physics, Chengdu 610200, China
Institute of Electronic Engineering, China Academy of Engineering Physics, Mianyang 621999, China

Micromachines
https://doi.org/10.3390/mi10120875

Herein, the optical field distribution and electrical property improvements of the InGaN laser diode with an emission wavelength around 416 nm are theoretically investigated by adjusting the relative thickness of the first or last barrier layer in the three In0.15Ga0.85N/In0.02Ga0.98N quantum wells, which is achieved with the simulation program Crosslight. It was found that the thickness of the first or last InGaN barrier has strong effects on the threshold currents and output powers of the laser diodes. The optimal thickness of the first quantum barrier layer (FQB) and last quantum barrier layer (LQB) were found to be 225 nm and 300 nm, respectively. The thickness of LQB layer predominantly affects the output power compared to that of the FQB layer, and the highest output power achieved 3.87 times that of the reference structure (symmetric quantum well), which is attributed to reduced optical absorption loss as well as the reduced vertical electron leakage current leaking from the quantum wells to the p-type region. Our result proves that an appropriate LQB layer thickness is advantageous for achieving low threshold current and high output power lasers.

Effects of electron blocking layer configuration on the dynamics of laser diodes emitting at 450 nm

Academy of Scientific and Innovative Research (AcSIR), CSIR-Central Electronics Engineering Research Institute Campus, Pilani, Rajasthan 333 031, India
Optoelectronics and MOEMS Group, CSIR-Central Electronics Engineering Research Institute, Pilani, Rajasthan 333 031, India

Laser Physics
https://doi.org/10.1088/1555-6611/ab5587

In this paper, a theoretical study is presented, analysing the Al x Ga(1−x)N electron blocking layer (EBL) at different Al content and Mg-doping levels for the InGaN-based laser diode (LD) emitting at 450 nm. It is observed that the performance of LDs not only depends on the Al content in the EBL but also on the Mg doping levels in the EBL and the In content in the InGaN waveguide. The optimum selection of AlGaN EBL strongly depends upon the In content in the InGaN waveguide. It is found that, for an In0.08Ga0.92N waveguide, the higher Al content in the EBL degrades the performance due to the increase in leakage current, thus an Al-free EBL i.e. a GaN EBL, is optimal for an In0.08Ga0.92N waveguide. However, the increased Mg doping in the p-GaN (Al = 0) EBL shows improvement in the performance of LDs. For the p-GaN EBL with a Mg-doping level of 1 × 1019 cm−3, the output power is 138 mW, for 3 × 1019 cm−3 doping it is 364 mW and for 5 × 1019 cm−3 doping it increased to 556 mW. For the p-GaN EBL, the threshold current at 1 × 1019 cm−3 is 319 mA, at 3 × 1019 cm−3 doping it falls to 231 mA and for 5 × 1019 cm−3 doping it is 227 mA. For the heavily doped p-GaN EBL, the threshold current dependency is negligible at higher Al content in the EBL, but power output shows a strong dependency on the Al content. In the case of an In-free waveguide i.e. a GaN waveguide (In = 0), the performance of the LD is optimal at 15% Al content in the EBL.

Ion-induced Electrical Isolation in GaN-based Platform for Applications in Integrated Photonics

Center for Advanced Electronics and Photovoltaic Engineering (CAEPE), International Islamic University Islamabad, Pakistan

IEEE Access
https://doi.org/10.1109/ACCESS.2019.2960608

GaN based Photonic Integrated Circuits (PICs) have now become a global contender for their wide range of applications owing their physical characteristics. The GaN material system acts as a promising platform; compatible with silicon and sapphire substrates. Both the carrier transport and carrier removal techniques are vital to develop the efficient platform for the integration of photonic circuits. We demonstrate the carrier removal mechanism in silicon (Si) doped GaN (0001) epitaxially grown on c-plane sapphire wafer using ion engineering of the devices. Ion-engineered regions within the active layers of the device are modelled, fabricated and characterized to assess the isolation created. Helium and Carbon ions with pre-designed doses and energies are used to irradiate the device structures. We have modelled and fabricated ion-engineered regions within the active layers and studied the carrier transport properties on said regions to isolate that particular part with either of active photonic components placed at the common platform. After ion irradiation, detailed analysis in terms of electric field dependent current characteristics, sheet resistance, carrier mobilities, activation energies, dark and photo currents under zero (ground) and multiple biases are examined to see the extent of charge leakage and to map the charge behavior under nominal operation. Device characteristics under wide regime of annealing temperatures ranging from 300oC to 1000oC are mapped to evaluate the thermal stability of implant driven isolated regions. Activation energies of implanted and parent regions has also been studied. The dark and photon driven electric currents at ground and under biased have been measured to investigate the photo-induced transport phenomenon.

Suppression the formation of V-pits in InGaN/ GaN multi-quantum well growth and its effect on the performance of GaN based laser diodes

State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, 100083, China
School of Electronic, Electrical and Communication Engineering, University of Chinese Academy of Sciences, Beijing, 100049, China

Journal of Alloys and Compounds
https://doi.org/10.1016/j.jallcom.2019.153571

The mechanism for the formation of V-pits in InGaN/GaN multi-quantum well (MQW) growth and its effect on the performance of GaN based laser diodes (LDs) are investigated in detail. It is observed that the V-pits in InGaN/GaN MQWs begin at the GaN barrier layer rather than InGaN well layer due to the low atomic migration ability of Ga atoms at low growth temperature. In addition, it is found that the formation of V-pits can be suppressed remarkably when a small amount of In atoms is introduced during GaN barrier layer growth. This may be attributed to the decrease of the potential barrier for atom migration around the dislocation region. In this way, the thermal stability of InGaN/(In)GaN MQWs is enhanced. Therefore, the threshold current decreases abruptly when using InGaN/InGaN MQWs instead of InGaN/GaN MQWs.

Emission Properties of GaN Planar Hexagonal Microcavities

Department of Physics, Chemistry and Biology (IFM), Linköping University, S-581 83 Linköping, Sweden
St-Petersburg Academic University, Khlopina 8/3, 194021 St. Petersburg, Russian Federation
ITMO University, Kronverkskiy pr. 49, 197101 St. Petersburg, Russian Federation
Ioffe Institute, Politekhnicheskaya 26, 194021 St. Petersburg, Russian Federation

physica status solidi a
https://doi.org/10.1002/pssa.201900894

Fabrication of microcavities based on III-nitrides is challenging due to difficulties with the coherent growth of heterostructures having a large number of periods, at the same time keeping a good precision in terms of thickness and composition of the alloy. A

planar design for GaN microresonators supporting whispering gallery modes is suggested. GaN hexagonal microstructures are fabricated by selective-area metalorganic vapor phase epitaxy using focused ion beam for mask patterning. Low-temperature cathodoluminescence spectra measured with a high spatial resolution demonstrate two dominant emission lines in the near bandgap region. These lines merge at room temperature into a broad emission band peaking at ≈3.3 eV, which is shifted toward lower energies compared with the reference excitonic spectrum measured for the GaN layer. A numerical analysis of exciton–polariton modes shows that some strongly localized cavity modes can have high Purcell coefficients and can strongly interact with the GaN exciton.

Research Toward a Heterogeneously Integrated InGaN Laser on Silicon

Department of Electrical and Computer EngineeringUniversity of California, Santa Barbara, CA 93106-9560, USA
National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8568, Japan

physica status solidi a
https://doi.org/10.1002/pssa.201900770

A heterogeneously integrated InGaN laser diode (LD) on Si is proposed as a path toward visible wavelength photonic integrated circuits (PICs) on Si. Herein, InGaN films are vertically stacked on a TiO2 waveguide (WG) fabricated on a Si wafer by bonding. In the light propagation direction, it is composed of a hybrid InGaN/TiO2 section, a TiO2 WG, an adiabatic taper, and mirrors that can form a cavity. As the refractive index of GaN is well matched with that of TiO2, the optical transverse mode extends to both the GaN and TiO2 in a hybrid mode. Modes between a hybrid InGaN/TiO2 and a pure TiO2 WG can transfer with an adiabatic taper structure. The coupling loss is calculated to be less than 0.5 dB with fairly short taper length of 78 µm and tip width of 200 nm. GaN substrate removal and bonding are critical fabrication steps of this LD and PIC. The substrate removal is successfully done by photoelectrochemical etching. Although direct bonding of GaN wafers with thermal oxide on Si is successful, GaN epitaxial wafers are more difficult. An implication and remedy of this is discussed in terms of surface roughness of GaN epitaxial film.

Electron-Beam-Driven III-Nitride Plasmonic Nanolasers in the Deep-UV and Visible Region

Jiangsu Provincial Key Laboratory of Advanced Photonic and Electronic MaterialsSchool of Electronic Science and Engineering, Nanjing University, Nanjing 210093, P. R. China
Nanjing National Laboratory of Microstructures, Nanjing University, Nanjing 210093, P. R. China
College of Electronic and Optical Engineering & College of Microelectronics, Nanjing University of Posts and Telecommunications, Nanjing 210023, P. R. China

small
https://doi.org/10.1002/smll.201906205

Plasmonic nanolasers based on wide bandgap semiconductors are presently attracting immense research interests due to the breaking in light diffraction limit and subwavelength mode operation with fast dynamics. However, these plasmonic nanolasers have so far been mostly realized in the visible light ranges, or most are still under optical excitation pumping. In this work, III-nitride-based plasmonic nanolasers emitting from the green to the deep-ultraviolet (UV) region by energetic electron beam injection are reported, and a threshold as low as 8 kW cm−2 is achieved. A fast decay time as short as 123 ps is collected, indicating a strong coupling between excitons and surface plasmon. Both the spatial and temporal coherences are observed, which provide a solid evidence for exciton-plasmon coupled polariton lasing. Consequently, the achievements in III-nitride-based plasmonic nanolaser devices represent a significant step toward practical applications for biological technology, computing systems, and on-chip optical communication.

GROUP 3 - Power Electronics

Group leader: Frédéric Morancho (LAAS-CNRS)

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

Influence of Metal-Insulator-Semiconductor gate Structure on Normally-off P-GaN Heterojunction Field-Effect Transistors

Institute of Technology and Science, Tokushima University, Tokushima 770-8506, Japan
School of Electronics and Information Technology, Sun Yat-Sen University, Guangzhou 510275, China
Wide Bandgap Semiconductor Technology Disciplines State Key Laboratory, Xidian University, China

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.125395

Normally-off MIS p-GaN HFETs were demonstrated with the self-aligned-gate first (SAG) and the conventional gate (CG) processes. The good ohmic contact with a contact resistance of 1.45 Ω·mm was obtained by the low-temperature ohmic technique. By employing the SiO2 as the insulator layer, the Vth was enhanced to 2 V and 2.5 V for the SAG and CG devices, respectively. On the other hand, the CG device presented a higher channel resistance than the SAG one. Those phenomena were interpreted by the different gate structures of two kinds of devices. It demonstrated that the SAG structure was more advanced to achieve good performance in normally-off MIS HFETs with p-GaN cap layer.

Fast-switching Tri-Anode Schottky Barrier Diodes for monolithically integrated GaN-on-Si power circuits

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

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2957700

Tri-Anode GaN Schottky Barrier Diodes (SBDs) have recently shown excellent DC performance with low turn-on voltage and large breakdown thanks to their 3D contact structure around the two-dimensional electron gas (2DEG) channel. However, the 3D nature of the Tri-Anode structure is also often believed to hinder the device switching performance. In this work, we demonstrate that, on the contrary, the Tri-Anode architecture significantly enhances the device switching performance with respect to conventional planar SBDs, as shown by a substantial decrease in the recovery charge and an improvement in frequency response. The Tri-Anode SBDs excellent static and dynamic performance is then applied to a real circuit to demonstrate a monolithically integrated high-frequency Full Bridge Rectifier. These results show the potential of Tri-Anode SBDs for high-efficiency and fast-switching power integrated circuits.

High-k HfO2 based AlGaN/GaN MIS-HEMTs with Y2O3 interfacial layer for high gate controllability and interface quality

School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, China

IEEE Journal of the Electron Devices Society
https://doi.org/10.1109/JEDS.2019.2956844

High-k HfO2 has been widely adopted in Si based MOSFETs as gate dielectric for the superior control over gate leakage and channel electrostatics. However, in AlGaN/GaN HEMTs, the additional interface issue as well as high oxygen transparency of HfO2 has hindered its practical applications. In this work, high-k Y2O3 with ultra-low oxygen permeability and high thermodynamic robustness has been introduced as the interfacial layer between HfO2/GaN for the interface engineering. It has been demonstrated that, the HfO2/Y2O3 gate dielectric stacks have obtained the GaN MIS-HEMT an ultra-small subthreshold swing of 70 mV/decade, an extremely low gate leakage of 10-12 A/mm, and a desirable dielectric/semiconductor interface quality with interface state density in level of 1012 cm-2eV-1. Meanwhile, a maximum drain current of 600mA/mm has been achieved together with an on-state resistance (Ron) of 10.7 Ω ·mm and a specific Ron of 2.62 mΩ ·cm2.

Improving Performances of Enhancement-Mode AlGaN/GaN MIS-HEMTs on 6-inch Si Substrate Utilizing SiON/Al2O3 Stack Dielectrics

School of Optoelectronic Engineering and Instrumentation Science & School of Microelectronics, Dalian University of Technology, Dalian 116024, China
Dalian Xinguan Technology Corporation, Dalian 116023, China

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2957376

Enhancement-mode (E-mode) GaN-based MIS-HEMTs still suffer from undeniable gate leakage or low gate breakdown voltage due to the low quality of gate dielectrics, resulting in a notorious tailing effect of the off-state current. In this letter, a gate scheme featuring SiON/Al2O3 stack dielectrics and partially recessed gate barrier has been employed in the AlGaN/GaN MIS-HEMTs. A high on/off current ratio over 109 and a small threshold voltage (Vth) hysteresis less than 20 mV are achieved in the fabricated E-mode devices with a Vth around 2.5 V, mainly owing to the reduction of the net positive fixed charge density in the SiON/Al2O3 gate stack confirmed by the C-V measurements. Meanwhile, a good performance uniformity on 6-inch wafer is achieved which demonstrates the promising scheme for fabricating GaN-based E-mode MIS-HEMT products.

Effect of C-doped GaN film thickness on the structural and electrical properties of AlGaN/GaN-based high electron mobility transistors

Key Laboratory of Semiconductor Materials Science, and Beijing Key Laboratory of Low Dimensional Semiconductor, Materials and Devices, Institute of Semiconductors, Chinese Academy of Sciences, PO Box 912, Beijing 100083, People's Republic of China
Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 101408, People's Republic of China

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab4b01

High-resistivity carbon doped GaN (C-GaN) is highly desirable for high electron mobility transistors (HEMTs) application to reduce the leakage current at high electric fields. Herein, we investigate the structural and electrical properties of AlGaN/GaN-based HEMTs with different thicknesses of the underlying C-GaN layer. Reciprocal space mapping analysis indicates more lattice defects within GaN layer of the AlGaN/GaN heterostructure with thicker underlying C-GaN layer. Finite element method simulations reveal that the stress distribution over the AlGaN/GaN heterostructure thickness can be tuned by increasing the underlying C-GaN layer thickness from 2 to 7 µm. Consequently, a significant decrease of two-dimensional electrons gas mobility from 1188 to 653 cm2 V−1 s−1 measured by Hall effect method is observed at a higher underlying C-GaN layer thickness (7 µm). The change of electrical properties for HEMT structures with different underlying C-GaN thicknesses is not only affected by structural quality of the epilayers but also by thermal stress over HEMT structure thickness. Our results pave the avenue for improving the electrical properties of HEMT with a suitable thickness of underlying C-GaN layer.

Investigations of the gate instability characteristics in Schottky/ohmic type p-GaN gate normally-off AlGaN/GaN HEMTs

School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, People's Republic of China
CorEnergy Semiconductor Co. Ltd., Suzhou 215600, People's Republic of China
School of Electronics and Information, Nantong University, Nantong 226019, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab52cc

In this work, the impacts of Schottky- and ohmic-type gate contacts on devices stability of p-GaN gate AlGaN/GaN high electron mobility transistors were experimentally investigated. In the Schottky-gate devices, drastic gate instability was observed under positive gate bias and elevated temperatures, featuring evident negative threshold voltage shift especially at low gate voltage region. By contrast, ohmic-gate devices exhibit superior gate stability with near-zero threshold voltage shift. Correspondingly, a physics picture of hole injection/emission processes in the p-GaN layer was established for the understanding of the distinct gate stability behaviors with different gate contact types.

A Novel GaN Metal-Insulator-Semiconductor High Electron Mobility Transistor Featuring Vertical Gate Structure

School of Optoelectronic Engineering and Instrumentation Science & School of Microelectronics, Dalian University of Technology, Dalian 116024, China
Department of Electrical and Electronic Engineering, Xi'an Jiaotong-Liverpool University, Suzhou 215123, China
Department of Electrical and Computer Engineering, National University of Singapore, Singapore 119260, Singapore

Micromachines
https://doi.org/10.3390/mi10120848

A novel structure scheme by transposing the gate channel orientation from a long horizontal one to a short vertical one is proposed and verified by technology computer-aided design (TCAD) simulations to achieve GaN-based normally-off high electron mobility transistors (HEMTs) with reduced on-resistance and improved threshold voltage. The proposed devices exhibit high threshold voltage of 3.1 V, high peak transconductance of 213 mS, and much lower on-resistance of 0.53 mΩ·cm2 while displaying better off-state characteristics owing to more uniform electric field distribution around the recessed gate edge in comparison to the conventional lateral HEMTs. The proposed scheme provides a new technical approach to realize high-performance normally-off HEMTs.

Hole-Induced Degradation in E-Mode GaN MIS-FETs: Impact of Substrate Terminations

Department of Electrical and Electronic Engineering, The Southern University of Science and Technology, Shenzhen 518055, China

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2954282

We conducted reliability characterization under reverse-bias stress (i.e., stress at OFF-state with high VDS) on the E-mode GaN metal-insulator-semiconductor field-effect-transistors (MIS-FETs) with various substrate terminations. The MIS-FETs with floating substrate (FS) show worse threshold voltage (VTH) stability than that with a grounded substrate. A non monotonic dependence of VTH shifts and OFF-state time-to-breakdown (tBD) on the positive substrate bias (Vsub) was also observed. The underlying mechanisms are the different impacts of positive Vsub on the drift of electrons and holes during the long-term stress. An important indication is that positive-biased and FS terminations should be restricted at OFF-state in order to obtain good VTH stability in applications of the GaN MIS-FET.

Device Design Assessment of GaN Merged P-i-N Schottky Diodes

School of Information Science and Technology, ShanghaiTech University, Shanghai 201210, China
Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai 200050, China
University of Chinese Academy of Sciences, Beijing 100049, China
State Key Laboratory of Optoelectronic Materials and Technologies, School of Electronics and Information Technology, Sun Yat-sen University, Guangzhou 510275, China

Electronics
https://doi.org/10.3390/electronics8121550

Device characteristics of GaN merged P-i-N Schottky (MPS) diodes were evaluated and studied via two-dimensional technology computer-aided design (TCAD) after calibrating model parameters and critical electrical fields with experimental proven results. The device's physical dimensions and drift layer concentration were varied to study their influence on the device's performance. Extending the inter-p-GaN region distance or the Schottky contact portion could enhance the forward conduction capability; however, this leads to compromised electrical field screening effects from neighboring PN junctions, as well as reduced breakdown voltage. By reducing the drift layer background concentration, a higher breakdown voltage was expected for MPSs, as a larger portion of the drift layer itself could be depleted for sustaining vertical reverse voltage. However, lowering the drift layer concentration would also result in a reduction in forward conduction capability. The method and results of this study provide a guideline for designing MPS diodes with target blocking voltage and forward conduction at a low bias.

Superjunction Power Transistors with Interface Charges: A Case Study for GaN

Center for Power Electronics Systems, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 USA
Ming Hsieh Department of Electrical Engineering, University of Southern California, Los Angeles, CA 90089 USA

IEEE Journal of the Electron Devices Society
https://doi.org/10.1109/JEDS.2019.2959713

Recent progress in p-GaN trench-filling epitaxy has shown promise for the demonstration of GaN superjunction (SJ) devices. However, the presence of n-type interface charges at the regrowth interfaces has been widely observed. These interface charges pose great challenges to the design and performance evaluation of SJ devices. This work presents an analytical model for SJ devices with interface charges for the first time. In our model, two approaches are proposed to compensate interface charges, by the modulation of the SJ doping or the SJ geometry. Based on our model, an analytical study is conducted for GaN SJ transistors, revealing the design windows and optimal values of doping concentration and pillar width as a function of interface charge density. Finally, TCAD simulation is performed for vertical GaN SJ transistors, which validated our analytical model. Our results show that, with optimal designs, interface charges would only induce small degradation in the performance of GaN SJ devices. However, with the increased interface charge density, the design windows for pillar width and doping concentration become increasingly narrow and the upper limit in the pillar width window reduces quickly. When the interface charge density exceeds 3×1012 cm-2, the design window of pillar width completely falls into the sub-micron range, indicating significant difficulties in fabrication. Vertical GaN SJ transistors with interface charges retain great advantages over conventional GaN power transistors, but have narrower design windows and require different design rules compared to ideal GaN SJ devices.

Design and Fabrication of Ion-Implanted Moat Etch Termination Resulting in 0.7 mΩ·cm2/1500 V GaN Diodes

Department of Electrical Engineering, Stanford University, CA, 95616 USA

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2960349

The design space of ion-implanted moat etch termination in GaN p-n diodes is discussed in this study. Based on experimental data, the design window for ion-implanted moat etch termination has been carefully studied and optimized for vertical GaN p-n diodes grown on bulk GaN substrates. A high-performance diode with a breakdown voltage of 1500 V and a low specific on-state resistance of 0.7 mΩ·cm2 is demonstrated using the optimized edge termination based on moat etch and Mg ion implantation. The p-n diode shows a device figure-of-merit of 3.2 GW/cm2. By using the proposed ion-implanted moat etch termination, GaN diodes with three different drift region designs approach the avalanche breakdown electric field, which indicates the efficacy of the proposed edge termination design and method.

Design of GaN/AlGaN/GaN Super-Heterojunction Schottky Diode

School of Electrical Engineering and Computer Science, The Pennsylvania State University, University Park, PA 16802 USA

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2953843

We present a systematic study on the design of a novel GaN/AlGaN/GaN super-heterojunction Schottky diode. Through physics-based TCAD simulation, we discuss three important design aspects: 1) how to design a GaN/AlGaN/GaN structure to form a high-density 2-D electron gas and to scale it to multiple vertically stacked channels with less risk in reaching the critical thickness limited by the strain in epitaxy; 2) how to reach charge balance and how sensitive is the breakdown voltage with respect to the doping imbalance; and 3) how to ensure that the processes of depleting and accumulating electrons and holes in the structure are

fast enough for practical power switching applications.

On the threshold voltage of normally-OFF AlGaN/GaN heterostructure field effect transistors (HFETs) with p-(Al)GaN gate

Department of Electronics and Electrical Communication Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal, 721302—India

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab5607

A physics-based analytical model has been developed to correctly estimate the threshold voltage of normally-OFF AlGaN/GaN heterostructure field effect transistors (HFETs) with p-(Al)GaN gate. This analysis considers the effect of all polarization charges at different interfaces/surface, the layer structure, doping concentration of deep acceptors in p-(Al)GaN cap layer, incomplete ionization of deep Mg acceptors, out-diffusion of Mg to AlGaN barrier layer as well as the effect of compensated buffer/back barrier. Threshold voltage extracted from this analytical model is rigorously validated with experimental results. This analysis also provides a physical insight of charge distribution, gate voltage division in the heterostructure and the effect of device parameters on the threshold voltage. Besides, this model can also be extended to estimate the threshold voltage of normally-OFF MIS-HFETs with p-GaN gate.

Degradation Behavior and Mechanisms of E-Mode GaN HEMTs With p-GaN Gate Under Reverse Electrostatic Discharge Stress

Science and Technology on Reliability Physics and Application of Electronic Component Laboratory, The No.5 Electronics Research Institute of the Ministry of Industry and Information Technology, Guangzhou 510610, China
South China University of Technology, Guangzhou 510610, China

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2959299

The degradation behavior and its mechanisms of E-mode GaN high electron mobility transistors (HEMTs) with p-GaN gate under electrostatic discharge (ESD) stress were investigated. Reverse short-pulse stress was generated by a transmission line pulse (TLP) tester in order to simulate the static electricity. The experiment results show that the reverse short-pulse stress leads to the characteristic degradation of the E-mode GaN HEMTs with p-GaN gate. The values of the threshold voltage and on-resistance increase, and the gate capacitance curve shifts positively. The low-frequency noises (LFNs) were obtained for the E-mode GaN HEMTs with p-GaN gate before and after the reverse short-pulse stress. The concentration of traps was extracted, and it has doubled after 700 cycles. The degradation mechanism could be attributed to the generation of traps at p-GaN/AlGaN heterointerface, AlGaN barrier, and GaN/AlGaN interface. Such an investigation can be a significant reference in the design and application of E-mode GaN power devices.

A review of selective area grown recess structure for insulated-gate E-mode GaN transistors

State Key Laboratory of Optoelectronic Materials and Technologies, Sun Yat-Sen University, 510275, Guangzhou, People's Republic of China
School of Electronics and Information Technology, Sun Yat-Sen University, 510006, Guangzhou, People's Republic of China
School of Materials Science and Engineering, Sun Yat-Sen University, 510275, Guangzhou, People's Republic of China

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab4e5e

Recess structure is one of the main schemes for insulated-gate E-mode GaN transistors. In this work, selective area growth (SAG) is proposed to fabricate damage-free recess-gate device, and related progresses regarding process optimization and structure evolution have been reviewed. Firstly, the SAG process has been optimized by interface separation (conduction interface and regrowth interface) and n-type Si impurity removal to achieve high-quality AlGaN/GaN heterostructure. Compared to the traditional etching method, the feasibility and superiority of SAG scheme are demonstrated for realizing E-mode Al2O3/GaN MISFET with small V th hysteresis. Then, by inserting an in situ AlN interlayer, the SAG Al2O3/AlN/GaN MISFET yields improved frequency dispersion and gate channel conduction performances. To further enhance the channel

conduction, the SAG partially recess-gate Al2O3/AlGaN/GaN MIS-HFET structure is proposed, by which both high V th and high-field-effect channel mobility have been achieved. Those results indicate that SAG method gives a perspective way for insulated-recess-gate GaN transistors fabrication.

Modeling dislocation-related leakage currents in GaN p-n diodes

Materials Department, University of California, Santa Barbara, California 93106, USA
Department of Electrical Engineering, National Taiwan University, Taipei City 10617, Taiwan

Journal of Applied Physics
https://doi.org/10.1063/1.5123394

Finite element analysis software was used to model and visualize two p-n junction models: one with a single threading dislocation (TD) and a control model without a dislocation. TDs are modeled as a Gaussian distribution of trap states with an FWHM of 5 nm localized around the r=0 line in a cylindrical coordination such that the linear trap state density was 1 trap/c-translation; this model allows the cylindrical symmetry of the c-plane GaN crystal orientation to be utilized to avoid more computationally intensive 3D models. It was discovered that the interaction of the charged dislocation region with the p-n junction had many notable effects. At zero bias, it was observed that the depletion region width (using the Depletion Approximation) and the maximum electric field were markedly reduced near the dislocation line. More significantly, an asymmetric reduction in the diffusion barrier for electrons (Veffbi=3.03eV) and holes (Veffbi=0.81eV) was observed due to the asymmetric nature of the dislocation band bending related to the doping. The asymmetric reductions in diffusion barriers persisted into VA=2.4V leakage case where asymmetric current profiles for electrons and holes were also observed. Lastly, the diffusion barrier reduction resulted in an additional Shockley-Read-Hall nonradiative recombination leakage caused by a high np-product and trap state density near the intersection of the dislocation with the junction.

Physical mechanism on the suppression of dynamic resistance degradation by multi-mesa-channel in AlGaN/GaN high electron mobility transistors

Department of Electrical and Computer Engineering, National University of Singapore, Singapore 119260, Singapore
Department of Electrical Engineering, National Tsing Hua University, Hsinchu 30013, Taiwan

Applied Physics Letters
https://doi.org/10.1063/1.5132991

In this letter, the suppression of dynamic on-state resistance (RON) degradation for faster dynamic RON recovery is achieved by the multimesa-channel (MMC) structure in AlGaN/GaN high electron mobility transistors. The measurement results are discussed with the physical mechanisms investigated. The initial transient RON degradation is reduced in the MMC structure, resulting from the lower peak electric field around the drain-side gate edge in the trigate structure compared to that in a planar device. The faster dynamic RON recovery in MMC devices is attributed to the quick emission of electrons at sidewall traps of shallower energy levels. The energy levels of dominant traps at the sidewall and top interfaces are found to be 0.26 eV and 0.37 eV below the conduction band edge, respectively, verified by Technology Computer Aided Design simulations in agreement with the measurement data.

Deep Submicron Normally Off AlGaN/GaN MOSFET on Silicon with VTH > 5V and On-Current > 0.5 A mm−1

Centre for Nano Science and Engineering(CeNSE), Indian Institute of Science (IISc), Bengaluru, India
Institute of Materials Research and Engineering (IMRE), Agency for Science, Technology, and Research (A*STAR), Singapore

physica status solidi a
https://doi.org/10.1002/pssa.201900709

A submicron gate normally off AlGaN/GaN high-electron-mobility transistor (HEMT) with a high on-current and high threshold voltage (VTH) is demonstrated. The high-performance device is realized utilizing a gate recess with a length and depth of 200 and 124 nm, respectively. The recess-etched region has a roughness of 0.7 nm.

Various recess-etch depths and dielectric annealing conditions are used to tune VTH. The optimized device exhibits an on-current and VTH of 500 mA mm−1 and 5 V, respectively. The measured breakdown characteristics of the devices and their limitations are investigated using 2D-technology computer-aided design (TCAD) device simulation. The penetration of the residual electric field in most of the recess region can be the reason for the premature breakdown of deeply scaled recess-gate e-mode HEMTs.

The Role of Carbon Doping on Breakdown, Current Collapse, and Dynamic On-Resistance Recovery in AlGaN/GaN High Electron Mobility Transistors on Semi-Insulating SiC Substrates

Department of Engineering“Enzo Ferrari”, University of Modena and Reggio Emiliavia P. Vivarelli 10, 41125 Modena, Italy
Department of Sciences and Methods for Engineering (DISMI) andEN&TECH Center, University of Modena and Reggio Emilia, ia G. Amendola, 2, 42122 Reggio Emilia, Italy

physica status solidi a
https://doi.org/10.1002/pssa.201900762

Herein, the critical role of carbon doping in the electrical behavior of AlGaN/GaN high electron mobility transistors (HEMTs) on semi-insulating SiC substrates is assessed by investigating the off-state three-terminal breakdown, current collapse, and dynamic on-resistance recovery at high drain–source voltages. Extensive device simulations of typical GaN HEMT structures are conducted and compared with experimental data from published, state-of-the-art technologies to 1) explain the slope of the breakdown voltage as a function of the gate-to-drain spacing lower than GaN critical electric field as a result of the nonuniform electrical field distribution in the gate–drain access region; 2) attribute the drain current collapse to trapping in deep acceptor states in the buffer associated with carbon doping; and 3) interpret the partial dynamic on-resistance recovery after off-state stress at high drain–source voltages as a consequence of hole generation and trapping.

Normally-Off Operation of Lateral Field-Effect Transistors Fabricated from Ultrapure GaN/AlGaN Heterostructures

TU Dresden, Electrical and Computer Engineering, Institute of Semiconductors and Microsystems, Nöthnitzer Str. 64, 01187 Dresden, Germany
Max-Planck-Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany
Institute of Solid State Physics RAS, 142432 Chernogolovka, Moscowdistrict, Russia
Namlab gGmbH, Nöthnitzer Str. 64, 01187 Dresden, Germany
National Research University Higher School of Economics, 101000 Moscow, Russia

physica status solidi a
https://doi.org/10.1002/pssa.201900732

The presence of a 2D electron gas (2DEG) in GaN/AlxGa1–xN heterostructures with low aluminum mole fraction is found to depend on the residual background impurity concentration in the GaN/AlGaN layer stack. At a residual donor level of 2×1016 cm−3, a 2DEG is absent at 300 K in dark environment. Such a 2DEG can be generated at the GaN/AlGaN interface either by illumination with ultraviolet light or by applying an electrostatic potential. The latter results in inherently normally-off switching characteristics of lateral field-effect transistors.

Lateral and vertical power transistors in GaN and Ga2O3

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany
Chair of Power Electronics, Technische Universität, Berlin, Einsteinufer 19, 10587 Berlin, Germany

IET Power Electronics
https://doi.org/10.1049/iet-pel.2019.0059

Vertical silicon carbide transistors and lateral gallium nitride (GaN) transistors for power-electronic applications currently target applications with different voltage and power ratings. Meanwhile, research and development activities continue on vertical GaN transistors and new gallium oxide (Ga2O3) transistors. What are their perspectives in the application and how do they compete against

each other and against established transistor technologies? This study discusses the specific characteristics of lateral and vertical GaN and Ga2O3 transistors to assess their strengths and weaknesses.

GROUP 4 - Advanced Electronics and RF

Group leader: Jean-Claude Dejaeger (IEMN)

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

Performance evaluation of linearity and intermodulation distortion of nanoscale GaN-SOI FinFET for RFIC design

ECE Department, Jaypee Institute of Information Technology, Noida, India
Department of Applied Science and Humanities, ADGITM, New Delhi, India
Electrical Engineering Department, Delhi Technological University, India
Applied Physics Department, Delhi Technological University, Delhi, India

AEU - International Journal of Electronics and Communications
https://doi.org/10.1016/j.aeue.2019.153052

This work presents, performance evaluation of linearity and intermodulation distortion of novel nanoscale Gallium Nitride (GaN) Silicon-on-Insulator (SOI) N-channel FinFET (n-FinFET) for RFIC design and results so obtained are simultaneously compared with conventional (Si-based) FinFET and bulk GaN-based FinFET with 8 nm gate length. It is found that the proposed device enhances on-current (ION) by four times and thereby transconductance, subthreshold slope, threshold voltage, surface potential, and energy band (conduction band energy and valence band energy) profiles have been improved at ultra-low voltage power supply (VDS = 0.1 V). Thus, the improved electrical performance of GaN-SOI FinFET makes it suitable for low power and high-performance CMOS circuits. Also a further investigative study has been performed on the linearity behavior of GaN-SOI FinFET and the outcomes of the study have been compared with the results of the GaN Bulk FinFET and the conventional Silicon FinFET. The SOI device shows better linear performance in the likes of higher-order voltage and current intercept points as VIP2, VIP3, IIP3, and 1-dB compression point with lesser harmonic distortions as HD2, HD3 and, IMD3. Thus, the results with higher efficiency, better linearity, and distortionless performance pave the way for RFIC design.

HAD fabricated on UTB AlGaN/GaN heterostructure for high-sensitivity zero-bias microwave detection

Xi'an International University, School of Engineering, Xi'an, People's Republic of China
University of Electronic Science and Technology of China, School of Electronic Science and Engineering, Chengdu 610054, People's Republic of China

Electronics Letters
https://doi.org/10.1049/el.2019.2548

A novel technology based on aluminium gallium nitride (AlGaN)/GaN hybrid-anode diode (HAD) for precise modulation of turn-on voltage is proposed and experimentally demonstrated. By delicately tailoring the as-grown barrier thickness, the turn-on voltage of the HAD and yet the non-linearity at zero bias (i.e. 0 V) for efficient microwave detection can be flexibly modulated. An AlGaN/GaN ultra-thin-barrier HAD (UTB-HAD) was designed and fabricated for zero-bias microwave detection. The AlGaN-barrier thickness was optimised to be 5 nm by TCAD simulation, which yields a strong non-linearity at zero bias featuring a high-curvature coefficient (γ) of 27 V -1 in the fabricated UTB-HAD. The first-order voltage sensitivity β V is projected to be as high as 2.7 mV/μW. The proposed approach of precise sensitivity modulation is of great interests for high-efficient zero-bias microwave detection applications.

The Effects of Gate-Connected Field Plates on Hotspot Temperatures of AlGaN/GaN HEMTs

Mechanical Engineering Department, Boğaziçi University, 34342 İstanbul, Turkey

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2953123

To increase the reliability and the maximum performance of AlGaN/GaN high electron mobility transistors (HEMTs), gate field plates are frequently used with surface passivation. Although significant research has been done to understand the electrical effects of gate field plates on devices, their thermal effects are still not fully understood. For this purpose,

electrothermal simulations are performed on devices with and without gate field plates having different thicknesses of Si_3N_4 surface passivation at two different biasing conditions. These simulations prove that more than 8% reduction of maximum temperature can be achieved with the use of gate field plates on devices operated at P=4 W/mm. Field plates, when used in multifinger device configurations, have a greater impact on the outermost fingers' temperatures and can be used to achieve temperature uniformity. Surface passivation studies suggest that while thick passivation layers (~200 nm in case of Si_3N_4) eliminate the thermal advantages of the field plate technology, very thin passivation layers (~45 nm) cause an increase in the electric field and a decrease in the breakdown voltage. Thus, significant thermal advantages can be achieved when gate field plates are introduced following a field plate length and passivation thickness optimization based on the device biasing conditions.

Mechanical tensile strain for AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors on a silicon-on-insulator substrate

Department of Electronic Engineering, Chang Gung University, Tao-Yuan, 33302, Taiwan
Centre for Reliability Sciences and Technologies, Chang Gung University, Tao-Yuan, 33302, Taiwan
Department of Dermatology, Chang Gung Memorial Hospital, Linkou Branches, Tao-Yuan, 33305, Taiwan
Department of Materials & Mineral Resources Engineering, National Taipei University of Technology, Taipei, 10608, Taiwan

Journal of Alloys and Compounds
https://doi.org/10.1016/j.jallcom.2019.153178

The impacts of various tensile strains on both DC and RF performance of AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) on a silicon-on-insulator (SOI) substrate were investigated using pulsed-IV and pulsed-S-parameter tests. The sensitivity of MIS-HEMTs to various tensile strains was observed via pulse measurements because of the improved self-heating effect. The DC and RF performance of MIS-HEMTs on a SOI substrate were found to be enhanced with the pulse width decreasing under small tensile strain. A significant hot phonon effect was observed for MIS-HEMTs under larger tensile strain, particularly for shorter pulse widths. Additionally, an obvious reduction of fmax was observed under larger tensile strain because the channel resistance increased via the hot phonon effect, despite the increase in ft. The results indicated that tensile strain in the ultra-thin thinned substrate of AlGaN/GaN HEMTs should be carefully monitored in compact packages for high-power and high-frequency applications.

Effect of oxygen plasma modification on Pd/Al/Au Ohmic contacts on undoped AlN

Department of Physics, College of Science, Beijing University of Chemical Technology, 15 East Road, Beisanhuan, Beijing 100029, People's Republic of China
Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Science, Beijing 100083, People's Republic of China

Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/ab407a

The influence of surface modification of undoped AlN by oxygen plasma on the Pd/Al/Au Ohmic contacts was studied. Pd/Al/Au alloys were deposited on undoped AlN films by electron beam evaporation and annealed from 750 °C to 900 °C for 30 s to form metal–semiconductor contacts. All the samples without oxygen plasma treatment were Schottky contacts. After oxygen plasma treatment, the contacts below annealing temperature of 850 °C were Schottky type. However, the contacts changed to be Ohmic type with specific contact resistivity of 3.01 Ω centerdot cm2 when the annealing temperature was 900 °C. The samples were characterized by scanning electron microscopy and x-ray diffraction, which indicated that the formation of AlPd alloy was believed to play a key role for the formation of low Ohmic contacts. The first-principle calculation indicated that the surface modification by oxygen plasma could increase the work function of AlN and therefore benefit the formation of Ohmic contacts. This result can promote the application prospects of AlN in deep ultraviolet optoelectronic devices and high frequency and high power RF devices.

2 W mm−1 power density of an AlGaN/GaN HEMT grown on free-standing GaN substrate at 40 GHz

Microwave Power Devices Group Institut d'Electronique, de Microélectronique et de Nanotechnologie, University of Lille, Villeneuve d'Ascq, F-59652, France
Laboratoire d'Analyse et d'Architecture des Systèmes, Centre National de la Recherche Scientifique, Toulouse, F-31400, France
Université Côte d'Azur, CNRS, Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Valbonne, F-06560, France

Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab4e74

In this letter, a record performance at 40 GHz obtained on an AlGaN/GaN high electron mobility transistor (HEMT) grown on hydride vapor phase epitaxy free-standing GaN substrate is reported. An output power density of 2 W mm−1 associated with 20.5% power added efficiency and a linear power gain (G p) of 4.2 dB is demonstrated for 70 nm gate length device. The device exhibits a maximum DC drain current density of 950 mA mm−1 and a peak extrinsic transconductance (g m Max) of 300 mS mm−1 at V DS = 6 V. A 100 GHz maximum intrinsic cutoff frequency f T, and a maximum intrinsic oscillation frequency f Max of 125 GHz are obtained from S-parameters measurement. This performance is very promising for HEMTs grown on free-standing GaN substrate.

Deeply-scaled GaN-on-Si high electron mobility transistors with record cut-off frequency f T of 310 GHz

Low Energy Electronic Systems, Singapore-MIT Alliance for Research and Technology Centre, 139802, Singapore
School of Electrical and Electronic Engineering, Nanyang Technological University, 639798, Singapore
School of Microelectronics, Xidian University, Xi'an, 710071, People's Republic of China
Temasek Laboratories@NTU, Nanyang Technological University, 637553, Singapore

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab56e2

A deeply-scaled GaN-on-Si high electron mobility transistor with a record-high cut-off frequency (f T) of 310 GHz has been demonstrated. The device has an InAlN/GaN heterojunction structure, a source–drain spacing of 400 nm, and a gate length of 40 nm. The device exhibited a high drain current of 2.34 A mm−1, a peak transconductance of 523 mS mm−1, and a gate-to-drain breakdown voltage (BV gd) of 15 V. A Johnson's figure-of-merit (FOM = f T × BV) of 4.65 THz V has been achieved, which is comparable to those reported in GaN-on-SiC. These results indicate GaN-on-Si transistors are promising in low-cost emerging mm-wave applications.

Physics-based simulation for studying the impact of contact resistance on DC and RF characteristics of AlGaN/AlN/GaN HEMT

Microelectronics Group, Space Applications Centre, ISRO, Ahmedabad, India

Radio Science
https://doi.org/10.1029/2019RS006855

Formation of a two-dimensional electron gas in AlGaN/AlN/GaN heterostructures plays a vital role in high power and high frequency device technology. Such kinds of heterostructures are used for the fabrication of high electron mobility transistors (HEMTs). Ohmic contacts to AlGaN/AlN/GaN-based heterostructures with low contact resistance and smooth surface are crucial in the development of high power, high frequency transistors in the GaN system. In the present study, physics-based simulation of impact of ohmic contact resistance on DC and RF characteristics of AlGaN/AlN/GaN HEMT on 6H-SiC substrate has been addressed for the first time. Samples A, B, and C of contact resistance 0.25, 0.27, and 0.59 Ω ∗ mm, respectively, were fabricated with different process variations. By using measured contact resistance values, physics-based simulation of 100-nm gate length GaN HEMT was done, and corresponding device behavior was studied using TCAD. It has also been shown that simulated results for AlGaN/AlN/GaN heterostructure are closely matching with reported measured data.

3 GHz RF measurements of AlGaN/GaN transistors transferred from silicon substrates onto single crystalline diamond

Fraunhofer Institute for Applied Solid State Physics, Tullastrasse 72, 79108 Freiburg, Germany

AIP Advances
https://doi.org/10.1063/1.5127579

The integration of AlGaN/GaN thin film transistors onto diamond substrates enables the efficient dissipation of device heat, thus providing a boost in performance and reliability of current high-frequency GaN power amplifiers. In this paper, we show 3 GHz load-pull measurements of GaN transistors on silicon (Si) and single crystalline diamond (SCD) as fabricated by our recently presented direct low-temperature bond process. After the transfer onto SCD, the efficiency and output power are increased by 15%, which is explained by a calculated temperature difference of ∼100 K. In addition, the temperature between individual gate fingers is reduced such that the output power density (Pout) is independent of the amount of fingers. A drawback of our GaN epilayer is identified in the huge thermal resistance of the buffer layer so that the heat spreading performance of our technology is significantly impaired. Nevertheless, we demonstrate a large GaN-on-diamond output power of 14.4 W at a Pout of 8.0 W/mm.

Lateral and vertical power transistors in GaN and Ga2O3

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany
Chair of Power Electronics, Technische Universität, Berlin, Einsteinufer 19, 10587 Berlin, Germany

IET Power Electronics
https://doi.org/10.1049/iet-pel.2019.0059

Vertical silicon carbide transistors and lateral gallium nitride (GaN) transistors for power-electronic applications currently target applications with different voltage and power ratings. Meanwhile, research and development activities continue on vertical GaN transistors and new gallium oxide (Ga2O3) transistors. What are their perspectives in the application and how do they compete against each other and against established transistor technologies? This study discusses the specific characteristics of lateral and vertical GaN and Ga2O3 transistors to assess their strengths and weaknesses.

Characteristic Function Approach to Analytical Parameter Extraction, Verification, and Circuit Calibration for Small-Signal Equivalent Circuit of Field Effect Transistors

Institute of Information Science and Engineering, South-east University, Nanjing, 210096, China
S-TEK Research Center, Shanghai, 201203, China

Solid-State Electronics
https://doi.org/10.1016/j.sse.2019.107753

An analytical approach to parameter extraction and circuit calibration based on characteristic functions is proposed for small-signal equivalent circuit of field effect transistors (FETs). By using a π-topology of the original intrinsic sub-circuit to replace the conventional T-topology of a supplemental sub-circuit in the equivalent circuit, with the characteristic functions being fitted for both the intrinsic and extrinsic sub-circuits, high precision model parameters of the transistor can be extracted analytically without numerical curve fitting. The present method can serve as an effective way to verify and screen non-physical multiple solutions pertaining to conventional approaches. By comparing measured and simulated characteristic functions, series channel resistance along with channel inductance has been found critical for high frequency modeling. The validity of the present approach is demonstrated for 0.1 µm GaN HEMTs up to 65 GHz.

Broadband Zero-Bias RF Field-Effect Rectifiers Based on AlGaN/GaN Nanowires

Power and Wide-Band-Gap Electronics Research Laboratory (POWERlab), Ecole Polytechnique Federale de Lausanne (EPFL), 1015 Lausanne, Switzerland

IEEE Microwave and Wireless Components Letters
https://doi.org/10.1109/LMWC.2019.2953632

Microwave zero-bias rectifiers are fast devices capable of rectifying RF signals without applied bias, which have applications ranging from RF power

detection to terahertz imaging systems. In this letter, we present gated nanowire field-effect rectifiers (NW-FERs) fabricated with a process compatible with other RF devices on a standard AlGaN-GaN high electron mobility transistor (HEMT) platform as a new potential RF zero-bias diode. Signal rectification relies on the electrostatic modulation of the gated-NW carrier concentration, which is optimized by a judicious NW width design. NW-FERs presented a large curvature (30.1 V^{-1}), close to the theoretical limit (38.7 V^{-1}) for ideal Schottky diodes, and an excellent tradeoff between a flat frequency response, up to a few tens of gigahertz, and a large responsivity (3000 V/W). The compatible fabrication process and the very good results provide a promising high-performance zero-bias diode architecture that could be integrated on AlGaN/GaN microwave monolithic integrated circuits (MMICs).

A 20W Wide Bandwidth GaN HEMT Power Amplifier for VHF/UHF Applications

Hanbat National University, 65733 Daejeon Korea
Wavepia Incorporated, Korea (the Republic of)
Mokpo National Maritime University, 34990 Mokpo, Jeollanam-do Korea (the Republic of)
QUALCOMM Inc, 40753 Santa Clara, California United States
Korea University of Technology and Education, Korea (the Republic of)

IEEE Transactions on Industrial Electronics
https://doi.org/10.1109/TIE.2019.2960749

Broadband GaN HEMT power amplifier with shunt feedback and push-pull technique is presented. Shunt-feedback and push-pull realization provide the robust broad bandwidth covering VHF and low-frequency UHF bands. The benefit due to the feedback presented in the form of shunt-shunt network on power amplifier module provides the linear and broadband frequency amplification. The push-pull topology provides enhanced efficiency and high power generation along with the cancellation of the second-order distortions and thus helps to compensate for the efficiency degradation from the feedback. These techniques are realized with the help of in-house designed GaN HEMT transistor, which provides high power, good efficiency, and high reliability (bandgap). The prototype was realized in 0.25µm GaN HEMT, operates from 30 to 520 MHz, and dissipates 650mA of quiescent current from 28V supply. The power amplifier delivered a saturated output power of > 43 dBm and < 1 dB gain flatness with > 40% PAE at 20W output power. The linearity of the amplifier was characterized by the two-tone injection test. The measurement result shows that the 3rd-order intermodulation distortion tones are below -35 dBc at 35 dBm output power.

Thermal Analysis and Operational Characteristics of an AlGaN/GaN High Electron Mobility Transistor with Copper-Filled Structures: A Simulation Study

Division of Electronics and Electrical Engineering, Dongguk University-Seoul, Seoul 04620, Korea
Electronics and Telecommunications Research Institute, Daejeon 34129, Korea

Micromachines
https://doi.org/10.3390/mi11010053

In this study, we investigated the operational characteristics of AlGaN/GaN high electron mobility transistors (HEMTs) by applying the copper-filled trench and via structures for improved heat dissipation. Therefore, we used a basic T-gate HEMT device to construct the thermal structures. To identify the heat flow across the device structure, a thermal conductivity model and the heat transfer properties corresponding to the GaN, SiC, and Cu materials were applied. Initially, we simulated the direct current (DC) characteristics of a basic GaN on SiC HEMT to confirm the self-heating effect on AlGaN/GaN HEMT. Then, to verify the heat sink effect of the copper-filled thermal structures, we compared the DC characteristics such as the threshold voltage, transconductance, saturation current, and breakdown voltage. Finally, we estimated and compared the lattice temperature of a two-dimensional electron gas channel, the vertical lattice temperature near the drain-side gate head edge, and the transient thermal analysis for the copper-filled thermal trench and via structures. Through this study, we could optimize the operational characteristics of the device by applying an effective heat dissipation structure to the AlGaN/GaN HEMT.

Broadband Power Amplifier Based on a Generalized Step-Impedance Quasi-Chebyshev Lowpass Matching Approach

School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
Design Department, HunterSun Electronics Company, Ltd., Suzhou 215000, China

IEEE Transactions on Plasma Science
https://doi.org/10.1109/TPS.2019.2954494

In this article, a 1.7-2.6-GHz broadband power amplifier (PA) was proposed using the generalized quasi-Chebyshev lowpass matching approach, which was directly composed of step-impedance transmission lines (SITLs). First, the complete design theory for the introduced step-impedance matching network was provided with the detailed design equations. The impedance of the SITLs can be calculated directly based on the specified bandwidth, maximum allowable return loss, and impedance-transforming ratio. The electrical length of SITLs was utilized to adjust the harmonic impedances to perform a PA high-efficiency region. For demonstration, a PA using the 10-W gallium nitride high electron mobility transistor (GaN HEMT) with the measured drain efficiency (DE) of 65%-78% from 1.7 to 2.6 GHz was achieved. A good agreement between the simulated and measured results can be observed.

Thermal Management of GaN-on-Si High Electron Mobility Transistor by Copper Filled Micro-Trench Structure

Department of Photonics, National Chiao Tung University, Hsinchu, 30010, Taiwan, ROC
Department of Physics, Tamkang University, New Taipei City, 25137, Taiwan, ROC
Institute of Electronics, National Chiao Tung University, Hsinchu, 30010, Taiwan, ROC
Center for Emergent Functional Matter Science, National Chiao Tung University, Hsinchu, 30010, Taiwan, ROC

Scientific Reports
https://doi.org/10.1038/s41598-019-56292-3

Self-heating effect is a major limitation in achieving the full performance potential of high power GaN power devices. In this work, we reported a micro-trench structure fabricated on the silicon substrate of an AlGaN/GaN high electron mobility transistor (HEMT) via deep reactive ion etching, which was subsequently filled with high thermal conductive material, copper using the electroplating process. From the current-voltage characteristics, the saturation drain current was improved by approximately 17% with the copper filled micro-trench structure due to efficient heat dissipation. The IDS difference between the pulse and DC bias measurement was about 21% at high bias VDS due to the self-heating effect. In contrast, the difference was reduced to approximately 8% for the devices with the implementation of the proposed structure. Using Micro-Raman thermometry, we showed that temperature near the drain edge of the channel can be lowered by approximately ~22 °C in a HEMT operating at ~10.6 Wmm−1 after the implementation of the trench structure. An effective method for the improvement of thermal management to enhance the performance of GaN-on-Silicon HEMTs was demonstrated.

Small signal behavioral modeling technique of GaN high electron mobility transistor using artificial neural network: An accurate, fast, and reliable approach

Department of Electrical Engineering,Jamia Millia Islamia (A CentralUniversity), New Delhi, India
Department of Electrical and ComputerEngineering, Nazarbayev University,Astana, Kazakhstan
Department of Electronics andCommunication Engineering,Indraprastha Institute of InformationTechnology-Delhi (IIIT-Delhi), NewDelhi, India

International Journal of RF and Microwave Computer-Aided Engineering
https://doi.org/10.1002/mmce.22112

This article reports a comparative study of two artificial neural network structures and associated variants used to describe and predict the behavior of 2 × 200 µm2 GaN high electron mobility transistors (HEMTs), utilizing radiofrequency characterization. Two architectures namely multilayer perceptron and cascade feedforward, have been investigated in this work to develop the behavioral model. A study is conducted utilizing the two architectures, all trained using Levenberg-Marquardt, in terms of accuracy, convergence rate, and generalization capability to

develop the behavioral model of GaN HEMT. However, to ensure the robustness of the model, accuracy, convergence rate, time elapsed, and generalization capability of the proposed model is also tested under couple of training algorithms, activation functions, number of hidden layers and neuron embedded inside it, methods for initialization of weights and bias and certain other vital parameters playing vital role in influencing the model accuracy and effectiveness. An excellent agreement found between measured S-parameters and the proposed model proves the effectiveness of the proposed approach and excellent prediction ability for a sweeping multibias set and broad frequency range of 1 to 18 GHz. Moreover, a very good generalization capability is also recorded under variation of crucial parameters of GaN HEMT-based neural model.

High-efficiency broadband GaN HEMT power amplifier based on harmonic-tuned matching approach

Key Lab of RF Circuit and System ofMinistry of Education, Hangzhou DianziUniversity, Hangzhou, China

International Journal of RF and Microwave Computer-Aided Engineering
https://doi.org/10.1002/mmce.22097

A new type of broadband class-F power amplifier is proposed with GaN HEMT device CGH40010F. And a new harmonic control network is designed by improving the traditional harmonic control network, with the second harmonic and third harmonic broadband matched, which effectively solves the problem of class-F power amplifier in the design of the bandwidth. To improve the efficiency of power amplifier, all high-order harmonics are controlled in a certain bandwidth. CGH40010F power transistor is utilized to build the power amplifier working from 1.5 to 2.6 GHz, with the measured saturated output power >10 W, drain efficiency 60%-80%, and gain >10 dB. The second and the third harmonic suppression levels are maintained from −19.13 to −47.44 dBc and from −16.18 to −47.9 dBc, respectively. The simulation and measurement results of the proposed power amplifier show good consistency.

Analysis of Al0.15Ga0.85N/GaN/Al0.15Ga0.85N DH-HEMT for RF and Microwave Frequency Applications

University School of Information, Communication and Technology, Guru Gobind Singh Indraprastha University, 110078, Dwarka, New Delhi, India
Department of Electronics, Acharya Narendra Dev College, 110019, Kalkaji, New Delhi, India
Department of Electronics and Communication Engineering, Maharaja Agrasen Institute of Technology, Sector-22, 110086, Rohini, New Delhi, India

Semiconductors
https://doi.org/10.1134/S1063782619130050

A charge control based analytical model is followed to study the impact of donor-layer doping and gate-length on microwave frequency performance of AlGaN/GaN/AlGaN double heterostructure high electron mobility transistor (DH-HEMT). DH-HEMT is observed to be more sensitive to gate-length and doping variation as compared to single heterostructure high electron mobility transistor (SH-HEMT). The effect of gate-length and doping on various performance parameters, i.e., transconductance, drain conductance, cut-off frequency and maximum oscillation frequency has been analysed. The results so obtained are compared with simulation results and are found to be in good agreement.

Improvement of transconductance and cut-off frequency in In0.1Ga0.9N back-barrier-based double-channel Al0.3Ga0.7N / GaN high electron mobility transistor by enhancing the drain source contact length ratio

School of Electronics Engineering, Kalinga Institute of Industrial Technology Deemed to be University,Bhubaneswar 751 024, India

Pramana
https://doi.org/10.1007/s12043-019-1866-4

An aluminium gallium nitride / gallium nitride (Al0.3Ga0.7N/GaN) high electron mobility transistor (HEMT) is designed at a gate length (LG) of 0.1 µm, drain-to-source spacing (LSD) of 3 µm and drain length to source length ratio (LD:LS) of 1. The HEMT is investigated by considering four different heterostructures, namely single channel, single channel with back-barrier, double channel and

double channel with back-barrier. A two-dimensional electron gas (2DEG) is formed at the interface of AlGaN / GaN HEMT (DC HEMT). The physical importance of indium gallium nitride (InGaN) as back-barrier is to increase carrier confinement by raising the conduction band of GaN buffer. The double-channel HEMT (DC HEMT) with back-barrier shows the highest current drive. There is an improvement of 3.16% in drain current and an improvement of 4.58% in cut-off frequency at a gate-to-source voltage of −0.5 V for the DC HEMT with back-barrier compared to the DC HEMT without back-barrier. For further improvement in transconductance and cut-off frequency, the structure of DC HEMT with back-barrier is modified by increasing the drain contact length and decreasing the source contact length, that is LD:LS=3, keeping the drain-to-source spacing unchanged, i.e. LSD=3 µm. There is 32.55% improvement in transconductance and 14.03% improvement in cut-off frequency at a gate-to-source voltage of −0.5 V for the DC HEMT with back-barrier at LD:LS=3 compared to the DC HEMT with back-barrier at LD:LS=1.

MOVPE Growth of Buffer Layers on 3C-SiC/Si(111) Templates for AlGaN/GaN High Electron Mobility Transistors with Low RF Losses

Université Côte d'Azur, CNRS, CRHEA, rue Bernard Grégory, 06560 Valbonne, France
CNRS-IEMN –Université de Lille, UMR8520, Av. Poincaré, 59650 Villeneuve d'Ascq, France
NOVASiC, Savoie Technolac -Arche Bat.4, BP 26717 Allée du Lac d'Aiguebelette, 73370 Le Bourget-du-Lac, France

physica status solidi a
https://doi.org/10.1002/pssa.201900760

In the present work, it is shown the interest of cubic silicon carbide as a template for the growth of AlGaN/GaN High Electron Mobility Transistor (HEMT) heterostructures on silicon substrates for high frequency operation. On the one hand, 0.6-0.8 µm thick 3C-SiC grown by chemical vapor deposition on intrinsic Silicon substrate having initial resistivity superior to 5 kOhm.cm enabled the metalorganic vapor phase epitaxy of GaN buffer layers with propagation losses below 0.4 dB/mm at 40 GHz and 0.5 dB/mm at 67 GHz. On the other hand, a HEMT heterostructure has been grown on 1.5 µm thick 3C-SiC on 4° off-axis Silicon substrate having an initial resistivity superior to 200 Ohm.cm that allowed to keep a sufficiently resistive epilayer stack limiting the loss up to 0.78 dB/mm at 40 GHz. Device process developed on a piece of the 100 mm diameter wafer led to the demonstration of DC transistor operation with low leakage currents. Compared with direct growth on silicon, these templates enable reduced RF propagation losses which are very interesting for high frequency transistors and circuits operation.

Effect of material composition on noise performance of sub-micron high electron mobility transistor

Department of Electronics and Communication Engineering, RCC Institute of Information Technology, Kolkata, India
Department of Electronics and Communication Engineering, Kalyani Govt Engineering College, Kalyani, India

Microsystem Technologies
https://doi.org/10.1007/s00542-019-04742-3

Noise figure, reflection coefficient and normalized resistance for AlxGa1−xN/GaN based sub-micron high electron mobility transistor is analytically investigated as a function of material composition from small-signal equivalent circuit over the period of C-band to X-band. A few other significant parameters like phase of both reflection coefficient and optimum impedance, average gain are studied; and critical variations are found for optimum impedance phase profile which gives maximum magnitude at a particular frequency for different material systems. Variations of noise figure and other relevance parameters are explored for an assortment of external biasing conditions and threshold parameter, and results suggests very close agreements with experimental data and also with Pospieszalski model. Phase of optimum impedance depicts peak at a particular frequency within the choice of range, and it shifts with change of material composition. Simulated results are significant in designing HEMT based RF oscillator circuits with proper amalgamation of material composition, drain and gate voltages, leakage current and threshold voltage.

Low leakage GaN HEMTs with sub-100 nm T-shape gates fabricated by a low-damage etching process

School of Microelectronics, Southern University of Science and Technology, Shenzhen 518055, China
Harbin Institute of Technology, Harbin 150001, China
Department of Electronic and Computer Engineering, The Hong Kong University of Science and Technology, Hong Kong, China
Department of Materials Engineering, The University of British Columbia, Vancouver, BC V6T 1Z4, Canada
School of Engineering and Computer Science, Washington State University, Vancouver, WA 98686, USA
GaN Device Engineering Technology Research Center of Guangdong, Shenzhen 518055, China
Shenzhen Institute of Wide-Bandgap Semiconductors, ShenZhen 518100, China

Journal of Materials Science: Materials in Electronics
https://doi.org/10.1007/s10854-019-02758-z

This paper demonstrates a new fabrication process for gallium nitride high-electron mobility transistors (HEMTs) free of plasma damages in the sub-100 nm T-shape gate area. The common peeling-off problems of electron beam resists during gate metal deposition process were solved by introducing a fluorine plasma treatment process before gate metal deposition. By combining dry and wet etching processes appropriately, an on/off ratio of 107 at a drain-to-source voltage of 1 V was achieved. This work also investigated the short channel effect in devices with gate lengths from 70 to 440 nm. Reducing gate length results in decrease of threshold voltage due to the drain-induced barrier-lowering effect. Current gain cut-off frequency fT and maximum oscillation frequency fmax increase while gate length reduces till 250 nm. However, below 250 nm, fT and fmax no longer increase while gate length reduces till sub-100 nm, which reflect the short channel effect.

HAD fabricated on UTB AlGaN/GaN heterostructure for high-sensitivity zero-bias microwave detection

Xi'an International University, School of Engineering, Xi'an, People's Republic of China
University of Electronic Science and Technology of China, School of Electronic Science and Engineering, Chengdu 610054, People's Republic of China

Electronics Letters
https://doi.org/10.1049/el.2019.2548

A novel technology based on aluminium gallium nitride (AlGaN)/GaN hybrid-anode diode (HAD) for precise modulation of turn-on voltage is proposed and experimentally demonstrated. By delicately tailoring the as-grown barrier thickness, the turn-on voltage of the HAD and yet the non-linearity at zero bias (i.e. 0 V) for efficient microwave detection can be flexibly modulated. An AlGaN/GaN ultra-thin-barrier HAD (UTB-HAD) was designed and fabricated for zero-bias microwave detection. The AlGaN-barrier thickness was optimised to be 5 nm by TCAD simulation, which yields a strong non-linearity at zero bias featuring a high-curvature coefficient (γ) of 27 V -1 in the fabricated UTB-HAD. The first-order voltage sensitivity β V is projected to be as high as 2.7 mV/μW. The proposed approach of precise sensitivity modulation is of great interests for high-efficient zero-bias microwave detection applications.

Influence of thin MOCVD-grown GaN layer on underlying AlN template

Wide-gap semiconductor group, National Institute for Materials Science, Tsukuba 305-0044, Japan
Department of Electric Engineering and Electronics, Graduate School of Engineering, Kogakuin University, Hachioji, Tokyo 192-0015, Japan

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.125376

We have studied the direct growth of a GaN film on an AlN template/sapphire substrate by metalorganic chemical vapor deposition. It was found that the GaN layer causes marked deformation of the underlying AlN template at the initial growth. The intensity of x-ray diffraction from AlN drops by a factor of 5 and the full widths at half maximum of the rocking curves of the on- and off-axis planes are increased from 50 to 300 arcsec. With increasing GaN growth time, these values gradually recover, and the crystalline quality of the GaN film is improved. No alloy formation is observed at the interface between AlN and GaN. An AlN template on a sapphire substrate seems to act as a buffer layer, adjusting the lattice constant to improve the crystallinity of the direct grown GaN. Compared with a GaN film grown on a sapphire substrate, GaN grown directly on an AlN template forms a smoother surface with better crystalline quality in a shorter growth time, and at a lower temperature with fewer nonradiative defects in the band gap.

Bio sensing with InGaN-heterostructures using a compact spectrometer approach

Institute of Functional Nanosystems, Ulm University, Germany
Institute of Quantum Matter/Semiconductor Physics Group, Ulm University, Germany
Institute of Inorganic Chemistry I, Ulm University, Germany
Max Planck Institute for Polymer Research, Mainz, Germany
Institute of Electronic Devices and Circuits, Ulm University, Germany

Sensors and Actuators B: Chemical
https://doi.org/10.1016/j.snb.2019.127189

Here, we report on an integrated sensor system based on InGaN heterostructures for (bio)chemical sensing. The system is compact in size and fits into a relatively small volume, which makes it versatile for many applications including liquid biomolecule and gas sensing in hospitals or doctors' offices. A GaN-based heterostructure with an InGaN quantum well close to its surface excited by a 405 nm diode laser reacts to molecules adsorbing on the surface (quantum-confined Stark effect, QCSE) by shifting its photoluminescence (PL) emission wavelength, thus acting as a chemical sensor. The PL signal is guided to

a linear wavelength selecting filter and then detected by a split Si photodiode. This simplification yields reduction in size and cost; possible limitations and challenges are discussed. Simulation calculations about the split diode detector responsiveness indicate that best results can be obtained when fitting the diode spectral resolution to the width of the PL signal of the InGaN sensor and the expected PL shift. The system's utility is applied to different analytes, such as isopropanol, ferritin and apoferritin. For ferritin, a wavelength shift sensitivity of was found.

Achieving homogeneity of InGaN/GaN quantum well by well/barrier interface treatment

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
Microsystem & Terahertz Research Center, Chinese Academy of Engineering Physics, Chengdu 610200, China
Suzhou Institute of Nano-tech and Nano-bionics, Chinese Academy of Sciences, Suzhou, 215125, China

Applied Surface Science
https://doi.org/10.1016/j.apsusc.2019.144283

A new pretreatment method is adopted during the metal-organic chemical vapor deposition (MOCVD) epitaxial growth of InGaN/(In)GaN multiple quantum well (MQW), in which when the growth of under barrier of each QW is finished, i. e. before the growth of each well layer, the gallium precursor flow is switched off while indium and nitrogen precursor flows are kept on for an extra period of time. The structural and luminescence properties of samples with different pretreatment duration are investigated by high resolution x-ray diffraction, electroluminescence, temperature dependent photoluminescence and micro-photoluminescence. The results show that a better homogeneity of quantum wells can be achieved by this preprocess. This method operates mainly due to partially releasing the deformation energy and thus attenuating the composition pulling effect in InGaN well layer growth.

Nonlinearity in piezotransistive GaN microcantilevers

Holcombe Department of Electrical and Computer Engineering, Clemson University, Clemson, SC 29634, United States of America

Journal of Micromechanics and Microengineering
https://doi.org/10.1088/1361-6439/ab4961

We have investigated nonlinear dynamic characteristics of piezotransistive GaN microcantilevers, with integrated AlGaN/GaN heterostructure field effect transistor as a highly sensitive deflection transducer. When excited with a piezochip actuator, both softening and hardening type of nonlinear behavior were exhibited by the GaN microcantilevers in their first flexural mode. The nonlinear behavior was found to strongly depend on the dimensions of these microcantilevers. While the hardening behavior was found to be enhanced with increase in length of the cantilever for a fixed width, the nonlinear behavior changed much more sharply with width, exhibiting a clear switchover from hardening to softening type, with an increase in width of the cantilever for a constant length. The nonlinear characteristics of the cantilevers were modeled using a Duffing equation with excellent agreement observed between the theoretical model and experimental data for both nonlinearity types and frequency sweep directions.

Suppression of persistent photoconductivity AlGaN/GaN heterostructure photodetectors using pulsed heating

Department of Microelectronics, Delft University of Technology, 2628 CD Delft, The Netherlands
Research and Development Center for Solid State Lighting, Institute of Semiconductors, Chinese Academy of Sciences, Qinghua East Road 35A, 100083, Beijing, People's Republic of China
State Key Laboratory of Solid State Lighting, Beijing, 100083, People's Republic of China
Institutue of Microelectronic, Tsinghua University, 100084, Beijing, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab4f5b

This paper demonstrates a method to reduce the decay time in AlGaN/GaN photodetectors by a pulsed

heating mode. A suspended AlGaN/GaN heterostructure photodetector integrated with a micro-heater is fabricated and characterized under ultraviolet illumination. We have observed that the course of persistent photoconductivity was effectively accelerated by applying pulsed heating. The decay time is significantly reduced from 175 s by DC heating to 116 s by 50 Hz pulsed heating at the same power (280 mW). With the same pulse duty cycle and a 50 Hz pulsed heating frequency, a reduction of 30%–45% in decay time is measured compared to DC heating.

Ultra-robust Deep-UV Photovoltaic Detector Based on Graphene/(AlGa)2O3/GaN with High-Performance in Temperature Fluctuations

State key Laboratory of Optoelectronic Materials and Technologies, School of Materials, Sun Yat-sen University, Guangzhou, Guangdong, 510275, China

ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.9b18352

A strategy of adopting Ga2O3 alloyed with Al element to reduce the oxygen vacancy defect density and to enhance the interface barrier height of Ga2O3 heterojunction is proposed to fabricate deep-UV photovoltaic detectors with high thermal stability, high photoresponsivity and fast response speed. Here, a graphene/(AlGa)2O3/GaN device with a photoresponsivity of ~20 mA/W, a rise time of ~2 μs and a decay time of ~10 ms is presented at 0 V bias. At the working temperature of 453 K, the device still exhibits a photo-to-dark current ratio (PDCR) of ~1.8×103, which is 1-2 orders of magnitude higher than that of reported high temperature deep-UV film detectors. By comparing the formation energy of oxygen vacancy defects and the interface barrier height of heterojunction at different temperatures in graphene/Ga2O3/GaN and graphene/(AlGa)2O3/GaN systems respectively, the strategy of synthesizing (AlGa)2O3 ternary composite alloy is proved reliable for fabricating high performance deep-UV photovoltaic detectors. The method proposed in this paper can provide reference for the preparation of deep-UV photovoltaic detectors with high photoresponsivity and thermal stability in the future.

Ammonia Sensing Characteristics of a Platinum (Pt) Hybrid Structure/GaN-Based Schottky Diode

Department of Electrical Engineering, Institute of Microelectronics, National Cheng Kung University, Tainan 70101, Taiwan
Department of Electronic Engineering, National Ilan University, Yilan City 260, Taiwan
Department of Computer Science and Information Engineering, Chaoyang University of Technology, Taichung 41349, Taiwan

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2953703

A hybrid structure of platinum nanoparticles (Pt NPs) and a Pt thin film are employed to fabricate a new Pt NP/Pt thin film/GaN-based Schottky diode-type ammonia sensor. Pt NPs are formed by a drop coating and UV illumination approach. The increased surface-area-to-volume ratio and ``spillover'' effect of Pt NPs are beneficial in ammonia sensing. Due to the synergistic catalytic activity of Pt NPs and Pt thin film, the studied device shows good ammonia sensing properties, including a high sensing response of 522.1 under 1000-ppm NH_3/air gas at 473 K and an extremely low detecting level of 0.4-ppm NH_3/air. A thermodynamic analysis is employed to study the related ammonia sensing mechanism. Furthermore, a Kalman filter and the related algorithm are introduced to effectively reduce the redundant data without affecting the original sensing results. Based on the good performance and advantages of a relatively simple structure and easy fabrication, the studied device is promising for ammonia sensing and wireless transmission applications.

Improved visible-blindness of AlGaN deep ultraviolet photodiode with monolithically integrated angle-insensitive Fabry–Perot filter

Department of Electrical and Computer Engineering, Ajou University, Suwon 16499, South Korea
Genicom Co., Ltd., Daejeon 34036, South Korea
Department of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA 22904, USA

Optics Express
https://doi.org/10.1364/OE.27.037446

Despite the rapidly increasing demand for accurate ultraviolet (UV) detection in various applications,

conventional Si-based UV sensors are less accurate due to disruption by visible light. Recently, Ga(Al)N-based photodiodes have attracted great interest as viable platforms that can avoid such issues because their wide bandgap enables efficient detection of UV light and they are theoretically blind to visible and infrared light. However, the heteroepitaxy of a Ga(Al)N layer on sapphire substrates inevitably leads to defects, and the Ga(Al)N photodiode (PD) becomes not perfectly insensible to visible light. Employment of a dielectric stacked UV pass filter is possible to avoid unwanted absorption of visible light, but the angle-dependent pass band limits the detection angle. Here, we have demonstrated the Ag-Al2O3 Fabry–Perot UV pass filter-integrated AlGaN ultraviolet photodiode. The inherent optical extinction characteristics of Ag was utilized to design the fabrication-tolerant UV pass filter with a peak transmittance at ~325 nm. As the angle of incidence increased, the peak transmission decreased from 45% to 10%, but the relative transmission spectrum remained almost unchanged. By integrating these filters, the visible light rejection ratio (responsivity for 315 nm light to responsivity for 405 nm light) was improved by a factor of 10, reaching a value of 106 at angles of up to 80 degrees.

Fast Response Characteristics of Flexible Ultraviolet Photosensors with GaN Nanowires and Graphene

Department of Electronic and Information Materials Engineering, Division of Advanced Materials Engineering, and Research Center of Advanced Materials Development,
Department of Polymer-Nano Science and Technology, and Polymer Materials Fusion Research Centre, Chonbuk National University, Jeonju 54896, South Korea
Applied Quantum Composites Research Center, Korea Institute of Science and Technology, Wanju 55324, South Korea

ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.9b13109

We report the fast response characteristics of flexible ultraviolet (UV) photosensors with GaN nanowires (NWs) and a graphene channel. The GaN NWs used as light-absorbing media are horizontally and randomly embedded in a graphene sandwich structure in which the number of bottom graphene layers is varied from zero to three and the top is a fixed single layer of graphene. In the response curve of the photosensor with a double-layer bottom graphene, as obtained under pulsed illumination with a pulse width of 50 ms and a duty cycle of 50%, the rise and decay times were measured as 24.1 ± 0.1 and 28.2 ± 0.1 ms, respectively. The eye-crossing percentage was evaluated as 52.1%, indicating no substantial distortion of the duty cycle and no pulse symmetry problem. The rise and decay times estimated from equivalent circuit analysis represented by resistances and capacitances agree well with the measured values. When the device was under bending condition, the rise and decay times of the photosensor were comparable to those in the unbent state.

Investigation of Stability and Power Consumption of an AlGaN/GaN Heterostructure Hydrogen Gas Sensor Using Different Bias Conditions

School of Electronic and Electrical Engineering, Hongik University, Seoul 04066, Korea

Sensors
https://doi.org/10.3390/s19245549

A Pd-functionalized hydrogen gas sensor was fabricated on an AlGaN/GaN-on-Si heterostructure platform. The AlGaN layer under the Pd catalyst area was partially recessed by plasma etching, which resulted in a low standby current level enhancing the sensor response. Sensor stability and power consumption depending on operation conditions were carefully investigated using two different bias modes: constant voltage bias mode and constant current bias mode. From the stability point of view, high voltage operation is better than low voltage operation for the constant voltage mode of operation, whereas low current operation is preferred over high current operation for the constant current mode of operation. That is, stable operation with lower standby power consumption can be achieved with the constant current bias operation. The fabricated AlGaN/GaN-on-Si hydrogen sensor exhibited excellent sensing characteristics; a response of 120% with a response time of < 0.4 s at a bias current density of 1 mA/mm at 200 °C. The standby power consumption was only 0.54 W/cm2 for a sensing catalyst area of 100 × 24 µm2.

High-Resolution AlGaN/GaN HEMT-Based Electrochemical Sensor for Biomedical Applications

Department of Electronics and Communication Engineering, Malaviya National Institute of Technology, Jaipur 302017, India
Nano Bio Sensors Group, Central Electronics Engineering Research Institute (CSIR), Pilani 33031, India
Optoelectronics and MOEMs Group, Central Electronics Engineering Research Institute (CSIR), Pilani 33031, India
Process Technologies Group, Central Electronics Engineering Research Institute (CSIR), Pilani 33031, India

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2949821

We have investigated the characteristics of pH and salinity sensor derived from the gated AlGaN/GaN high-electron mobility transistor (HEMT) structures in phosphate buffer saline (PBS) and aqueous salt solutions (NaCl + DI). In deionized (DI) water, the HEMT device showed good drain I-V characteristics, which is very close to the output characteristics of the typical HEMT structures subjected to the air. We observed a significant change in the output drain characteristics curves concerning to the variation in the pH values of PBS solutions, signifying the subsequent potential variation at the AlGaN surface. The output drain current recorded at Vds= +1 V was linearly decremented with the pH value. A high sensitivity of 4.32 µA/mm-pH was obtained. These GaN HEMT structures demonstrated a quick response to the pH changes. It was also investigated that the devices were susceptible toward the aqueous salt solution (NaCl + DI). The percentage change in drain current linearly decreased with decreasing NaCl molar concentration in DI water. We have reported on the change in current with the smaller range of molar concentration of NaCl present in water. Evaluating the sensitivity and response time, we obtained a high sensitivity of 6.48 mA/mm-molar and a response time of 250-350 ms at Vds= +1 V. We have also reported on the change in current with the molar concentration of NaCl present in PBS with a high sensitivity of 2.02 mA/mm-molar at Vds= +5 V. These outcomes show that the AlGaN/GaN HEMTs are exceptionally promising as a high-sensitivity pH sensor and salinity sensor for biological experiments.

Hydrogen gas ppb-level detection based on AlGaN/GaN high electron mobility transistor with 2.0 nm thick Pt gate layer

College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, People's Republic of China
Shenzhen Key Laboratory of Advanced Thin Films and Applications, Shenzhen University, Shenzhen 518060, People's Republic of China

Applied Physics Letters
https://doi.org/10.1063/1.5135047

In this work, ppb-level H2 gas detection based on the Pt-gated AlGaN/GaN high electron mobility transistor device was obtained through minimizing the H atom diffusion distance by the utilization of a critical Pt gate thickness of ~2.0 nm. The Ids-Vds curves show that the device exhibits a pinch-off characteristic with an on-to-off ratio of about four orders of magnitude. High response (775% at 100 ppm, 25.4% at 1 ppm) and short response times (2.5 s at 10 000 ppm) are observed at 150 °C. Particularly, the device has a response to trace H2 gas as low as 60 ppb, indicating a small low limit of detection (LOD) < 60 ppb. Its capability to detect very low H2 gas together with a high response makes it promising for trace H2 gas detection such as exhale breath analysis. Moreover, it is found that the H2 detection range depends on the operating temperature, which is useful in real applications that require various H2 gas detection ranges.

Third-Harmonic and Intermodulation Distortion in Bulk Acoustic-Wave Resonators

Signal Theory and Communications Department, Universitat Politecnica de Catalunya, 08034 Barcelona, Spain
Qorvo, Inc., Orlando, FL 32703 USA

IEEE Transactions on Microwave Theory and Techniques
https://doi.org/10.1109/TMTT.2019.2955135

This article discusses on the measured third-order intermodulation (IMD3) products and third harmonics (H3) appearing in a set of six different solidly mounted resonators (SMR) and bulk acoustic-wave (BAW) resonators with different shapes and stack configurations. The discussion is supported by a comprehensive nonlinear distributed circuit model

that considers the nonlinear effects potentially occurring in any layer of the resonator stack. The aluminum-nitride (AlN) and silicon-dioxide (SiO_2) layers are identified as the most significant contributors to the IMD3 and H3. The frequency profile of the third-order spurious signals also reveals that, in temperature-compensated resonators, where the SiO_2 layers are usually thicker, the remixing effects from the second-order nonlinear terms are the major contributors to the IMD3 and H3. These second-order terms are those that explain the second-harmonic (H2) generation, whose measurements are also reported in this article. Unique values of the nonlinear material constants can explain all the measurements despite the resonators have different shapes, resonance frequencies, and stack configurations.

Analysis of High-Temperature Carrier Transport Mechanisms for High Al-Content Al0.6Ga0.4N MSM Photodetectors

School of Internet of Things Engineering, Jiangnan University, Wuxi 214122, China
Jiangsu Provincial Research Center of Light Industrial Optoelectronic Engineering and Technology, School of Science, Jiangnan University, Wuxi 214122, China
Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117583
38th Research Institute of China Electronics Technology Group Corporation, Hefei 230000, China
Institution of Next Generation Semiconductor Materials, Southeast University, Suzhou 215123, China

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2953881

An AlGaN-based solar blind ultraviolet (UV) metal-semiconductor-metal (MSM) photodetector (PD) with a high Al-content of 0.6 has been successfully fabricated. The device exhibits a cutoff wavelength of 255 nm corresponding to the sharp cutoff transmission spectrum of Al0.6Ga0.4N. In addition, dislocations in the Al0.6Ga0.4N epi-layer has been analyzed by high-resolution transmission electron microscope (TEM). The Al0.6Ga0.4N-based solar blind PD exhibits a responsivity of 0.51 A/W at 10 V with a high breakdown voltage of 470 V. Suggesting its potential applications for high-temperature solar blind UV detection, the I-V-T characteristics have been comprehensively investigated to explore its high-temperature carrier transport mechanisms. It is convincingly demonstrated that the bias leakage current across the device is dominated by thermionic-field emission transport at low bias voltages and Poole-Frenkel emission at high bias voltages from room temperature up to 425 K.

UV-light enhanced CO gas sensors based on InGaN nanorods decorated with p-Phenylenediamine-graphene oxide composite

Department of Physics, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon, 34134, Republic of Korea
Department of Chemistry, SRM Institute of Science and Technology, Kattankulathur, Chennai 603203, India
Department of Polymer Science and Engineering, Department of IT Convergence (BK21 PLUS), Chemical Industry Institute, Korea National University of Transportation, Chungju 27469, Republic of Korea
Department of Chemical Engineering, College of Engineering, Kyung Hee University, Yongin-si, Gyeonggi-do 17104, Republic of Korea
Department of Electronic Engineering, Institute for Wearable Convergence Electronics, Kyung Hee University, Yongin-si, Gyeonggi-do 17104, Republic of Korea
Department of Information and Communications, Joongbu University, 305 Donghen-ro, Goyang, Kyunggi-do, 10279, Republic of Korea

Sensors and Actuators B: Chemical
https://doi.org/10.1016/j.snb.2019.127649

Coupling of graphene and its derivatives with organic moieties is one of the promising strategies to enhance the gas sensing performance. A novel ternary nanocomposite of p-Phenylenediamine-graphene oxide (PGO)/InGaN nanorods (NRs) probed as chemiresistive gas sensor for carbon monoxide (CO) in ppm concentrations. The InGaN NRs were grown by molecular beam epitaxy, and a drop-casting method was employed to decorate the PGO composite on InGaN NRs. The sensor devices consisting of PGO/InGaN NRs with interdigitated electrodes have been fabricated, and their sensing characteristics for CO were studied. PGO composite provided a significant decrease in the electrical resistance of the ternary nanocomposite of PGO/InGaN at the operating temperature (27 °C – 100 °C). The sensor device based on PGO/InGaN NRs exhibited a higher response than the GO/InGaN NRs.

The PGO/InGaN NRs device exhibited a maximum sensing response of ~131 % at a CO concentration of 100 ppm at an operation temperature of 100 °C, which is 2.7 times higher than the GO/InGaN NRs sensor response. Also, the response (~93.58%) was remarkably improved under UV illumination at room temperature. The combined effect of active cites in GO and the increased electron density at the nitrogen atom in the amine groups of the PGO are responsible for the excellent performance.

Toward AlGaN Focal Plane Arrays for Solar-Blind Ultraviolet Detection

Business Unit Photodetectors, Fraunhofer Institute for Applied Solid State Physics IAF, Tullastr. 72, 79108 Freiburg, Germany

physica status solidi a
https://doi.org/10.1002/pssa.201900769

Missile approach warning (MAW) systems of airborne military platforms require ultrasensitive detection capabilities in the solar-blind UV regime below 280 nm. Today, these needs are answered with UV photomultiplier tubes, which are bulky, complex, and require external filtering to suppress clutter signatures beyond 280 nm.This study investigates whether AlGaN focal plane array (FPA) detectors may develop into a viable alternative. The compact, lightweight, all-solid-state solution promises intrinsic solar blindness and excellent out-of-band suppression ratios realizable at affordable costs on large-area substrates. Yet, does today's state of technology allow mastering the fabrication processes so that the electrooptical performance is sufficient to achieve the required sensitivity? Herein, three device wafers are grown by metalorganic chemical vapor deposition and subsequently processed into detector arrays with a spatial resolution of 640 × 512 pixels on a 15 µm pitch. After hybridization with an off-the-shelf capacitive transimpedance input amplifier (CTIA) read-out integrated circuit (ROIC), their electrooptical performance is characterized. The characterized FPAs show a very low percentage of defective pixels, excellent linearity at high photon fluxes, and, at low flux, their already remarkable sensitivity is limited by the off-the-shelf CTIA ROIC. Therefore, with further improvements MAW systems based on AlGaN FPAs seem feasible.

Enhancing the sensitivity of the reference electrode free AlGaN/GaN HEMT based pH sensors by controlling the threshold voltage

School of Microelectronics, Dalian University of Technology, Dalian 116024, Liaoning, China
Shandong NovoShine Optoelectronics Co., Ltd., Weifang 261061, Shandong, China
Jiangsu Xinguanglian Technology Co., Ltd., Wuxi 214192, Jiangsu, China

Sensors and Actuators B: Chemical
https://doi.org/10.1016/j.snb.2019.127609

The threshold voltage (VT) of the AlGaN/GaN HEMT based pH sensor was adjusted by the method of the photoelectrochemical (PEC) oxidation on the GaN cap layer surface. After the PEC oxidation treatments, the VT of the device shifted from -3.46 V to -1.15 V and the gate voltage (VG) corresponding to the maximum transconductance (gmMAX) position (VG|gmMAX) of the device shifted from -2.6 V to -0.1 V. The drain current (ID) variation per pH of the AlGaN/GaN HEMT based pH sensor without reference electrode increased from 0.7 µA to 14 µA when the drain voltage (VD) was 0.5 V. The sensitivity of the reference electrode free AlGaN/GaN HEMT based pH sensor can be significantly increased by regulating the VT to make VG|gmMAX approached the equivalent VG when liquid droplet on the sensing window surface (VG-EQU), which is beneficial to the miniaturization and integration of the AlGaN/GaN HEMT based sensors in the future.

High figure-of-merit NEMS thermal detectors based on 50-nm thick AlN nano-plate resonators

Northeastern University, Boston, Massachusetts 02115, USA

Applied Physics Letters
https://doi.org/10.1063/1.5128643

This paper reports on the demonstration of ultrafast (thermal time constant, $\tau \sim 166$ µs) and high resolution (noise equivalent power, NEP ~ 549 pW/Hz1/2) thermal detectors based on high quality factor 50-nm thick aluminum nitride (AlN) piezoelectric resonant nanoplates. Here we show that by employing nanoscale (30 nm) aluminum anchors, both high thermal resistance

(Rth ~ 1.1 × 106 K/W) and high quality factor (Q ~ 1000) can be achieved in greatly scaled AlN nanoplate resonators. Furthermore, the absorptance of such ultrathin AlN resonators was characterized, in mid-wavelength infrared region showing an average absorptance of ~36% from 2.75 µm to 6.25 µm. These unique features were exploited for the experimental demonstration of AlN NEMS resonant thermal detectors with greatly reduced thermal capacitance and over doubled figure of merit [FoM = 1/(NEP × τ)] compared to what was previously achieved by the same technology.

In-plane enhanced epitaxy for step-flow AlN yielding a high-performance vacuum-ultraviolet photovoltaic detector

State Key Laboratory of Optoelectronic Materials and Technologies, School of Materials, Sun Yat-sen University, Guangzhou, Guangdong 510275, China

CrystEngComm
https://doi.org/10.1039/C9CE01852B

Vacuum ultraviolet (VUV) photodetection has great application prospects in the fields of space exploration, environmental science and biomedicine. In this work, we will present VUV-sensitive AlN single crystalline films (SCFs) with low defect density, grown by our independently designed in-plane enhanced hetero-epitaxial method. By combining the as-grown films with p-type graphene (p-Gr) serving as a transparent conductive layer, a VUV photovoltaic detector with a p-Gr/i-AlN/n-GaN structure was constructed. At zero bias, the detector exhibits an ultrafast response time of 2.86 µs, which is 2 orders of magnitude faster than that of a previously reported h-BN photoconductive detector. Besides, it also has an ultra-high photovoltage of 2 V and an excellent spectral selectivity. The results have demonstrated that the in-plane enhanced epitaxy strategy is expected to provide reference for the preparation of high-quality AlN and to promote the development of VUV detectors in deep space science.

GROUP 6 - Photovoltaics and Energy harvesting

Group leader: Eva Monroy (INAC-CEA)

Information selected by Knowmade

Effect of Indium Composition on the Microstructural Properties and Performance of InGaN/GaN MQWs Solar Cells

Key Laboratory of Auxiliary Chemistry and Technology for Chemical Industry, Ministry of Education, Shaanxi University of Science and Technology, Xi'an, 710021, China
Materials Institute of Atomic and Molecular Science, Shaanxi University of Science and Technology, Xi'an, 710021, China
School of Information and Technology, Northwest University, Xi'an, 710127, China
Department of integrated circuit design, Xi'an Microelectronics Technology Institute, Xi'an 710065, China
Taiyuan University of Technology, Taiyuan, 030024, China

IEEE Access
https://doi.org/10.1109/ACCESS.2019.2959844

In the present work, InGaN/GaN multiple quantum wells (MQWs) solar cells with different concentrations of indium have been investigated in-depth. It was demonstrated that applying a medium-high indium content (about 28%) does not facilitate solar cell photoelectric conversion efficiency due to the increase of edge dislocations. Moreover, the effects of different indium contents on InGaN/GaN MQWs solar cells were investigated and was revealed, that the short-circuit current density and photoelectric conversion efficiency are improved with the increase of indium contents. However, they show a noticeable reduction in the indium content of 28%. Furthermore, the optical properties and the behaviour of the microstructure defects were analysed. It was also demonstrated that the number of edge dislocations acted as non-radiation recombination centers increasing rapidly when the indium content reaches 28%, playing a key role in decreasing the active number of photon-generated carriers. As a result, the short-circuit current density and photoelectric conversion efficiency decrease obviously for an indium content of 28%. This work can provide insight into the origin of the degradation of these structures and the improvement of device design with medium-high indium contents.

Improved electron capture capability of field-assisted exponential-doping GaN nanowire array photocathode

Department of Optoelectronic Technology, School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing 210094, China

Journal of Materials Science & Technology
https://doi.org/10.1016/j.jmst.2019.10.014

The exponential-doping GaN nanowire arrays (GaN NWAs) photocathode has a "light-trapping effect", and the built-in electric field can promote the concentration of the photogenerated carrier center to the top surface of the nanowire. However, in the preparation of actual NWAs photocathodes, the problem that photons emitted from the sides of the nanowires cannot be effectively collected has been encountered. Our proposed field-assisted exponential-doping GaN NWAs can bend the motion trajectory of the emitted electrons toward the collecting side. In this study, the quantum efficiency (QE) and collection efficiency (CE) of the external field-assisted exponential-doping GaN NWAs photocathode are derived based on the two-dimensional carrier diffusion equation and the initial energy and angular distribution, respectively. For a field-assisted exponential-doping GaN NWAs with a width $d = 200$ nm and a height $H = 400$ nm, the optimal structural parameters are obtained: the incident angle $\theta = 50°$ and the nanowire spacing is $L = 335.6$ nm. On this basis, the field intensity of 0.5 V/μm can maximize the CE of the NWAs. All the results show that the field-assisted approach does contribute to the collection of emitted electrons, which can provide theoretical guidance for high-performance electron sources based on exponential-doping GaN NWAs photocathodes. And field-assisted exponential-doping GaN NWAs cathode is expected to be verified by the experimental results in the future.

Research on quantum efficiency of exponential-doping GaN monolayer reflection-mode photocathode with ultra-thin emission layer

Department of Optoelectronic Technology, School of Electronic and Optical Engineering, Nanjing University of Science and Technology, NanjingPeople's Republic of China

Applied Nanoscience
https://doi.org/10.1007/s13204-019-01228-6

In this paper, we present an exponential-doping GaN monolayer reflection-mode photocathode whose emission layer is composed of few GaN monolayers with different doping concentrations. To understand its optoelectronic emission performance, the quantum efficiency formula of exponential-doping GaN photocathode with ultra-thin monolayers as the emission layer is obtained. Then, we simulate the impact of recombination velocity of AlGaN/GaN ML interface, recombination velocity of GaN ML/GaN ML interface, thickness of emission layer with GaN monolayers, surface escape probability and surface reflectivity on quantum efficiency based on the formula, respectively. The results imply that interface recombination velocity made a significant contribution to quantum efficiency of photocathode. When interface recombination velocity in AlGaN/GaN ML and GaN ML/GaN ML is appropriate, they will promote electrons' escape to the cathode surface and achieve higher quantum efficiency finally. Through our simulation results, a helpful reference can be given for design of exponential-doping GaN monolayer photocathode.

Transferred monolayer MoS2 onto GaN for heterostructure photoanode: Toward stable and efficient photoelectrochemical water splitting

Department of Physics, Chonnam National University, Gwangju, 61186, Republic of Korea
Department of Photonic Engineering, Chosun University, Gwangju, 61452, Republic of Korea
Optoelectronics Convergence Research Center, Chonnam National University, Gwangju, 61186, Republic of Korea

Scientific Reports
https://doi.org/10.1038/s41598-019-56807-y

Solar-driven photoelectrochemical water splitting (PEC-WS) using semiconductor photoelectrodes is considered a promising solution for sustainable, renewable, clean, safe and alternative energy sources such as hydrogen. Here, we report the synthesis and characterization of a novel heterostructure MoS2/GaN to be used as a photoanode for PEC-WS. The heterostructure was synthesized by metal-organic chemical vapor deposition of single crystalline GaN onto a c-plane sapphire substrate, followed by the deposition of a visible light responding MoS2 monolayer (Eg = 1.9 eV) formed by a Mo-sulfurization technique. Our experimental results reveal that MoS2/GaN photoanode achieved efficient light harvesting with photocurrent density of 5.2 mA cm−2 at 0 V vs Ag/AgCl, which is 2.6 times higher than pristine GaN. Interestingly, MoS2/GaN exhibited a significantly enhanced applied-bias-photon-to-current conversion efficiency of 0.91%, whereas reference GaN yielded an efficiency of 0.32%. The superior PEC performance of the MoS2/GaN photoelectrode is mainly related to the enhanced light absorption due to excellent photocatalytic behavior of MoS2, which reduces charge transfer resistance between the semiconductor and electrolyte interface, and the improvement of charge separation and transport. This result gives a new perspective on the importance of MoS2 as a cocatalyst coated onto GaN to synthesize photoelectrodes for efficient solar energy conversion devices.

A van der Waals Heterostructure Based on Graphene-like Gallium Nitride and Boron Selenide: A High-Efficiency Photocatalyst for Water Splitting

School of Mechanical Engineering, Southeast University, Nanjing, Jiangsu 211189, China
College of Science, Jinling Institute of Technology, Nanjing, Jiangsu 211169, China
Department of Mechanical Engineering, City University of Hong Kong, Kowloon, Hong Kong 999077, China
School of Materials Science and Engineering, Southeast University, Nanjing, Jiangsu 211189, China

ACS Omega
https://doi.org/10.1021/acsomega.9b02143

Hydrogen generation by photocatalytic water splitting has attained more and more research interests in the recent years since the solar energy can be directly transferred and stored as hydrogen. However, the search for a high-efficiency photocatalyst for water splitting is a really challenge. In this paper, we designed a novel 2D material-based

van der Waals heterostructure (vdWH) composed by g-GaN and BSe, which is thermally stable at room temperature. The g-GaN/BSe vdWH has suitable band-edge positions for the oxidation and reduction reactions of water splitting at pH 0 and 7. The carrier mobility of this heterostructure is high, indicating the effective occurrence of reactions for water splitting. The g-GaN/BSe vdWH also possesses a type-II band alignment, which can promote the separation of the photogenerated electron–hole pairs constantly. Moreover, a large built-in electric field can be established at the interface, which will further prevent the recombination of photogenerated charges. In addition, the g-GaN/BSe vdWH also exhibits outstanding sunlight-absorption ability, and the biaxial strain can further enhance this ability. Thus, we conclude that the g-GaN/BSe vdWH can act as a high-efficiency photocatalyst for water splitting.

III-Nitride/Si Tandem Solar Cell for High Spectral Response: Key Attributes of Auto-tunneling Mechanisms

Department of Electronics, Communication Engineering, Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram, India
Department of Electronics, Communication Engineering, SRM University, Kattankulathur, India

Silicon
https://doi.org/10.1007/s12633-019-00342-y

The key attributes of double hetero junction tandem solar cell based on III-Nitride alloys and silicon is investigated thoroughly. GaN/InGaN/GaN based tandem solar cells are predicting impressive efficiency, however due to its high cost; it is far from immediate implementation. Hence, an attempt is made to realize GaN/InGaN on crystalline silicon(c-Si) substrate that results in high spectral efficiency and cost effectiveness. The proposed multi-junction tandem solar cell consists of a GaN layer, intrinsic-InxGa1−xN (i-InGaN), tandem InxGa1−xN (t-InGaN) upon crystalline p-silicon and n-silicon layers. Energy band diagrams, current-voltage curve, power graph, electric field and potential graphs are explored using TCAD tool. Additionally, key parameters such as 'In' content, thickness of layers, absorption coefficients, polarization charges are optimized. A remarkable conversion efficiency of 25.6% and 26.1% are achieved with & without polarization effect, respectively and became a potential candidate for next-generation photovoltaics applications.

Influence of Si-Doping on the Performance of InGaN/GaN Multiple Quantum Well Solar Cells

School of Physics and Optoelectronic Engineering, Xidian University, Xi'an, China
Laboratory of Nanophotonic Functional Materials and Devices, Institute of Optoelectronic Materials and Technology, South China Normal University, Guangzhou, China

Semiconductors
https://doi.org/10.1134/S1063782619130049

The performance of InGaN/GaN multiple quantum well (MQW) solar cells with five different Si-doping concentrations, namely 0, 4 × 1017 cm–3, 1 × 1018 cm–3, 3 × 1018 cm–3 and 6 × 1018 cm–3, in GaN barriers is investigated. Increasing Si-doping concentration leads to better transport property, resulting in smaller series resistance (Rs). However, the crystal quality degrades when Si-doping concentration is over 1 × 1018 cm–3, which reduces the external quantum efficiency, short circuit current density and open circuit voltage. As a result, the sample with a slight Si-doping concentration of 4 × 1017 cm–3 exhibits the highest conversion efficiency.

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

van der Waals gap-inserted light-emitting p–n heterojunction of ZnO nanorods/graphene/p-GaN film

Department of Nanotechnology & Advanced Materials Engineering, Sejong University, Seoul, 05006, Republic of Korea
Graphene Research Institute–Texas Photonics Center (GRI–TPC) International Research Center, Sejong University, Seoul, 05006, Republic of Korea
Department of Physics & Astronomy and GRI, Sejong University, Seoul, 05006, Republic of Korea
School of Physics and Astronomy, University of Manchester, Manchester, M13 9PL, United Kingdom
Department of Materials Science and Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Gyeongbuk, 37673, Republic of Korea

Current Applied Physics
https://doi.org/10.1016/j.cap.2019.11.022

We report on the electroluminescent (EL) and electrical characteristics of graphene-inserted ZnO nanorods (NRs)/p-GaN heterojunction diode. In a comparative study, ZnO NRs/p-GaN and ZnO NRs/graphene/p-GaN heterojunctions exhibit white and yellow EL emissions, respectively, at reverse bias (rb) voltages. The different EL colors are results of different dichromatic EL peak intensity ratios between 2.25 and 2.8 eV light emissions which are originated from ZnO and p-GaN sides, respectively. The 2.25 eV EL is predominant in both the heterojunctions, because of recombination by numerous electrons tunneled from p-GaN to ZnO across the thin barriers of the staggered broken gap with a large band offset in ZnO/p-GaN and the van der Waals (vdW) gap formed by graphene insertion at ZnO NRs/p-GaN. However, as for the 2.8 eV EL intensity, ZnO NRs/graphene/p-GaN hardly shows the EL emission, whereas ZnO NRs/p-GaN exhibits the substantially strong EL peak. We discuss that the significantly reduced 2.8 eV EL emission of ZnO NRs/graphene/p-GaN is a result of decreased depletion layer thickness at p-GaN side where the recombination events occur for 2.8 eV EL before the reverse bias-driven tunneling because the insertion of graphene (or vdW gap barrier) inhibits the carrier diffusion whose amount determines the depletion thickness when forming the heterojunctions. This study opens a way of suppressing (or enhancing) the specific EL wavelength for the dichromatic EL-emitting heterojunctions simply by inserting atom-thick vdW layer.

Strongly Confined Excitons in GaN/AlN Nanostructures with Atomically Thin GaN Layers for Efficient Light Emission in Deep-Ultraviolet

Ioffe Institute, St. Petersburg 194021, Russia
University of Notre Dame, Notre Dame, Indiana 46556, USA
Université Montpellier, L2C, UMR 5221, 34095 Montpellier Cedex 5, France

NanoLetters
https://doi.org/10.1021/acs.nanolett.9b03517

Fascinating optical properties governed by extremely confined excitons have been so far observed in 2D crystals like monolayers of transition metal dichalcogenides. These materials, however, are limited for production by epitaxial methods. Besides, they are not suitable for the development of optoelectronics for the challenging deep-ultraviolet spectral range. Here, we present a single monolayer of GaN in AlN as a heterostructure fabricated by molecular beam epitaxy, which provides extreme 2D confinement of excitons, being ideally suited for light generation in the deep-ultraviolet. Optical studies in the samples, supplemented by a group-theory analysis and first-principle calculations, make evident a giant enhancement of the splitting between the dark and bright excitons due to short-range electron–hole exchange interaction that is a fingerprint of the strongly confined excitons. The practical significance of our results is in the observation of the internal quantum yield of the room-

temperature excitonic emission as high as ~75% at 235 nm.

Column diameter dependence of the strain relaxation effect in GaN/AlGaN quantum wells on GaN nanocolumn arrays

Department of Electric and Electronic Engineering, Yamagata University, Yonezawa, Yamagata 992-8510, Japan
Sophia University, Chiyoda, Tokyo 102-8554, Japan
Sophia Nanotechnology Research Center, Sophia University, Chiyoda, Tokyo 102-8554, Japan

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab51e1

We experimentally demonstrated the strain relaxation effect in uniform GaN/Al0.19Ga0.81N quantum wells on GaN nanocolumn (NC) arrays with various column diameters and periods created using the Ti-mask selective area growth technique. The photoluminescence (PL) emission from the GaN well layer was not affected by the period of the NC arrays. As the column diameter decreased, the PL peak energy of the GaN well layer blueshifted, whereas that of the GaN NC underlayer remained almost unchanged. This blueshift was reproduced with the calculated strain relaxation effect, indicating that the strain in the GaN well layer decreased as the column diameter decreased.

Self-Assembly of Well-Separated AlN Nanowires Directly on Sputtered Metallic TiN Films

Paul-Drude-Institut für Festköperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117 Berlin, Germany
L-NESS and Dipartimento di Scienza dei Materiali, Università di Milano -Bicocca,Via R. Cozzi 55, 20125Milano, Italy

physica status solidi rrl
https://doi.org/10.1002/pssr.201900615

Herein, the self-assembled formation of AlN nanowires (NWs) by molecular beam epitaxy on sputtered TiN films on sapphire is demonstrated. This choice of substrate allows growth at an exceptionally high temperature of 1180 °C. In contrast to previous reports, the NWs are well separated and do not suffer from pronounced coalescence. This achievement is explained by sufficient Al adatom diffusion on the substrate and the NW sidewalls. The high crystalline quality of the NWs is evidenced by the observation of near-band-edge emission in the cathodoluminescence spectrum. The key factor for the low NW coalescence is the TiN film, which spectroscopic ellipsometry and Raman spectroscopy indicate to be stoichiometric. Its metallic nature will be beneficial for optoelectronic devices using these NWs as the basis for (Al,Ga)N/AlN heterostructures emitting in the deep ultraviolet spectral range.

Fast Response Characteristics of Flexible Ultraviolet Photosensors with GaN Nanowires and Graphene

Department of Electronic and Information Materials Engineering, Division of Advanced Materials Engineering, and Research Center of Advanced Materials Development,
Department of Polymer-Nano Science and Technology, and Polymer Materials Fusion Research Centre, Chonbuk National University, Jeonju 54896, South Korea
Applied Quantum Composites Research Center, Korea Institute of Science and Technology, Wanju 55324, South Korea

ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.9b13109

We report the fast response characteristics of flexible ultraviolet (UV) photosensors with GaN nanowires (NWs) and a graphene channel. The GaN NWs used as light-absorbing media are horizontally and randomly embedded in a graphene sandwich structure in which the number of bottom graphene layers is varied from zero to three and the top is a fixed single layer of graphene. In the response curve of the photosensor with a double-layer bottom graphene, as obtained under pulsed illumination with a pulse width of 50 ms and a duty cycle of 50%, the rise and decay times were measured as 24.1 ± 0.1 and 28.2 ± 0.1 ms, respectively. The eye-crossing percentage was evaluated as 52.1%, indicating no substantial distortion of the duty cycle and no pulse symmetry problem. The rise and decay times estimated from equivalent circuit analysis represented by resistances and capacitances agree

well with the measured values. When the device was under bending condition, the rise and decay times of the photosensor were comparable to those in the unbent state.

Advanced Hybrid GaN/ZnO Nanoarchitectured Microtubes for Fluorescent Micromotors Driven by UV Light

Institute for Materials ScienceKiel UniversityKaiserstraße 2, 24143 Kiel, Germany
National Center for Materials Study and TestingTechnical University of MoldovaStefan cel Mare 168, Chisinau 2004, Moldova
NanochemistryMax Planck Institute for Solid State ResearchHeisenbergstraße 1, 70569 Stuttgart, Germany
Functional Nanomaterials, Institute for Materials Science, Kiel University, Kaiserstraße 2, 24143 Kiel, Germany
Department of Physics and Engineering, State University of Moldova, Alexei Mateevici Str. 60, Chisinau 2009, Moldova
Institute for Integrative Nanosciences (IIN), Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany
Material Systems for Nanoelectronics, Chemnitz University of Technology, Reichenhainer Straße 70, 09107 Chemnitz, Germany
Academy of Sciences of Moldova, Stefan cel Mare av. 1, Chisinau 2001, Moldova

small
https://doi.org/10.1002/smll.201905141

The development of functional microstructures with designed hierarchical and complex morphologies and large free active surfaces offers new potential for improvement of the pristine microstructures properties by the synergistic combination of microscopic as well as nanoscopic effects. In this contribution, dedicated methods of transmission electron microscopy (TEM) including tomography are used to characterize the complex hierarchically structured hybrid GaN/ZnO:Au microtubes containing a dense nanowire network on their interior. The presence of an epitaxially stabilized and chemically extremely stable ultrathin layer of ZnO on the inner wall of the produced GaN microtubes is evidenced. Gold nanoparticles initially trigger the catalytic growth of solid solution phase (Ga1–xZnx)(N1–xOx) nanowires into the interior space of the microtube, which are found to be terminated by AuGa-alloy nanodots coated in a shell of amorphous GaOx species after the hydride vapor phase epitaxy process. The structural characterization suggests that this hierarchical design of GaN/ZnO microtubes could offer the potential to exhibit improved photocatalytic properties, which are initially demonstrated under UV light irradiation. As a proof of concept, the produced microtubes are used as photocatalytic micromotors in the presence of hydrogen peroxide solution with luminescent properties, which are appealing for future environmental applications and active matter fundamental studies.

Red-Emitting InGaN-Based Nanocolumn Light-Emitting Diodes with Highly Directional Beam Profiles

Sophia University, 7-1, Kioi-cho, Chiyoda, Tokyo 102-8554, Japan

physica status solidi a
https://doi.org/10.1002/pssa.201900771

Various InGaN/GaN pn-junction nanocolumn arrays arranged in a triangle lattice are grown on the same substrate while changing the nanocolumn diameters (Dn-GaN) of the underlying n-side GaN region under the lattice constant (L) of 340 nm. The nanocolumn diameter increases during the growth of the active InGaN and p-side GaN regions. The periodic arrangement of nanocolumns leads to a photonic crystal effect. Redshift of the band edge wavelength, from 573 to 629 nm, is observed as Dn-GaN increases from 159 to 282 nm. This phenomenon can be explained by the fact that the larger filling factor increases the effective refractive index of the nanocolumn system, resulting in a redshift of the band edge. The light diffraction at the photonic band edge induces the directional radiation beam from the surface of the nanocolumn system. Using the nanocolumn array with Dn-GaN = 260 nm, the red-emitting (λ = 637 nm) nanocolumn light-emitting diodes with the radiation angle of ±30° are demonstrated.

GaN/AlN quantum-disk nanorod 280 nm deep ultraviolet light emitting diodes by molecular beam epitaxy

Semiconductor Lighting R&D center, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China
Deparment of Electrical and Computer Engineering, Cornell University, Ithaca, New York 14853, USA
Paul-Drude-Institut fürFestköperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

Optics Letters
https://doi.org/10.1364/OL.45.000121

We report optically and electrically pumped ~280nm deep ultraviolet (DUV) light emitting diodes (LEDs) with ultra-thin GaN/AlN quantum disks (QDs) inserted into AlGaN nanorods by selective epitaxial regrowth using molecular beam epitaxy. The GaN/AlN QD LED has shown strong DUV emission distribution on the ordered nanorods and high internal quantum efficiency of 81.2%, as a result of strain release and reduced density of threading dislocations revealed by transmission electron microscopy. Nanorod assembly suppresses the lateral guiding mode of light, and light extraction efficiency can be increased from 14.9% for planar DUV LEDs to 49.6% for nanorod DUV LEDs estimated by finite difference time domain simulations. Presented results offer the potential to solve the issue of external quantum efficiency limitation of DUV LED devices.

NON POLAR / SEMI POLAR

Information selected by Philippe de Mierry

Temperature-dependence of Cl2/Ar ICP-RIE of polar, semipolar, and nonpolar GaN and AlN following BCl3/Ar breakthrough plasma

Department of Condensed Matter Physics and Materials Science, Tata Institute of Fundamental Research, Mumbai 400005, India

Journal of Vacuum Science & Technology A
https://doi.org/10.1116/1.5123787

The authors report a comprehensive investigation of temperature-dependence of inductively coupled plasma reactive ion etching (ICP-RIE) of polar (0001), semipolar (11−22), and nonpolar (11−20) GaN and AlN, in the temperature range of 22–205 °C. The main objective is to study the effect of ICP etching near and beyond the boiling point of the volatile etch end-products: GaCl3 (201 °C) for GaN and AlCl3 (180 °C) for AlN. High-temperature ICP-RIE is beneficial in quicker removal of surface oxides and may permit the use of a single-step Cl2/Ar ICP-RIE for etching all orientations of GaN and AlN. However, the best results are still obtained with a combination of BCl3-plasma based surface oxide removal pretreatment and Cl2/Ar ICP-RIE etching, which provides a constant etch rate with a smooth surface morphology irrespective of the etching temperature.

Study of stress in ammonothermal non-polar and semi-polar GaN crystal grown on HVPE GaN seeds

School of Nano-Tech and Nano-Bionics, University of Science and Technology of China, Hefei, 230026, Anhui, China
Suzhou Institute of Nano-tech and Nano-bionics, Chinese Academy of Sciences, Suzhou, 215123, Jiangsu, China
Suzhou Nanowin Science and Technology Co, Ltd., Suzhou, 215123, Jiangsu, China

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.125423

GaN crystals were grown on non-polar and semi-polar HVPE GaN seeds by basic ammonothermal method. Stress distributions were investigated in cross-section of (11-20) plane, (10-10) plane, (20-21) plane and (10-11) plane GaN crystal. The cathodoluminescence (CL) images show cross-section information clearly and each examined object consisted of hydride vapor phase epitaxy (HVPE) seed and ammonothermal GaN (Am-GaN). The impurity concentration and free carrier concentration were estimated by secondary-ion mass spectroscopy (SIMS) and Hall. Moreover, Raman spectroscopy was used for studying stress distribution in the cross section. Shifts of E2(high) phonon lines were analyzed to determine stress. Our results indicate that the stress is about 35MPa in bulk GaN and the stress is less than 60MPa in the interface of Am-GaN.

Impact of growth conditions and strain on indium incorporation in non-polar m-plane (101—0) InGaN grown by plasma-assisted molecular beam epitaxy

Birck Nanotechnology Center, West Lafayette, Indiana 47907, USA
Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907, USA
School of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana 47907, USA
School of Materials Engineering, Purdue University, West Lafayette, Indiana 47907, USA

APL Materials
https://doi.org/10.1063/1.5121445

We establish the relationships between growth conditions, strain state, optical and structural properties of nonpolar m-plane (10-10) InGaN with indium composition up to 39% grown by plasma-assisted molecular beam epitaxy. We find that indium mole fraction as a function of growth temperature can be explained by an Arrhenius dependence of InN decomposition only for high temperature and low indium composition InGaN films. For the samples following the Arrhenius behavior, we estimate the effective activation energy for InN thermal decomposition in m-plane InGaN to be about 1 eV. This value is approximately a factor of two smaller than that reported for c-plane InGaN films. At low growth temperatures, InGaN layers show less efficient indium incorporation than predicted by Arrhenius behavior. We attribute the lower than expected indium composition at low temperatures to the strain-induced compositional pulling effect. We demonstrate that at 540 °C, the increase in the InGaN layer thickness leads to a preferential strain relaxation along the a-direction and an increase in the indium composition. For the indium mole fraction up to x ∼ 0.16, 30-nm-thick m-plane InGaN layers can be coherently grown on GaN with smooth morphology and pronounced low-temperature photoluminescence indicating that the material quality is suitable for device applications.

Semipolar (20-2-1) InGaN/GaN micro-photodetector for gigabit-per-second visible light communication

Photonics Laboratory, King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia
Materials Department, University of California, Santa Barbara, CA 93106, United States of America

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab58eb

This paper investigated the use of semipolar InGaN/GaN multiple quantum well based micro-photodetectors (μPDs) as the optical receiver for visible light communication (VLC). The fabricated semipolar μPDs exhibited a low dark current of 1.6 pA at −10 V, a responsivity of 0.191 A W−1, and a −3 dB modulation bandwidth of 347 MHz. A high data rate of up to 1.55 Gbit s−1 was achievable by utilizing the extended bandwidth of more than −10 dB, and based on a straight-forward non-return-to-zero on–off keying modulation scheme. This development demonstrated the feasibility of wavelength-selective detection scheme using semipolar μPD for high-data-capacity VLC systems.

High-Performance Semi-polar InGaN/GaN Green Micro Light-emitting Diodes

Nanjing University, 12581 Nanjing, Jiangsu China
College of Electronic and Optical Engineering & College of Microelectronics, Nanjing University of Posts and Telecommunications, 12577 Nanjing, Jiangsu China
Nanjing University, Research Institute of Superconductor Electronics (RISE), Nanjing, Jiangsu China

IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2019.2962184

Semi-polar micro-LEDs have gain increasing interests due to the advantages of polarization control and quantum efficiency improvement. In this work, a novel semi-polar (20-21)-plane micro-LEDs array has been designed and manufactured. In comparison with c-plane micro-LEDs, semi-polar micro-LEDs indicate better electrical and optical performance. The relative EQE of semi-polar micro-LEDs remains at 62% under the injected current density of 775.6 A/cm2, which indicates a reduced efficiency droop due to less polarization in MQWs.

It has been further proved by a significant reduction of 55% in emission peak blue-shift under the injected current density from 11.1 A/cm2 to 775.6 A/cm2. In addition, the carrier recombination dynamics and spatial light distribution of semi-polar micro-LEDs with different pixel sizes have been studied. Fast recombination lifetime in smaller size semi-polar micro-LEDs indicates a promising way to be used as a high modulation bandwidth light source. Stable and uniform light distribution in a wider range of spatial azimuths further supports for the semi-polar micro-LEDs as a strong candidate for the applications of high-resolution display and high-speed visible light communication.

Coaxial semipolar InGaN/GaN microwire array LED with substantially suppressed efficiency droop

Guangdong Engineering Research Center of Optoelectronic Functional Materials and Devices, South China Normal University, Guangzhou, 510631, People's Republic of China
Guangdong Institute of Semiconductor Industrial Technology, Guangdong Academy of Sciences, Guangzhou, 510650, People's Republic of China

Journal of Luminescence
https://doi.org/10.1016/j.jlumin.2019.117014

GaN nano/micro-structure based light-emitting diodes (LEDs) have drawn much attention owing to their potential applications in display and optoelectronics integration. Here, we have fabricated coaxial semipolar InGaN/GaN multiple quantum wells (MQWs) microwire array LED with superior performances in suppressing efficiency droop. The results show that our as-synthesized microwire has two semipolar planes (101) and (101), and the InGaN/GaN MQWs have superior crystal quality. In addition, the efficiency droop ratio of our device is about 9.7% as the injected current increases from 3 to 100 A/cm2, which is largely declined by 47% compared with that of the conventional polar c-plane LEDs. Meanwhile, the microwire array LED reveals a small wavelength shift (3 nm) as the injected current increases from 3 to 23 A/cm2. The effective advances in the device should be attributed to the weaker quantum-confined stark effect of InGaN/GaN MQWs in semipolar plane. This work proposes a high repeatability method to fabricate microwire array LED for future optoelectronic integrated systems.

Interfacial Impurities and Their Electronic Signatures in High-Voltage Regrown Nonpolar m-Plane GaN Vertical p–n Diodes

Center for High-Technology Materials, The University of New Mexico, Albuquerque, NM 87106, USA
Semiconductor Material and Device Sciences, Sandia National Laboratories, Albuquerque, NM 87123, USA
Advanced Materials Science, Sandia National Laboratories, Albuquerque, NM 87123, USA
Material, Physical, and Chemical Sciences, Sandia National Laboratories, Albuquerque, NM 87123, USA

physica status solidi a
https://doi.org/10.1002/pssa.201900757

Impacts of silicon, carbon, and oxygen interfacial impurities on the performance of high-voltage vertical GaN-based p–n diodes are investigated. The results indicate that moderate levels (≈5 × 1017 cm−3) of all interfacial impurities lead to reverse blocking voltages (Vb) greater than 200 V at 1 μA cm−2 and forward leakage of less than 1 nA cm−2 at 1.7 V. At higher interfacial impurity levels, the performance of the diodes becomes compromised. Herein, it is concluded that each impurity has a different effect on the device performance. For example, a high carbon spike at the junction correlates with high off-state leakage current in forward bias (≈100× higher forward leakage current compared with a reference diode), whereas the reverse bias behavior is not severely affected (> 200 V at 1 μA cm−2). High silicon and oxygen spikes at the junction strongly affect the reverse leakage currents (≈ 1–10 V at 1 μA cm−2). Regrown diodes with impurity (silicon, oxygen, and carbon) levels below 5 × 1017 cm−3 show comparable forward and reverse results with the reference continuously grown diodes. The effect of the regrowth interface position relative to the metallurgical junction on the diode performance is also discussed.

Strain relaxation process of undoped and Si-doped semipolar AlxGa1−xN grown on bulk GaN substrate

School of Materials Science and Engineering, Kyungpook National University, Daegu 41566, South Korea
U.S. Army Research Laboratory, Adelphi, MD 20783, USA
Materials Department, University of California, Santa Barbara, CA 93107, USA

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.125467

The strain relaxation process of undoped and Si-doped AlxGa1−xN with various compositions and thicknesses on semipolar (20-21) bulk GaN substrate was investigated via the cathodoluminescence (CL) and high-resolution x-ray diffraction (XRD) analyses. CL analyses showed that the strain relaxation occurred through three different mechanisms. At first, the relaxation was initiated by the basal-plane (BP) misfit dislocations (MDs) along [11-20] followed by the crack formation along [10-14]. As the Al composition and/or thickness of AlGaN layer further increased, the crack density saturated and non-basal plane (NBP) MDs almost parallel to [10-14] started emerging due to the prismatic slip. Observed crack spacing was 40–60 μm at which the energy of exposing new surfaces from the cracks is higher than Peierls potential associated with the prismatic slip. By introducing Si (2.0–6.0 × 1018 cm−3) into the film, the formation of both BP and NBP MDs could be suppressed within our growth conditions. However, Si doping was not effective in suppressing the crack formation but there was no significant change of its density either.

Stress relaxation in semipolar and nonpolar III-nitride heterostructures by formation of misfit dislocations of various origin

Faculty of Laser Photonics and Optoelectronics, ITMO University, St. Petersburg 197101, Russia
Materials Department, UCSB, Santa Barbara, California 93106, USA

Journal of Applied Physics
https://doi.org/10.1063/1.5126195

We present an analytical model describing misfit stresses relaxation in semipolar III-nitride heterostructures caused by misfit dislocations (MDs) originating from basal or prismatic slip and by sessile MDs. We analyze the critical thickness hc for the formation of MDs depending on crystal lattice mismatch and orientation of the semipolar growth plane. We explore transversely isotropic elasticity solutions to describe the relaxation processes in III-nitride semipolar heterostructures and compare the results for hc with those calculated within the isotropic elasticity approach. We find that the value of angle ϑ between the polar c-axis, and the direction of heterostructure growth has an impact on the realization of the stress relaxation mechanism by the generation of MDs originating either from basal or prismatic slip. A comparison of theoretical calculations with experimental data on the observation of MDs in the III-nitride heterostructures is provided.

High Quality, Mass-Producible Semipolar GaN and InGaN Light-Emitting Diodes Grown on Sapphire

Department of Electrical Engineering, Yale University, New Haven, Connecticut 06520, United States
State Key Laboratory of Transient Optics and Photonics, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China

physica status solidi b
https://doi.org/10.1002/pssb.201900565

The heteroepitaxy efforts of semipolar and nonpolar GaN grown on foreigner substrates are reviewed and summarized in the past 20 years. With the demonstration of three representative semipolar GaN grown on sapphire, the capability to produce semipolar GaN with any orientation on sapphire is exhibited. Also, a unique growth technology called facet-engineered orientation-controlling growth to eliminate the stacking faults (SFs) in semipolar GaN is developed and SF-free (20 2— 1) GaN grown on sapphire is presented, demonstrating the capability of producing device-quality, large-area semipolar GaN. InGaN green light-emitting diodes (LEDs) grown on the SF-free semipolar (20 2— 1) GaN/sapphire templates are performed with much higher external quantum efficiency in comparison with the typical semipolar/nonpolar LEDs heteroepitaxially grown on foreigner substrates reported before.

MATERIAL / CHARACTERIZATION / EQUIPMENT / NUMERICAL SIMULATION

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

Investigation of pits in Ge-doped GaN grown by HVPE

School of Nano Technology and Nano Bionics, University of Science and Technology of China, Hefei 230026, People's Republic of China
Suzhou Institute of Nano-tech and Nano-Bionics, Chinese Academy of Sciences, Suzhou 215123, People's Republic of China
Suzhou Nanowin Science and Technology Co., Ltd., Suzhou 215123, People's Republic of China

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab56f5

The pits in Ge-doped GaN grown by hydride vapor phase epitaxy were carefully studied. It was found that the pit density increases with Ge concentration and dislocation density. Cross-sectional cathodoluminescence (CL) image shows that the embedment of pit occurs immediately after the cut off of Ge precursor. Planar-view CL image shows that the center of every pit is a dislocation, which is further confirmed by transmission electron microscopy measurements. Ge droplets were found in the center of pits of heavily doped samples. These results are beneficial for the study on the origin of pits in Ge-doped GaN.

Al0.75Ga0.25N/AlxGa1-N/Al0.75Ga0.25N/AlN/SiC Metal-Oxide-Semiconductor Heterostructure Field-Effect Transistors with Symmetrically-Graded Widegap Channel

Feng Chia University
Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, Tainan 70101, Taiwan

IEEE Journal of the Electron Devices Society
https://doi.org/10.1109/JEDS.2019.2956497

Novel Al0.75Ga0.25N/AlxGa1-xN/Al0.75Ga0.25N/AlN metal-oxide-semiconductor heterostructure field-effect transistors (MOS-HFETs) with symmetrically-graded widegap AlxGa1-xN channel (x = 0.75 0.25 0.75) grown on a SiC substrate are investigated. Al2O3 was devised as the gate dielectric by using a non-vacuum ultrasonic spray pyrolysis deposition (USPD) technique. Device characteristics with respect to different etch depths of the source/drain recesses were studied. For a 2-µm gate length (LG), the present widegap V-shape-channel MOS-HFET has shown improved maximum drain-source current density (IDS, max) of 299.3 A/mm at VDS = 20 V, IDS density at VGS = 0 V (IDSS0) of 153.9 mA/mm, on/off-current ratio (Ion/Ioff) of 1.4 × 107, extrinsic transconductance (gm, max) of 16.7 mS/mm, two-terminal off-state gate-drain breakdown voltage (BVGD) of -379 V, and three-terminal on-state drain-source breakdown voltage (BVDS) of 339 V. Besides, superior deep-UV sensing performance with high spectral responsivity (SR) of 1780 (810.2) A/W at wavelength λ = 250 (300) nm are also achieved.

Growth behavior of GaN on AlN for fully coalesced channel of AlN-based HEMT

Nano-Optical Engineering, Korea Polytechnic University (KPU), Siheung, Gyeonggi 427-793, Republic of Korea
School of Electronic and Electrical Engineering, Hongik University, Seoul 04066, Republic of Korea
Department of Electrical and Computer Engineering, and Inter-university Semiconductor Research Center, Seoul National University, Seoul 08826, Republic of Korea

Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab4df3

We investigated the growth behavior of GaN grown on AlN along with V/III ratio and pressure variation, and found out the lateral growth regime for the fully coalesced channel layer of the AlN-based double-hetero structure high electron mobility transistor (HEMT). When the V/III ratio increases and pressure decreases, compressive stress in the GaN channel increases, and pit formation occurs to release the stress. The AlN-based HEMT structure was grown and the device was fabricated with an optimized channel layer. The two-dimensional electron gas mobility, sheet density, and sheet resistance were 1480 cm2 V−1 s−1, 1.32 × 1013 cm−2, and 319 Ω/sq., respectively, at room temperature. The device was characterized; direct current output result showed that the maximum

current was ~620 mA mm−1, on-resistance was 6.4 Ω mm, transconductance was ~140 mS mm−1, and current on/off ratio was ~104, respectively.

Role of adsorbed water in inducing electron accumulation in InN

Howard P. Isermann Department of Chemical and Biological Engineering, Rensselaer Polytechnic Institute, Troy, New York 12180, USA
Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute, Troy, New York 12180, USA

Journal of Applied Physics
https://doi.org/10.1063/1.5125720

Nominally undoped indium nitride (InN) is known to have an electron accumulation layer on its surface, and prior studies have shown this layer to be sensitive to chemical species. However, the exact roles of these species and the underlying mechanism of e− accumulation layer formation are not clear. In this work, it is shown that ambient adsorbed water on the InN surface strongly enhances the e− accumulation layer formed due to intrinsic surface states. Desorption of ambient physisorbates leads to a decrease in band bending, an increase in work function in undoped InN, and the observation of a p-type Mott-Schottky behavior in Mg:doped InN. The underlying mechanism of this surface-adsorbed water interaction may be through a process called “surface transfer doping,” which has previously been reported in hydrogenated diamond and other semiconductors such as GaN and ZnO.

Carbon pair defects in aluminum nitride

Leibniz-Institut für Kristallzüchtung, Max-Born-Straße 2, Berlin 12489, Germany
Institut für Energieforschung und Physikalische Technologien, Technische Universität Clausthal, Am Stollen 19B, Goslar 38640, Germany

Journal of Applied Physics
https://doi.org/10.1063/1.5123049

AlN bulk single crystals grown by the physical vapor transport method may be beneficially applied as substrates for deep ultraviolet light emitting devices or as a basic material for piezoelectric resonators operating at high temperatures. Identification of point defects which deteriorate the optical, electrical, and electromechanical properties of AlN crystals for such applications is the subject of the present work. Using Raman spectroscopy, two local vibrational modes (LVMs) were discovered at wave numbers of 1189 cm−1 and 1148 cm−1. By analyzing an AlN crystal intentionally enriched with the carbon isotope 13C, it is unambiguously shown that the two LVMs originate from two different, but in each case carbon-related defects. Furthermore, it is evidenced that the defect underlying the LVM at 1189 cm−1 contains exactly two carbon atoms. The tricarbon defect-related LVM reported earlier in an infrared absorption study is found to be Raman active at 1772 cm−1. The Raman scattering intensity of all three LVMs strongly depends on the photon energy of the exciting light what is interpreted as a resonance Raman effect. This allows linking the identified defects with their contribution to the strong, carbon-related ultraviolet absorption around 4.7 eV and proves that these defects introduce optically and electrically active deep levels in the bandgap of AlN.

Atomic-scale quantitative analysis of implanted Mg in annealed GaN layers on free-standing GaN substrates

Center for GaN Characterization and Analysis, National Institute for Materials Science, Tsukuba 305-0047, Japan
Research Center for Magnetic and Spintronic Materials, National Institute for Materials Science, Tsukuba 305-0047, Japan
Advanced Technology Laboratory, Fuji Electric Co., Ltd., Hino, Tokyo 191-8502, Japan

Journal of Applied Physics
https://doi.org/10.1063/1.5132345

Achieving efficient p-type conduction in Mg-implanted GaN depends largely on postimplantation annealing conditions. Here, we study the effect of postimplantation annealing on the evolution of defects and their interactions with implanted Mg ions by using scanning transmission electron microscopy and atom probe tomography. We found that Mg clusters start to form by annealing the implanted sample above 1000 °C. In addition to the Mg clusters, stacking faults form at

an annealing temperature of 1300 °C. The Mg concentrations of about 2–3 orders of magnitude higher than implanted Mg were segregated at the stacking faults. Nanobeam electron diffraction analysis revealed no distinct phase other than GaN formed at the Mg-enriched defects, suggesting that Mg is substituted for Ga in the GaN lattice at the edge of the stacking faults.

Remote epitaxy using graphene enables growth of stress-free GaN

Univ. Grenoble Alpes, F-38000 Grenoble, France
CEA, LETI, MINATEC campus, F-38000 Grenoble, France
CEA, INAC-MEM, LEMMA, F-38000 Grenoble, France
CNRS-CRHEA, Rue Bernard Gregory, F-06560 Valbonne, France
CEA, LITEN, MINATEC campus, F-38000 Grenoble, France
Nanoelectronics Research Institute, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Higashi, Tsukuba 305-8562, Japan
Department of Physical Electronics, Herzen State Pedagogical University of Russia, 48 Moïka Embankment, 191186 St. Petersburg, Russia

Nanotechnology
https://doi.org/10.1088/1361-6528/ab4501

The properties of group III-Nitrides (III-N) such as a large direct bandgap, high melting point, and high breakdown voltage make them very attractive for optoelectronic applications. However, conventional epitaxy on SiC and sapphire substrates results in strained and defective films with consequently poor device performance. In this work, by studying the nucleation of GaN on graphene/SiC by MOVPE, we unambiguously demonstrate the possibility of remote van der Waals epitaxy. By choosing the appropriate growth conditions, GaN crystals can grow either in-plane misoriented or fully epitaxial to the substrate. The adhesion forces across the GaN and graphene interface are very weak and the micron-scale nuclei can be easily moved around. The combined use of x-ray diffraction and transmission electron microscopy demonstrate the growth of stress-free and dislocation-free crystals. The high quality of the crystals was further confirmed by photoluminescence measurements. First principles calculations additionally highlighted the importance of the polarity of the underlying substrate. This work lays the first brick towards the synthesis of high quality III-N thin films grown via van der Waals epitaxy.

Improvement of the interfaces in AlGaN/AlN superlattice grown by NH3 flow-rate modulation epitaxy

Jiangsu Provincial Key Laboratory of Advanced Photonic and Electronic Materials, School of Electronic Science and Engineering, Nanjing University, Nanjing 210093, People's Republic of China
Science and Technology on Monolithic Integrated Circuits and Modules Laboratory, Nanjing Electronic Devices Institute, Nanjing 210016, People's Republic of China

Applied Physics Express
https://doi.org/10.7567/1882-0786/ab5fad

AlGaN/AlN superlattices (SLs) are key building blocks for vertical emitting devices, especially in the deep UV spectral range. Abrupt interfaces of 30-pair AlGaN/AlN (6.6 nm/3.3 nm) SLs with an average Al composition of 55.3% have been grown by NH3 flow-rate modulation epitaxy (FME). The interface and surface morphology can be largely improved using this growth technique due to enhancement of the surface migration of Al atoms. Moreover, basal stacking faults at the interfaces are observed by high resolution transmission electron microscopy. A stress relieving model has been proposed to explain the forming of BSFs.

On the thermal stability of nearly lattice-matched AlInN films grown on GaN via MOVPE

Center for Photonics and Nanoelectronics, Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, PA 18015, USA

Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2019.125469

The thermal stability of nearly lattice-matched AlInN films grown via metalorganic vapor phase epitaxy on GaN/sapphire is investigated. The structural and morphological changes of the AlInN layers, as determined by x-ray diffraction (XRD) and atomic force microscopy (AFM), are studied when systematically varying annealing times, temperatures, and ambients to gain a better understanding of the temperature limits of the

AlInN films. The samples are annealed either in the growth chamber with the same conditions (gases, pressure, and flow rates) as the original growth conditions of the AlInN samples, or in the XRD under N2. In general, the surface of the AlInN changes at temperatures >850 °C under growth and N2 conditions mostly likely due to a loss of In as determined by AFM. However, the bulk crystal structure of the AlInN remains stable up to temperatures of 950–1050 °C (depending on ambient) as determined by XRD. These findings provide a helpful guide for future experiments involving high-temperatures (790–1050 °C) for subsequent or transition layers during epitaxial growth, and for fabricating device structures employing AlInN layers.

Direct detection of rare earth ion distributions in gallium nitride and its influence on growth morphology

Department of Physics, West Chester University, West Chester, Pennsylvania 19383, USA
Division of Materials and Manufacturing Science, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
Department of Electrical and Computer Engineering, Texas Tech University, Lubbock, Texas 79409, USA
Center for Nanomaterials Science, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, USA
Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan
Department of Physics, Lehigh University, Bethlehem, Pennsylvania 18015, USA

Journal of Applied Physics
https://doi.org/10.1063/1.5134050

The dopant distribution and surface and structural properties of Er- and Eu-doped GaN samples were investigated using atom probe tomography (APT) and atomic force microscopy (AFM). Erbium accumulation within host GaN threading dislocations was directly detected by APT allowing for the dislocations to be imaged in three dimensions. In addition, photoluminescence spectroscopy with high lateral resolution, by means of scanning near-field optical microscopy, was performed on Eu-doped GaN samples. By combining these results with AFM mappings of the same area, it was concluded that Eu3+ ions also accumulate at threading dislocations. Moreover, high-resolution surface profiles of both samples show that even dilute doping (<0.2%) of Eu and Er has a significant influence on the growth morphology of the GaN host material and the nature of the threading dislocations within it. Transmission electron microscopy techniques were used to show the influence of rare-earth incorporation on the growth of GaN lattice and the propagation of threading dislocations.

Demonstration of a GaN/AlGaN superlattice based p-channel FinFET with high on-current

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

IEEE Electron Device Letters
https://doi.org/10.1109/LED.2019.2963428

In this letter, we report on the demonstration of a Mg-doped GaN/Al0.2Ga0.8N superlattice (SL) based depletion mode p-channel FinFET to improve the on current (Ion). A two-step approach involving a dry etch followed by a Tetramethylammonium hydroxide (TMAH) wet etch was employed to obtain fins with minimum width of 50 nm using optical lithography. Normalizing current with fin height, an Ion of 52 mA/mm and 110 mA/mm were achieved for 80 and 105 nm wide fins respectively.

Fine structure of another blue luminescence band in undoped GaN

Department of Physics, Virginia Commonwealth University, Richmond, Virginia 23220, USA

Applied Physics Letters
https://doi.org/10.1063/1.5126803

A blue luminescence band, labeled BL3, has been found in undoped GaN samples grown by hydride vapor phase epitaxy. It has a maximum at 2.8 eV and a phonon-related fine structure at its high-energy side. The zero-phonon line of this band consists of a duplet with two sharp lines at 3.0071 and 3.0147 eV. Three phonon modes, including the LO mode with an energy of 91.3 meV and two pseudolocal phonon modes with energies of 39.6 and 68.2 meV, form the characteristic fine structure

of the BL3 band. The BL3 band is attributed to internal transitions from excited states located near the conduction band to the 0/+ transition level of unknown defect. The defect is preliminarily identified as the RY3 center, which is also responsible for bright red-yellow luminescence bands in the studied samples.

Demonstration of Observation of Dislocations in GaN by Novel Birefringence Method

Institute of Materials and Systems for Sustainability, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan

physica status solidi b
https://doi.org/10.1002/pssb.201900553

Herein, a newly developed birefringence microscope is used to observe dislocations in gallium nitride (GaN) substrates. The comparison results of the observation method using this microscope with other observation methods, such as X-ray topography and Raman microscopy, confirms that dislocations in a GaN substrate can be detected with a birefringence microscope. In addition, the observation can be carried out as easily as with an optical microscope. It is also found that under certain observation conditions, the direction of the edge component of dislocations can be determined.

Terahertz intersubband absorption of GaN/AlGaN step quantum wells grown by MOVPE on Si(111) and Si(110) substrates

Centre de Nanosciences et de Nanotechnologies (C2N), CNRS UMR 9001, Université Paris-Sud, Université Paris-Saclay, 91120 Palaiseau, France
III-V Lab, 91767 Palaiseau, France
Université Côte d'Azur, CNRS, CRHEA, 06560 Valbonne, France

Applied Physics Letters
https://doi.org/10.1063/1.5129362

We demonstrate terahertz intersubband absorptions in nitride step quantum wells (SQWs) grown by metal organic vapor phase epitaxy simultaneously on two different substrate orientations [Si(111) and Si(110)]. The structure of the SQWs consists of a 3 nm thick Al0.1Ga0.9N barrier, a 3 nm thick GaN well, and an Al0.05Ga0.95N step barrier with various thicknesses. This structure design has been optimized to approach a flatband potential in the wells to allow for an intersubband absorption in the terahertz frequency range and to maximize the optical dipole moment. Structural characterizations prove the high quality of the samples. Intersubband absorptions at frequencies of 5.6 THz ($\lambda \approx 54$ µm), 7 THz (43 µm), and 8.9 THz (34 µm) are observed at 77 K on both substrate orientations. The observed absorption frequencies are in excellent agreement with calculations accounting for the depolarization shift induced by the electron concentration in the wells.

Impact of kinetics on the growth of GaN on graphene by plasma-assisted molecular beam epitaxy

Univ. Grenoble-Alpes, CEA-IRIG, PHELIQS, 17 av. des Martyrs, F-38000, Grenoble, France
Univ. Grenoble-Alpes, CNRS-Institut Néel, 25 av. des Martyrs, F-38000, Grenoble, France
Institute of Materials Science (ICMUV), Universidad de Valencia, PO Box 22085, Valencia, Spain
Univ. Grenoble-Alpes, CEA-IRIG, MEM, 17 av. des Martyrs, F-38000, Grenoble, France

Nanotechnology
https://doi.org/10.1088/1361-6528/ab5c15

The growth of GaN on graphene by molecular beam epitaxy was investigated. The most stable epitaxial relationship, i.e. [00.1]-oriented grains, is obtained at high temperature and N-rich conditions, which match those for nanowire growth. Alternatively, at moderate temperature and Ga-rich conditions, several metastable orientations are observed at the nucleation stage, which evolve preferentially towards [00.1]-oriented grains. The dependence of the nucleation regime on growth conditions was assigned to Ga adatom kinetics. This statement is consistent with the calculated graphene/GaN in-plane lattice coincidence and supported by a combination of transmission electron microscopy, x-ray diffraction, photoluminescence, and Raman spectroscopy experiments.

Compliant Micron-Sized Patterned InGaN Pseudo-Substrates Utilizing Porous GaN

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

Materials
https://doi.org/10.3390/ma13010213

The compliant behavior of densely packed 10 × 10 µm2 square patterned InGaN layers on top of porous GaN is demonstrated. The elastic relaxation of the InGaN layers is enabled by the low stiffness of the porous GaN under layer. High resolution X-ray diffraction measurements show that upon InGaN re-growths on these InGaN-on-porous GaN pseudo-substrates, not only was the regrown layer partially relaxed, but the degree of relaxation of the InGaN pseudo-substrate layer on top of the porous GaN also showed an increase in the a-lattice constant. Furthermore, methods to improve the surface morphology of the InGaN layers grown by metal-organic chemical vapor deposition (MOCVD) were explored in order to fabricate InGaN pseudo-substrates for future optoelectronic and electronic devices. The largest a-lattice constant demonstrated in this study using this improved method was 3.209 Å, corresponding to a fully relaxed InGaN film with an indium composition of 0.056.

Equilibrium Morphologies of Faceted GaN under Metalorganic Vapor Phase Epitaxy Condition: Wulff Construction using Absolute Surface Energies

Department of Physics Engineering, Mie University, Kuriya-Machiya,Tsu 514-8507, Japan

physica status solidi b
https://doi.org/10.1002/pssb.201900523

An equilibrium Wulff construction using absolute surface energies for various orientations is carried out to elucidate the morphology change of GaN under metalorganic vapor phase epitaxy (MOVPE) condition. The calculated equilibrium shapes suggest that the morphology mainly consists of { 11—01 } and { 11—00 } facets under Ga-rich condition for selective area growth (SAG) on [11—00] lateral direction. In contrast, equilibrium crystal shape including larger area of { 11—01 } facets and (0001) plateau with smaller { 11—00 } facets emerges under N-rich condition. Furthermore, by incorporating growth consition such as growth temperature and carrier gas, we find that (0001) plateau hardly emerge under H2 carrier gas condition at low temperature. The results under H2 carrier gas is found to be different from those under N2 carrier gas where (0001) plateau slightly emerges at low temperature. The calculated results manifest that our approach could provide the determination of equilibrium shape of semiconductor materials during epitaxial growth.

Comparison of MoS2/p-GaN Heterostructures Fabricated via Direct Chemical Vapor Deposition and Transfer Method

Nano-Optical Engineering, Korea Polytechnic University(KPU)237, Sangidaehak-ro, Siheung-si, Gyeonggi-do 15073,Republic of Korea

physica status solidi a
https://doi.org/10.1002/pssa.201900722

Herein, the fabrication of MoS2/p-GaN heterostructures via direct chemical vapor deposition (CVD) and transfer methods are demonstrated. The molybdenum disulfide (MoS2) layers are grown on p-GaN and sapphire substrates via CVD under the same growth conditions. Subsequently, in the case of sapphire substrate, MoS2 from the sapphire substrate is transferred onto the p-GaN substrates to produce a vertically stacked heterostructure. Atomic force microscopy (AFM) images indicate that the MoS2 that is directly grown on the GaN substrate exhibits granular structure, whereas the transferred MoS2 exhibits triangle-shaped grains. In the current–voltage measurement of the heterostructures, similar I–V curves are obtained for the direct CVD and transfer methods. However, the results indicate higher current in the transfer-produced heterostructure than in the CVD-produced heterostructure. The difference in resistance in both heterostructures is attributed to the density of the grain boundary of

MoS2. The results suggest that the type of substrate is crucial and the quality of the MoS2 layers depends on them.

Hydride Vapor-Phase Epitaxy Reactor for Bulk GaN Growth

Division of Solid State Electronics, Ioffe Institute, Politehnicheskaya 26, St. Petersburg 194021, Russia

physica status solidi a
https://doi.org/10.1002/pssa.201900629

An hydride vapor-phase epitaxy reactor for the growth of bulk GaN crystals with a diameter of 50 mm is developed. Growth rate nonuniformity of 1% is achieved using an axisymmetric vertical gas injector with stagnation point flow. Chemically resistant refractory materials are used instead of quartz in the reactor hot zone. High-capacity external gallium precursor sources are developed for the nonstop growth of the bulk GaN layers. A load-lock vacuum chamber and a dry in situ growth chamber cleaning are implemented to improve the growth process reproducibility. Freestanding GaN crystals with a diameter of 50 mm are grown with the reactor.

Growth of uniform MoS2 layers on free-standing GaN semiconductor for vertical heterojunction device application

Department of Physical Science and Engineering, Nagoya Institute of Technology, Nagoya, Japan
Frontier Research Institute for Material Science, Nagoya Institute of Technology, Nagoya, Japan

Journal of Materials Science: Materials in Electronics
https://doi.org/10.1007/s10854-019-02723-w

The feasibility of van der Waals (VdW) heteroepitaxy of molybdenum disulphide (MoS2) layers on gallium nitride (GaN) semiconductor has attracted significant interest in heterojunction optoelectronic device applications. Here, we report on the growth of uniform MoS2 layers on free-standing GaN semiconductor for vertical heterojunction device application. A uniform MoS2 layer was directly grown on the n-type GaN wafer by sulphurization process of molybdenum oxide thin layer. Raman and scanning electron microscopy (SEM) analyses showed homogenous growth of the few-layers MoS2 forming a continuous film, considering the suitability of GaN semiconductor substrate. The fabricated MoS2/GaN vertical heterojunction showed excellent rectifying diode characteristics with a photovoltaic photoresponsivity under monochromatic light illumination. The X-ray photoelectron spectroscopy (XPS) studies showed the conduction and valence band offset values are around 0.44 and 2.3 eV with type II band alignment in the fabricated heterojunction device. This will facilitate effective movement of photoexcited electrons across the MoS2–GaN junction, while a large valence band offset will prevent movement of holes towards the GaN, resulting in low recombination loss to obtain a photovoltage in the heterojunction device. Our study revealed the formation of large-area homogenous MoS2 layers on GaN wafer for vertical heterojunction device application.

Enhancement of 2D Electron Gas Mobility in an AlN/GaN/AlN Double-Heterojunction High-Electron-Mobility Transistor by Epilayer Stress Engineering

Centre for Micro-/Nano-electronics (NOVITAS), School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798
Temasek Laboratories @NTU, Nanyang Technological University, Singapore 637553

physica status solidi a
https://doi.org/10.1002/pssa.201900818

Herein, 2D electron gas (2DEG) enhancement in an AlN/GaN/AlN double-heterojunction high-electron-mobility transistor (DH-HEMT) is achieved by epilayer stress engineering. The epistructures are grown on a SiC substrate using plasma-assisted molecular beam epitaxy (PA-MBE). The stress in the AlN buffer is systematically studied as a function of the III/V ratio. An optimized AlN buffer layer with the relaxation of 66% and a smooth surface morphology with a root mean square (RMS) roughness of 0.5 nm is grown using the two-step growth method with recovery via metal consumption. It is observed that the stress in the GaN channel is influenced by the stress in the AlN buffer nonlinearly. Furthermore, the carrier mobility increases as the stress in the GaN channel is increased. However, the 2DEG density remains

unchanged. An optimized AlN/GaN/AlN DH-HEMT epistructure with very high 2DEG sheet carrier density of 4.1 × 1013 cm−2 and carrier mobility of 613 cm2 V−1 s−1 is achieved, which leads to higher device output power density.

MBE Growth of Large-Area GaN/AlN 2-dimensional Hole Gas Heterostructures

Department of Electrical Engineering, Cornell University, Ithaca NY 14853
School of Applied Physics and Engineering, Cornell University, Ithaca NY 14853
Department of Material Science and Engineering, Cornell University, Ithaca NY 14853
Kavli Institute of Nanoscience, Cornell University Ithaca NY 14853

physica status solidi b
https://doi.org/10.1002/pssb.201900567

We demonstrate large area growths of polarization-induced 2D hole gases (2DHG) in a GaN/AlN heterostructure using molecular beam epitaxy (MBE). A study of the effect of metal fluxes and substrate temperature during growth is performed to optimize the 2DHG transport. These conditions are adopted for the growth on 2-inch wafer substrates. The work represents a step towards enabling the GaN/AlN 2DHG platform for high performance wide-bandgap p-channel field effect transistors (FETs).

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

Cardiff-based consortium gains £5.2m funding for SMARTExpertise RF-GaN project

SemiconductorToday

A consortium led by Cardiff University's Centre for High Frequency Engineering and the Compound Semiconductor Applications Catapult has won £2.4m in Welsh Government SMARTExpertise funding to develop high-frequency electronic devices for next generation technologies – from 5G and radar to satellite systems. Eleven industrial partners have pledged a further £2.8m of support.

The industry-led project will involve partners in the South Wales compound semiconductor cluster CSConnected, working in chip design, fabrication, waveform-based characterization, testing and production. It will help researchers to develop radio-frequency gallium nitride (RF-GaN) technologies to make high-speed, cost-effective, higher-reliability and smaller chips that outperform traditional silicon.

"Gallium nitride is quickly becoming the technology of choice for many emerging applications, including 5G communications, high-resolution phased-array radars, electronic warfare equipment, automotive collision avoidance radar, healthcare and imaging applications," says professor Khaled Elgaid, who leads the academic team. "The popularity of GaN stems from the attractive properties the technology exhibits, including high operating voltage and high operational frequency (supporting emerging 5G markets providing high-efficiency telecommunications system, with higher data rate and wider coverage area)," he adds. "In addition, the high power density and excellent thermal performance offers compact designs and operational robustness in hostile environments, including space applications."

The funding announcement coincided with a 'topping out' ceremony for Cardiff University's Translational Research Facility (designed by HOK London Studio) that will house researchers and industry involved in compound semiconductor and catalytic science. Wales' Education Minister Kirsty Williams, Bouygues UK chief executive Rob Bradley and Cardiff University's vice-chancellor professor Colin Riordan topped out the facility by adding their signatures to a beam on the building's highest point.

"The program is part-funded by the European Regional Development Fund (ERDF) through the Welsh Government and offers financial support to innovative collaboration projects between industry and Welsh research organizations. These collaborative projects address strategic industrial challenges and provide opportunities to commercialize new products, processes or services and growth in key areas," notes Williams.

"The SMARTExpertise RF-GaN award perfectly complements the topping out of our state-of-the-art Translational Research Facility," says Riordan. "The building and the project are devoted to working with industry to unlock the power of research."

Cardiff University is a founding member of CSConnected – a cluster of compound semiconductor expertise across South Wales that brings together academic, industry and supply-chain partners.

The university has developed the Institute for Compound Semiconductors (ICS) – to be based within the TRF - and founded the Compound Semiconductor Centre (CSC), a joint venture with epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK to help translate compound semiconductor academic expertise into job creation with industry.

Cardiff University's School of Engineering will work alongside the Compound Semiconductor Applications Catapult (CSA Catapult) and ICS to deliver the project.

"The CS Cluster has the opportunity to deliver a substantive project that will fill gaps identified in GaN RF devices across the UK supply chain," says Dr Tudor Williams, head of RF & Microwave at CSA Catapult. "The SMARTExpertise project has a strong consortium with end users in defence and consumer markets driving a tailored technology development," he adds. "SMART Expertise will be a catalyst for future projects and activities, leading to tangible economic benefits for both Wales and the UK."

GaN Systems showcasing smaller, lighter and more efficient power electronics at CES

SemiconductorToday

At the 2020 Consumer Electronics Show (CES) in the Tech East, Renaissance Hospitality Suites next to the Las Vegas Convention Center (7–10 January), GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) is exhibiting the latest technology developments addressing energy-efficiency challenges by using GaN as a building block for power electronics systems (in consumer electronics, industrial and automotive applications) that are 4x smaller, 4x lighter and generate 4x less energy loss.

Customer product demonstrations at CES 2020 include:

- power supplies and AC adapters from 65W to 3kW with very high-power density;
- highest-efficiency Class D audio amplifiers with high sound quality;
- wireless power for 5G fixed-wireless access, scooters, drones, robots and consumer electronics;
- automotive onboard charger and traction inverter with what is claimed to be industry-leading power density;
- the world's most powerful light detection & ranging (LiDAR) laser/driver.

II-VI signs multi-year agreement of over $100m to supply SiC substrates

SemiconductorToday

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has signed a multi-year agreement of over $100m (the firm's largest ever) to supply silicon carbide (SiC) substrates for gallium nitride (GaN) RF power amplifiers deployed in 5G wireless base stations.

The accelerating rollout of 5G wireless services is driving deeper strategic relationships in the 5G wireless supply-chain ecosystem to meet the market windows, notes II-VI. The new agreement builds on the firm's experience as a global supplier of SiC substrates for the 4G and 5G markets.

"GaN-on-SiC RF power amplifiers have superior performance compared with devices based on GaN-on-silicon over a wide spectrum of 5G operating frequencies, from the low gigahertz range to millimeter-wave bands," claims Dr Gary Ruland, VP, Wide Bandgap Semiconductors business unit. "Customers forge strategic partnerships with II-VI because of our long track record of pushing the technology forward with larger substrate diameters and industry-leading crystal quality," he adds. "II-VI's recently announced semi-insulating 200mm

silicon carbide substrates, the first in the world, will enable our customers to scale production far into the future."

Leveraging an intellectual property portfolio of 30 active patents, II-VI is developing SiC substrates using proprietary technologies including crystal growth, substrate fabrication, and polishing. The firm is also expanding its ability to drive the 5G RF roadmap by establishing a vertically integrated, 150mm GaN-on-SiC HEMT device manufacturing platform. In addition to SiC substrates, II-VI provides an array of wavelength management solutions and transceivers for the wireless optical access infrastructure. Altogether, II-VI says that it offers a broad range of materials, devices, components and subsystems to enable the coming large-scale 5G rollout.

Record power density aluminium gallium nitride barrier transistors

SemiconductorToday

Researchers in France claim record power performance at 40GHz from aluminium gallium nitride (AlGaN)-barrier high-electron-mobility transistors (HEMTs) on freestanding gallium nitride substrates [Mohamed-Reda Irekti et al, Semicond. Sci. Technol., vol34, p12LT01, 2019]. The output power density reached 2W/mm with 20.5% power-added efficiency.

Although higher power densities have been achieved at lower frequency, the device from University of Lille, Laboratoire d'Analyse et d'Architecture des Systèmes, and Université Côte d'Azur, beat a previous high at 40GHz of 1W/mm.

The researchers used 2inch-diameter freestanding GaN substrates commercially produced by Saint-Gobain Lumilog via hydride vapor phase epitaxy (HVPE). The substrate had a resistivity of less than 30mΩ-cm.

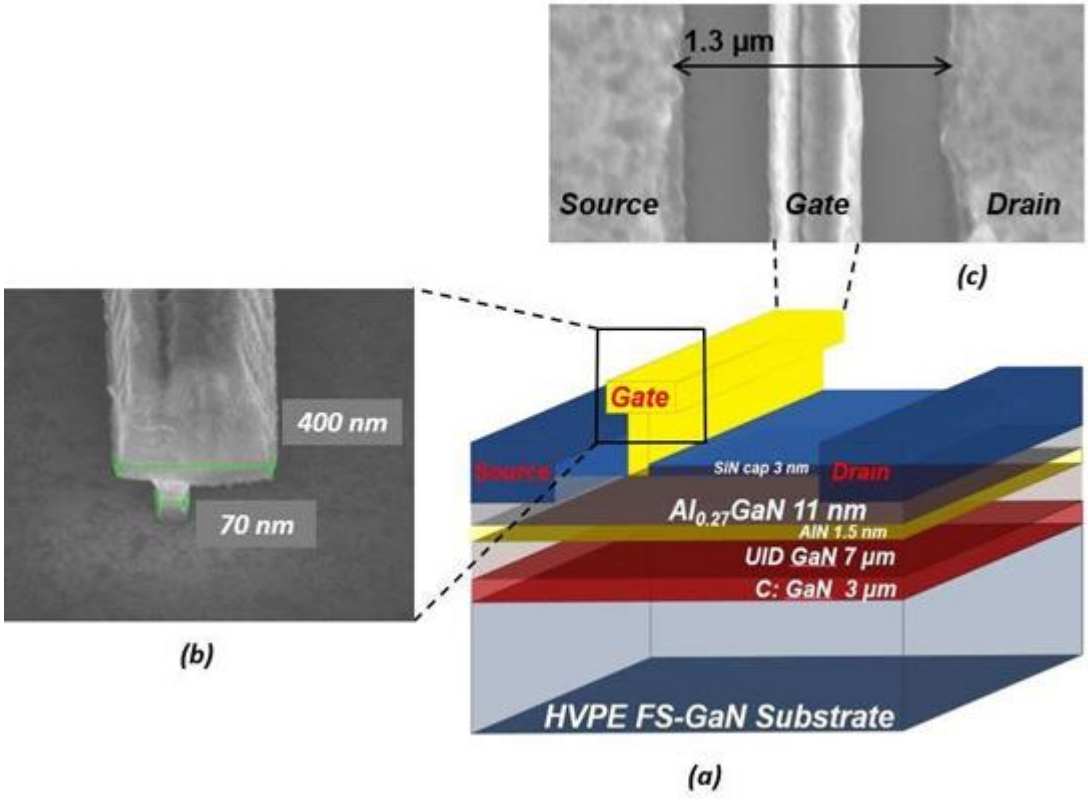


Figure 1: (a) Schematic of as-fabricated AlGaN/GaN HEMT on freestanding GaN substrate before passivation. Scanning electron micrographs: (b) after gate lift-off and (c) top view after gate fabrication

Metal-organic chemical vapor deposition (MOCVD) by the researchers added epitaxlial layers of 10µm resistive GaN buffer, 1.5nm AlN, 11nm Al0.26Ga0.74N barrier and 3nm in-situ silicon nitride cap (Figure 1). The resistive buffer was grown in two steps: 3µm carbon-doped GaN (C:GaN) and 7µm unintentionally doped GaN.

The exclusion layer aimed to reduce alloy scattering and enhance confinement of the electron carriers in the two-dimensional electron gas (2DEG) that formed the channel in the undoped GaN buffer near the interface. Hall-effect measurements gave 8.5x1012/cm2 electron density and 2200cm2/V-s. The corresponding sheet resistance was 356Ω/square.

The use of freestanding GaN substrates avoids the need for nucleation layers, which simultaneously create thermal barriers. Nucleation layers are needed when growing III-nitrides such as GaN on silicon carbide or silicon. These layers are highly dislocated to allow growth of lattice and thermal expansion mismatched materials.

The source-drain regions of the HEMTs were fabricated by argon-ion-beam etching more than half way through the AlGaN barrier layer and electron-beam evaporating and annealing titanium/aluminium/nickel/gold metal contact stacks. The etching brought the contact metals closer to the 2DEG channel, reducing access resistance.

The devices were electrically isolated using nitrogen-ion implantation. T-shaped nickel/gold gates were formed with a 70nm foot on AlGaN barrier. A 20-minute 400°C anneal was carried out in nitrogen to improve the Schottky contact, reducing trap states.

The devices were passivated with 340°C plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride. Metal connections with the device contacts were made with titanium/gold evaporation and patterning.

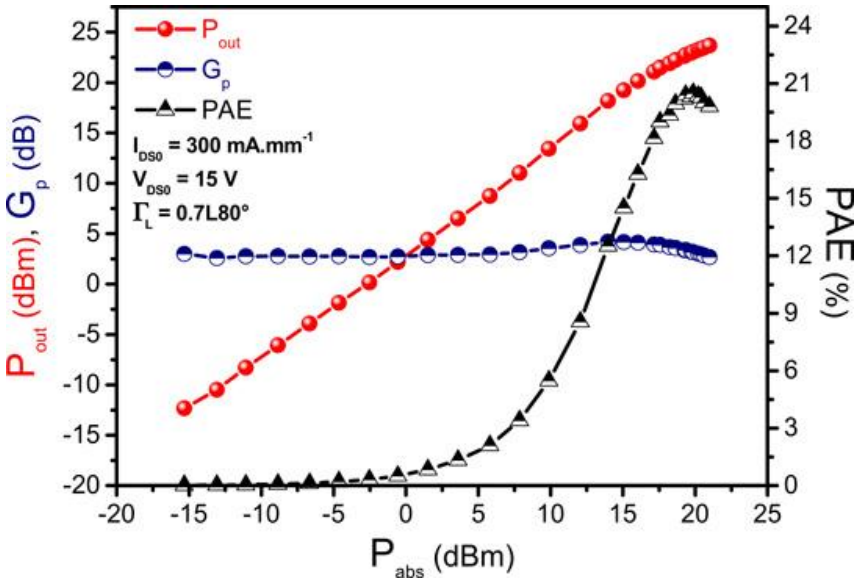


Figure 2: Output power, power gain and power-added efficiency versus absorbed power at 40GHz.

The tested devices consisted of two 50µm-wide gate fingers in a 1.3µm source-drain gap. The source-gate distance was 500nm.

With the gate at 1V relative to the source, the maximum drain current was 950mA/mm, and the on-resistance was 3Ω-mm. The transconductance under 6V drain bias peaked at 300mS/mm, when the gate was at -2.5V. The

threshold was -3.5V. The gate leakage was as low at 3x10-7A/mm, giving an on/off drain current ratio of more than 106.

Radio-frequency testing between 250MHz and 67GHz gave de-embedded/intrinsic gain cut-off frequency (fT) and maximum oscillation (fmax) values of 100GHz and 125GHz, respectively. The researchers believe that these parameters can be increased with optimization of the C:GaN layer, improving the trade-off between crystal quality and buffer isolation.

Power performance was assessed at 40GHz with active load-pull measurements under continuous-wave operation (Figure 2). The drain bias was 10V with the current at 300mA/mm, giving AB-class operation. The output power density was 1.2W/mm with 26.2% power-added efficiency. Increasing the drain bias to 15V, but keeping the current flow the same, increased the power density to a 2W/mm record, while decreasing the efficiency to 20.5%. The linear gain was 5dB with 10V drain, and 4.2dB at 15V.

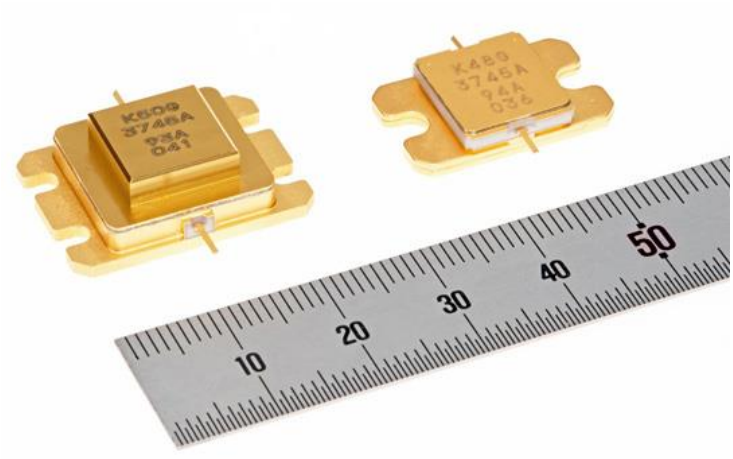
The researchers comment: "Up to now, this result constitutes the state-of-the-art large signal at 40GHz for AlGaN/GaN HEMTs on freestanding GaN substrate."

Mitsubishi Electric expanding lineup of Ku-band GaN HEMTs for SATCOM earth stations with 70W and 100W models

SemiconductorToday

Tokyo-based Mitsubishi Electric Corp is expanding its lineup of gallium nitride high-electron-mobility transistors (GaN HEMTs) for satellite communications (SATCOM) earth stations with the addition of new Ku-band (12-18GHz) 70W and 100W GaN HEMTs (operating at frequencies of 13.75–14.5GHz) suitable for multi-carrier applications.

Demand for Ku-band satellite communications and satellite news-gathering (SNG) is growing rapidly to support communications during natural disasters and in rural areas where the installation of cable network equipment is difficult. In addition, increasingly large-capacity, high-speed communications have expanded needs for both multi-carrier and single-carrier satellite communications.



Picture: GaN HEMTs for Ku-band SATCOM earth stations: the 100W MGFK50G3745A (left) and 70W MGFK48G3745A (right).

The new 70W (48.3dBm) MGFK48G3745A model GaN HEMT uses a new matching circuit to deliver what is claimed to be the industry's widest offset frequency of up to 400MHz (80 times higher than that of existing models) and a low third-order intermodulation distortion (IMD3), for large-capacity, high-speed satellite communications (including for multiple carriers).

The new 100W (50.0dBm) MGFK50G3745A model GaN HEMT uses optimized transistor matching circuits to deliver a combination of what is said to be unmatched peak output power of 100W together with low IMD3 and an offset frequency of up to 200MHz, helping to downsize SATCOM earth stations by reducing on-board components.

Mitsubishi Electric will begin shipping samples of both new models on 15 January. The firm expects its new GaN HEMTs to accelerate the realization of smaller earth stations as well as faster and larger-capacity communications for various needs.

FiDUS launches ultra-compact 200W desktop power supply features GaN switching

SemiconductorToday

FiDUS Power of Aldermaston, UK has launched the model GDA200 external power supplies, in which the use of gallium nitride (GaN) rather than silicon switches provides increased efficiency, reduced heat losses and operation at higher frequencies (allowing the size of magnetics and other components to be reduced). The result is a compact 200W external desktop power supply with power density of 12.5W/in3.

The GDA200 is targeted at designers of portable equipment and instrumentation in markets including; high-end audio, test & measurement, bench-top and audio broadcast equipment.

The ultra-compact size is also advantageous for incorporating external power supplies into designs to speed up the approvals process, the firm claims. The small size of just 150mm x 54mm x 33mm (5.9" x 2.12" x 1.3") can also reduce total system package size, resulting in higher shipping and storage densities, especially when the closest competing product is some 2.5 times larger, it is reckoned.

"The ultra-high power density and exceptionally small size of our new GDA200 external power supply gives designers of portable products a great deal more value for money and design flexibility," says engineering manager Mark Gibbons. "This is the first of a new family of ultra-compact external desk-top products to be announced by FiDUS Power, with the 300, 160 or 150 and finally GDA 120W series to follow early next year."

The GDA200 is available in class I or II (C14 and C8 inlet), with the C14 inlet model 11mm longer than the C8 model to accommodate the IEC input. It offers designers future proofing with the latest energy efficiency legislation; Department of Energy Level VI & Energy Related Products Tier 2, and latest general safety approval EN62368-1. The units offer global approvals for use in Japan (PSE), China (CCC) and Taiwan (BSMI) as well as the Americas (UL) and Europe (CE). They are suitable for use in ITE applications conforming to conducted and radiated emissions EN55032 level B.

Offering 192-200W of output power with output voltages available between 12VDC and 56VDC, the GDA200 range has a FiDUS 5-year warranty.

Northrop Grumman awarded $189m extension to US Marines contract for full-rate production of GaN-based G/ATOR radar systems

SemiconductorToday

Northrop Grumman Mission Systems of Linthicum, Maryland, has been awarded a $188,995,364 modification for the firm-fixed-price portion of a previous $958m contract (M67854-19-C-0043) awarded by the Marine Corps Systems Command of Quantico, Virginia.

The modification is for the purchase of six gallium nitride (GaN) full-rate-production Ground/Air Task-Oriented Radar (G/ATOR) systems and associated travel in support of Program Executive Officer Land Systems, Quantico, Virginia. Work will be performed in Linthicum and is expected to be complete by 4 April 2023.

University of Delaware reports record-setting InAlN/GaN HEMTs on silicon

SemiconductorToday

Assistant professor Yuping Zeng and a team of researchers in the University of Delaware's Department of Electrical and Computer Engineering recently fabricated a 80nm gate-length gallium nitride (GaN) high-electron-mobility transistor (HEMT) on a silicon substrate using indium aluminium nitride (In0.17Al0.83N) as the barrier layer that demonstrates record performance (Peng Cui et al, 'High-performance InAlN/GaN HEMTs on silicon substrate with high fTxLg, 2019 Appl. Phys. Express 12 104001).

Among devices of its type, the transistor is claimed to have record low gate leakage current (of 7.12x10−7A.mm−1), record high on/off current ratio (of 1.58x106) and (due to its DC performance) record high current-gain cutoff frequency (fT of 200GHz). The product fTxLg =16GHz.µm is also reckoned to be a new record for GaN HEMTs on silicon.

The researchers say that the transistor could be useful for higher-bandwidth wireless communication systems. For a given current, it can handle more voltage and would require less battery life than other devices of its type. "We want to expand the bandwidth of wireless communications, and this will give us more information for a certain limited time," says Zeng. "It can also be used for space applications because the gallium nitride transistor we used is radiation robust, and it is also wide-bandgap material, so it can tolerate a lot of power," he adds.

The transistors are made on a low-cost silicon substrate. "This process can also be compatible with silicon complementary metal–oxide–semiconductor (CMOS) technology," notes Zeng.

"We are trying to continue to break our own record, both for the low-power application as well as for the high-speed application," says Zeng. The team also plans to use the transistors to make power amplifiers that could be particularly useful for not only wireless communications but also Internet of Things (IoT) applications.

Several University of Delaware units helped Zeng's group set the new record. The group fabricated their device in the UD Nanofabrication Facility. Postdoctoral scholar Peng Cui, the first author on the Applied Physics Express paper, has received funding through the Horn Entrepreneurshiip Postdoctoral Innovation Fellow program and the Air Force Office of Scientific Research.

Fujitsu grows diamond film to boost heat dissipation efficiency of GaN HEMT

SemiconductorToday

At the 2019 MRS Fall Meeting in Boston, MA, USA (1-6 December), Fujitsu Ltd and Fujitsu Laboratories Ltd reported what is reckoned to be the first technology for growing a diamond film with highly efficient heat dissipation on the surface of gallium nitride (GaN) high-electron-mobility transistors (HEMTs).

Development background

In recent years, GaN HEMTs have been widely used as transistors for high-frequency amplifiers in weather radar and wireless communications equipment. In the future, achieving breakthroughs in areas like the highly accurate observation of localized torrential downpours and the creation of a stable millimeter-wave high-speed communication environment for 5G communications will require considerably increased deployed of radars and base stations worldwide.

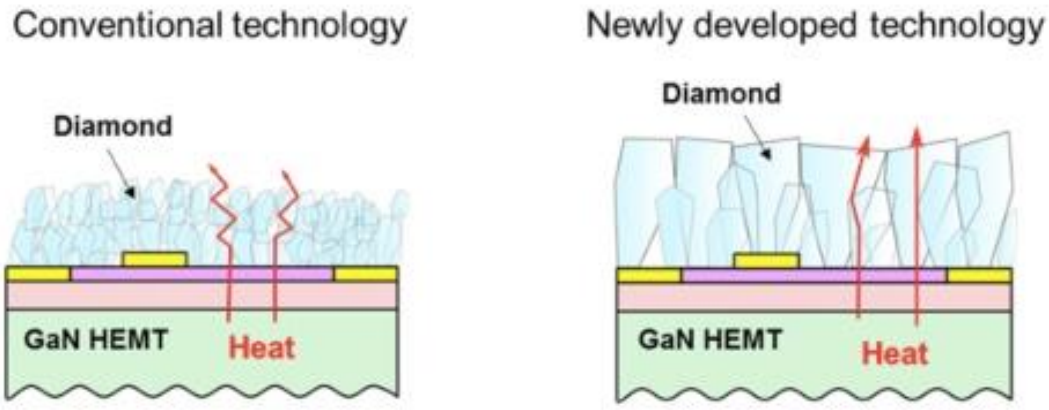
However, the limitations inherent to existing designs continue to prevent an increase in the number of installations. The transistors used in radar systems have higher output power due to the need to operate over-greater distances, which increases the amount of heat they generate. Cooling equipment is required because of the performance degradation caused by overheating. This remains expensive, and the large size of the entire

system, including the cooling apparatus, limits the installation location, making simplification and miniaturization of the cooling equipment an important challenge for designers.

Challenges

One way to reduce the size and complexity of the cooling system is to increase heat dissipation efficiency by covering not only the back surface of the GaN HEMT but also the front surface with a diamond film. This diamond film, which possesses excellent heat dissipation properties, would effectively lower the internal temperature of the GaN HEMT. To achieve this, however, a diamond crystal with large grain size is required to pass heat efficiently so that heat does not accumulate inside the diamond.

To grow such a diamond film, a high temperature of about 900°C is usually required, which unfortunately destroys the GaN HEMT underlying the diamond growth. When a diamond film is grown at low temperature (~650°C, at which the GaN HEMT is not destroyed), the resulting reduction in thermal energy given to the methane gas used to create the diamond means that growth of the diamond is incomplete. Using the low-temperature method, it is only possible to grow microscopic diamond particles (or nanodiamonds) of several hundred nanometers or less. Furthermore, each particle becomes an aggregate of crystals facing different directions, which inhibits efficient heat transfer between particles (Figure 1).



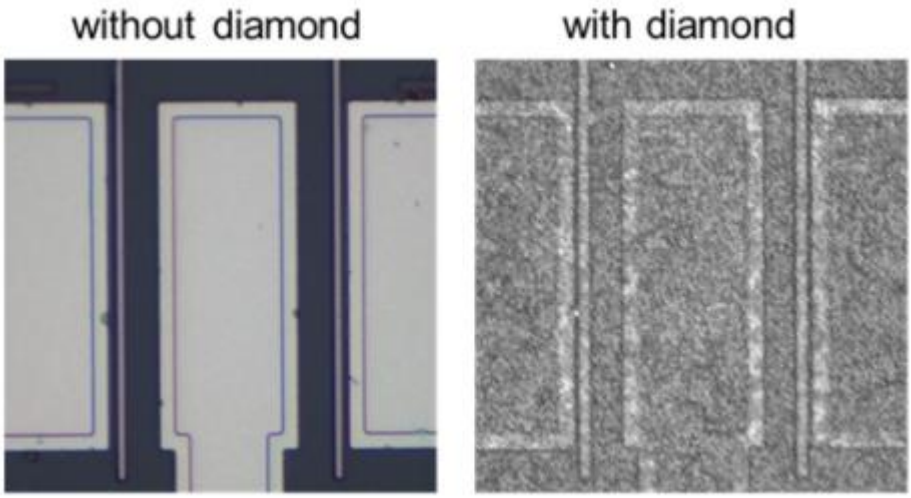
Newly developed technology

To address this challenge, Fujitsu has developed a technology for growing a highly heat-spreading diamond film at low temperatures (about 650°C) where transistors are not destroyed and, in what's claimed to be a world first, succeeded in demonstrating the operation of a GaN HEMT with a highly heat-spreading diamond film on its surface.

To grow the diamond film with this method, nanodiamond particles with a diameter of several nanometers are placed on the entire surface of the device. The nanodiamond particles are then exposed to methane gas with high thermal energy to convert the carbon contained in the methane gas into diamond, which can then be incorporated into the particles. Carbon, with its high energy, is selectively incorporated into diamonds that point in a particular direction, allowing diamonds that point in the same direction to bond together and grow.

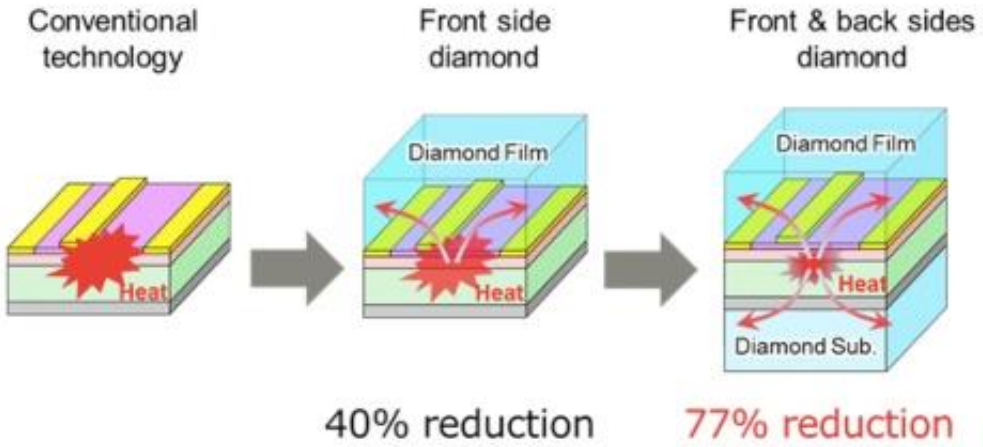
Focusing on the fact that the thermal energy given to methane varies depending on the pressure and the concentration of methane gas during diamond growth, Fujitsu discovered that nanodiamond particles oriented in a specific direction can be selectively enlarged at low temperatures. This makes it possible to convert a

nanodiamond into a micron-sized diamond 1000 times larger (Figure 2). As a result, heat can easily pass through the diamond and the GaN HEMT can dissipate heat efficiently.



Outcome

By using the newly developed technology, the amount of heat generated during GaN HEMT operation is reduced by about 40% compared to without diamond film, and the temperature can be lowered by 100°C or more. Furthermore, by combining heat dissipation from the backside of the GaN HEMTs with single-crystal diamond developed by Fujitsu and silicon carbide (SiC) bonding technology at room temperature, the front and back sides of the GaN HEMTs can be covered with a diamond film, which should reduce heat generation by about 77% (Figure 3).



This can enable the use of small cooling devices for high-performance radar systems that previously required large cooling devices, saving space and making it significantly easier to install the larger number of units needed for applications including improved weather forecasting and 5G communications, reckons Fujitsu.

The research was partially supported by the Innovative Science and Technology Initiative for Security, established by the Acquisition, Technology & Logistics Agency (ATLA) of the Japanese Ministry of Defense.

Going forward, Fujitsu aims to commercialize its new high-heat-dissipation GaN HEMT amplifiers in fiscal 2022 for use in weather radar systems and next-generation wireless communication systems.

Transphorm's GaN used in AES' power supplies for large passenger airplanes

SemiconductorToday

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V gallium nitride (GaN) field-effect transistors (FETs) — says that its customer AES Aircraft Elektro/Elektronik System GmbH of Bremen, Germany has released its first 650V GaN-based power supplies.

Serving the aviation industry, AES provides products and services ranging from electrical engineering to certification and testing. Its latest switch-mode power supplies are used by large CS-25 airplane manufacturers (e.g. Airbus A318-A321, A330, A340, A380 and Boeing B767, B787 VIP aircraft) and use Transphorm's GaN FETs to increase overall system efficiency by more than 10% compared with competing silicon-based power supply units (PSUs).

The two GaN-based switch-mode power supplies are the PS250X 500W system and the PS6120 1200W system (both currently shipping). Both support a 96–130VAC/360–800Hz input voltage with a 28VDC continuous power output at 15A for the 500W system and 42A for the 1200W system.

Further, AES certified the PS250X and PS6120 as DO-160 compliant — meeting the more than 25-point stringent standard of the Radio Technical Commission for Aeronautics (RTCA). This standard assesses system impact and performance under various external and internal conditions on aircraft — ranging from pressure and temperature to voltage spikes and RF emissions.

The flagship 500W PS250X is said to be the first passively cooled power supply at 420W and deploys Transphorm's GaN in a single-phase CCM boost power factor correction (PFC) topology. It offers more than 92% overall system efficiency at full load, which is claimed to be more than 10% greater than its competition. The system also yields a more than 0.98 power factor and 200mVpp nominal at 115VAC/400Hz input at full load, all within an end product that weighs just 1.4kg (~3lbs).

The 1200W PS6120 deploys Transphorm's GaN in a fan-cooled, three-phase CCM boost PFC topology. It offers more than 91.5% overall system efficiency at full load, which is 11.5% greater than its competition. The PS6120 also yields the same power factor and nominal ripple voltage at 115VAC/400Hz input at full load as the PS250X 500W PSU, all within an end product that weighs 4.0kg (~8.8lbs).

"The aviation industry is working toward reducing climate impact through any means possible," says Dr Andreas Hammer, head of Competence Center Power, AES. "We sought out Transphorm's GaN to replace previously used silicon MOSFETs so that we could provide a more efficient, lighter-weight power supply," he adds. "These supplies have the potential to make a notable impact when considering each aircraft deploys several such PSUs. After only a year of redesign, we were able to offer our customers a better power solution, while also raising the performance bar within our own industry."

Interested in the technology's inherent higher switching frequency, AES reviewed GaN power switch converters from several GaN device manufacturers. It ultimately selected Transphorm's 650V GaN technology due primarily to its ease of drivability and designability — specifically because Transphorm's GaN FETs do not require custom drivers. As a result, system design is simplified while engineers can drive the switches using technology they are already familiar with (i.e. drivers and packages). Other factors affecting AES' selection included Transphorm's proven reliability (underscored by its GaN platform earning both a JEDEC qualification and AEC-Q101 qualification at 175°C).

"Our two-switch normally-off GaN devices come in standard packages and require minimal supporting circuitry to drive them, which reduces the overall system size, increases reliability, and simplifies design," says Philip Zuk,

VP of worldwide technical marketing & NA sales. “It’s crucial to us that our customers can come to market quickly with a product they have confidence in,” he adds.

GaN Systems gets investment from SPARX Group

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) says that it has received investment from SPARX Group ‘Mirai Creation Fund II’.

Mirai fund provides capital to companies with the goal of accelerating innovation. One of the main targets is vehicle electrification. Mirai fund’s LP investors include Toyota Motor Corporation.

At the 2019 Tokyo Motor Show in October, the All GaN Vehicle was revealed. Developed by Nagoya University Institute for Future Materials and Systems and Toyota Advanced Power Electronics Research Division, it features multiple applications of gallium nitride in an electric car: in the traction inverter (where GaN improves efficiency by 20%, extending the driving range of the car on one battery charge), in the DC-DC converter (which allows a 75% reduction in size of the system), in the on-board charger, and in the LED lighting (where GaN lights the road during night driving). The All GaN Vehicle has recently been driven in and around Tokyo.

GaN Systems says that it continues to establish a strong position in the automotive industry with additional customers and strategic investors realizing the value proposition of GaN and using the transistors in EV powertrain applications, namely the traction inverter, on-board charger, and DC-DC converter.

“The combination of confidence in our best-in-class device performance, the release of the industry’s highest-current-rated devices, and our device reliability exceeding the AEC-Q101 automotive industry standards, has contributed to more and more automotive OEMs and tier-1 companies investing in our company and using our devices,” says CEO Jim Witham.

“After evaluating a variety of power semiconductor technologies and designs, GaN has emerged as a critical building block for power in automotive applications, and our investment in GaN Systems complements our vision to shape the future and impact our world,” comments SPARX Group’s president & CEO Shuhei Abe.

Fujitsu honored with IEEE Milestone for high-electron-mobility transistor

SemiconductorToday

The high-electron-mobility transistor (HEMT), developed by Fujitsu Laboratories, has been certified by the Institute of Electrical and Electronics Engineers as an IEEE Milestone. The firm was awarded the IEEE Milestone plaque at a ceremony in Tokyo, Japan.

The IEEE Milestone has recognized historic achievements in fields such as electricity, electronics, information and telecommunications that have contributed to the development of local communities and industries over the past 25 years.

The technology was developed by Fujitsu in 1979 and was recognized for its innovative achievements in improving the performance of radio telescopes and satellite broadcasting receivers.

The HEMT operates at high speed by creating a two-layer structure that spatially separates the source and travel regions of electrons within the transistor. This enables the transistor to receive weak, high-frequency signals with high sensitivity. In 1985, Fujitsu commercialized the HEMT as a microwave device with the world’s lowest

noise level and it was adopted for the radio telescope at the Nobeyama Radio Observatory (NRO) in Nagano, Japan. A year later, in 1986, the telescope discovered an unknown interstellar molecule.

Also, after being installed in satellite broadcasting receivers around the world, the transistors have become an essential part of various microwave and millimeter-wave devices, such as mobile devices, base stations, GPS receivers and millimeter-wave radar that prevents collisions between automobiles.

Teledyne e2v and GaN Systems unveil high-reliability 650V GaN power HEMT

SemiconductorToday

Teledyne e2v HiRel of Milpitas, CA, USA (part of the Teledyne Defense Electronics Group that provides solutions, sub-systems and components to the space, transportation, defense and industrial markets) is launching a ruggedized 650V/60A gallium nitride power high-electron-mobility transistor (HEMT) based on technology from GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications).

The new TDG650E60 GaN power HEMT is claimed to be the highest-voltage GaN power device on the market for hi-rel military and space applications, and is now available with both top- or bottom-side-cooled options.

Gallium nitride devices have revolutionized power conversion in other industries and are now available in radiation-tolerant, plastic-encapsulated packaging that has undergone stringent reliability and electrical testing to ensure mission critical success. The launch of the TDG650E60 GaN HEMT finally delivers the efficiency, size and power-density benefits required in critical aerospace and defense power applications, says Teledyne e2v HiRel.

For all product lines, the firm performs demanding qualification and testing tailored to the highest-reliability applications. This regime includes sulfuric test, high-altitude simulation, dynamic burn-in, step stress up to 175°C ambient, 9V gate voltage, and full temperature testing.

Teledyne says that its TDG650E60 GaN power HEMT has an extremely small form factor and leverages patented Island Technology from GaN Systems. This technology is a scalable, vertical charge dissipating system that gives the power transistor ultra-low thermal losses, high power density, no-charge storage, and very high switching speeds.

Unlike silicon carbide (SiC) devices, the GaN-based TDG650E60 can easily be implemented in parallel to increase the load current or lower the effective on-resistance (RDSon). The use of exclusive GaNpx packaging allows very high-frequency switching and excellent thermal characteristics, enabling a significant reduction in the size and weight of power electronics, it is said.

“Teledyne e2v has a proud heritage of space products, and we are now bringing the unprecedented efficiency of GaN power to our customers,” says Mont Taylor, VP of business development for Teledyne e2v HiRel. “These devices enable design engineers to create highly efficient, small power supplies and motor controllers which can comfortably function in high-radiation environments such as space.”

Qualified TDG650E60 devices with either top-side or bottom-side cooling are now shipping and available for immediate purchase.

EPC displaying GaN-enabled consumer applications at CES

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 – will be demonstrating the power of eGaN technology to enhance consumer applications, including self-driving cars, robots, drones, wireless power, world-class audio and cutting-edge automotive solutions, in its Demonstration & Hospitality Suite in the Venetian hotel at the 2020 Consumer Electronics Show (CES) in Las Vegas (7–10 January).

Wireless Power

- In the home: EPC will have multiple wirelessly powered surfaces on display to demonstrate the myriad of consumer uses in the home for systems with enough power to simultaneously power a computer, power a lamp, power an alarm clock, communicate via a digital assistant, charge a cell phone and charge a wearable – all without running a single power cord to any of the devices.

- Powering 5G: The extreme interconnectivity of 5G communications will enable the Internet of Things (IoT) to grow more rapidly and push hundreds of thousands of IoT connections and millions of sensors out into the world. For these devices to scale with 5G, they will need dependable, safe, automatic power: wireless power. Demonstrations of wireless power for 5G applications through glass windows and walls will be on display.

- Robotics: Greeting visitors in the EPC suite will be Misty, a wirelessly powered robotic digital assistant that can monitor its own charge levels, estimate the time needed to navigate back to the docking station, and manage recharging efficiently.

LiDAR

Also shown in the suite will be multiple eGaN FET-based light detection and ranging (LiDAR) systems. LiDAR technology has emerged as the leading technology to act as the 'eyes' for self-driving cars, and is increasingly finding new applications in other time-of-flight systems for warehouse automation, augmented reality, drones, and even vacuum cleaners. GaN enables these systems to see further, faster and better.

Class-D Audio

The EPC suite will be displaying the latest in class-D audio amplifier technology using GaN to enable the highest-fidelity sound. Systems for the very high-end prosumer and down to the consumer-level digital-assistant-enabled speakers will be playing in the suite.

GaN Systems and ON Semiconductor make available 300W AC adapter reference design

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) and power semiconductor IC supplier ON Semiconductor of Phoenix, AZ, USA have announced the availability of what is claimed to be the highest-power-density 300W AC adapter reference design using GaN Systems' 650V, 15A GaN enhancement-mode high-electron-mobility transistors (E-HEMTs) and multiple ON Semiconductor controller and driver ICs: NCP51820, NCP13992, NCP1616 and NCP4306.

The complete system reference design is said to be highly versatile and low cost, allowing designers to easily develop and bring to market ultra-high-power-density adapters for various applications in HDTV power supplies, gaming notebook and console adapters as well as ultra-small power supplies for industrial and medical devices.

The kit and application note provide detailed technical information including schematic, PCB layout and BOM (bill of material) files, and EMI and efficiency data. The kit hardware has complete PFC, LLC and secondary stages, and features a high-efficiency synchronous PFC that meets the CoC T2 benchmark, a highly versatile low-cost 2-Layer design, and universal input with 19V output at 340W peak. System designers using this GaN-based reference design can reach power densities up to 32W per cubic inch, it is reckoned.

"Fast-switching GaN works effectively with our advanced controller and drivers to optimize system designs for high power density, removing design barriers and enabling designers to take advantage of the numerous benefits provided by GaN E-HEMTs," says ON Semiconductor's director of marketing Ryan Zahn,. "With rising interest and adoption of GaN, we look forward to continued collaboration with GaN Systems to support and meet the new power requirements taking place across many industries," he adds.

"Our collaboration combines ON Semiconductors' system applications expertise and industry-leading power IC products with the world's most advanced 650V GaN E-HEMTs," Charles Bailley, senior director, worldwide business development, at GaN Systems. "This reference design, developed in collaboration with ON Semiconductor, makes it easier and more cost effective to design as GaN gains popularity as a building block in the adapter market," he adds. "This release is the first of several systems and integrated packaging innovations in development, which will significantly expand the GaN ecosystem."

Navitas wins Innovation Star award from Zhangjiang Hi-Tech, as well as investment-intent agreement

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA has been presented with the Shanghai Zhangjiang 895 and Zhangjiang Science City • ICV Pioneer Alliance 'Innovation Star' Award on 19 December.

Founded in 2014, Navitas introduced what it claimed to be the first commercial gallium nitride (GaN) power ICs. The firm says that its proprietary 'AllGaN' process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with GaN power, analog and logic circuits, enabling faster charging, higher power density and greater energy savings for mobile, consumer, enterprise, eMobility and new energy markets. Specifically, Navitas adds that its highly integrated, speed-optimized, next-generation GaNFast power IC technology can replace slow silicon switches to enable a new generation of fast-charging mobile adapters for smartphones, tablets and laptops from 27W to 300W+.

As a key element of the Shanghai Science and Technology Innovation Center, Shanghai Zhangjiang Hi-Tech Park Development Co Ltd takes technology investment banking as its strategic development direction, and aims to create new industrial real-estate operators, future-oriented high-tech industry integrators and technology and financial integration service providers.

Hosted by Zhangjiang Hi-Tech, the roadshow in December focuses on the development of the IC industry. In the 8th season of the competition, Navitas was selected from more than 100 projects to be one of 25 approved entrants. After three months of professional selection, the firm qualified for the final eight 'Starting from the Core Demo Day'. Over 80 technical and investment experts then reviewed and critiqued Navitas' GaNFast power IC approach.

"Navitas Semiconductor has demonstrated its core strength with its innovative GaNFast power IC technology, advanced company organization and deep market understanding, and has won recognition from us and from large professional investment institutions, earning the 'Innovation Star' award by outstanding performance and strength," commented Zhangjiang Hi-Tech's general manager Dajun He.

Zhangjiang Hi-Tech signed an investment-intent agreement with Navitas Semiconductor at the event, committing to free office space and free talent housing, and the group targets additional cooperation with Navitas in the future.

"Thanks to Zhangjiang Hi-Tech for organizing this 895 IC special session for industry investment and financial matchmaking, resource provision, and IC enterprise special courses after the start of business," says Navitas Semiconductor China's general manager Yingjie Zha. "As a third-generation semiconductor material, GaN has graduated from the laboratory to industry adoption and commercial acceptance, and Navitas Semiconductor is honored to receive the Demo Day Innovation Star."

Hydrogen-terminated diamond transistors on gallium nitride/silicon

SemiconductorToday

École polytechnique fédérale de Lausanne and Lake Diamond SA in Switzerland claim the first p-channel hydrogen-terminated diamond transistors (HTDTs) on gallium nitride (GaN) on silicon templates that demonstrate high-power device performance comparable with other HTDTs on polycrystalline and even monocrystalline diamond [Reza Soleimanzadeh et al, IEEE Electron Device Letters, published online 13 November 2019].

The researchers suggest that integration of p-channel HTDTs with n-channel GaN transistors opens "a pathway for future complementary power switch and logic applications". The diamond layer is also thermally conductive, allowing improved thermal management of GaN devices in high-power-density applications. The team sees potential for complementary logic operation, gate drivers and complementary power switches in integrated power inverters and converters.

The researchers used an aluminium gallium nitride barrier (AlGaN) GaN-on-silicon template, as used for the fabrication of n-channel high-electron-mobility transistors (HEMTs). The template was prepared for diamond deposition by applying layers of 30nm silicon nitride and 5nm silicon. These layers were designed to protect the template material from the harsh diamond deposition environment, along with enhancing adhesion and thermal conductivity between the materials.

The polycrystalline diamond deposition was seeded with 1-150µm nanoparticles applied in isopropanol solution. The main diamond deposition consisted of microwave-plasma chemical vapor deposition (MPCVD) at 800°C. The plasma power was 3.5kW. The carbon source was 5% methane at 140mbar pressure. Trace quantities of nitrogen and argon were added to improve the growth rate. The carrier gas is not mentioned, but hydrogen is one gas that is used in such processes elsewhere.

Microscopic analysis of the diamond layer showed grains of average size 34µm, smaller than the 100µm grains often reported for the technique. The grains are smaller in the nucleation region, becoming larger at the surface of the 130µm-thick diamond layer.

Further transistor processing (Figure 1) consisted of surface hydrogenation with 650°C 2.8kW hydrogen plasma, deposition of 200nm-thick gold ohmic contacts, wet-etch gold removal from non-contact areas, 800W oxygen plasma treatment to isolate devices, 200°C atomic layer deposition (ALD) of 80nm aluminium oxide as gate

oxide and surface termination, and deposition and plasma-etch patterning of 300nm-thick aluminium gate electrode.

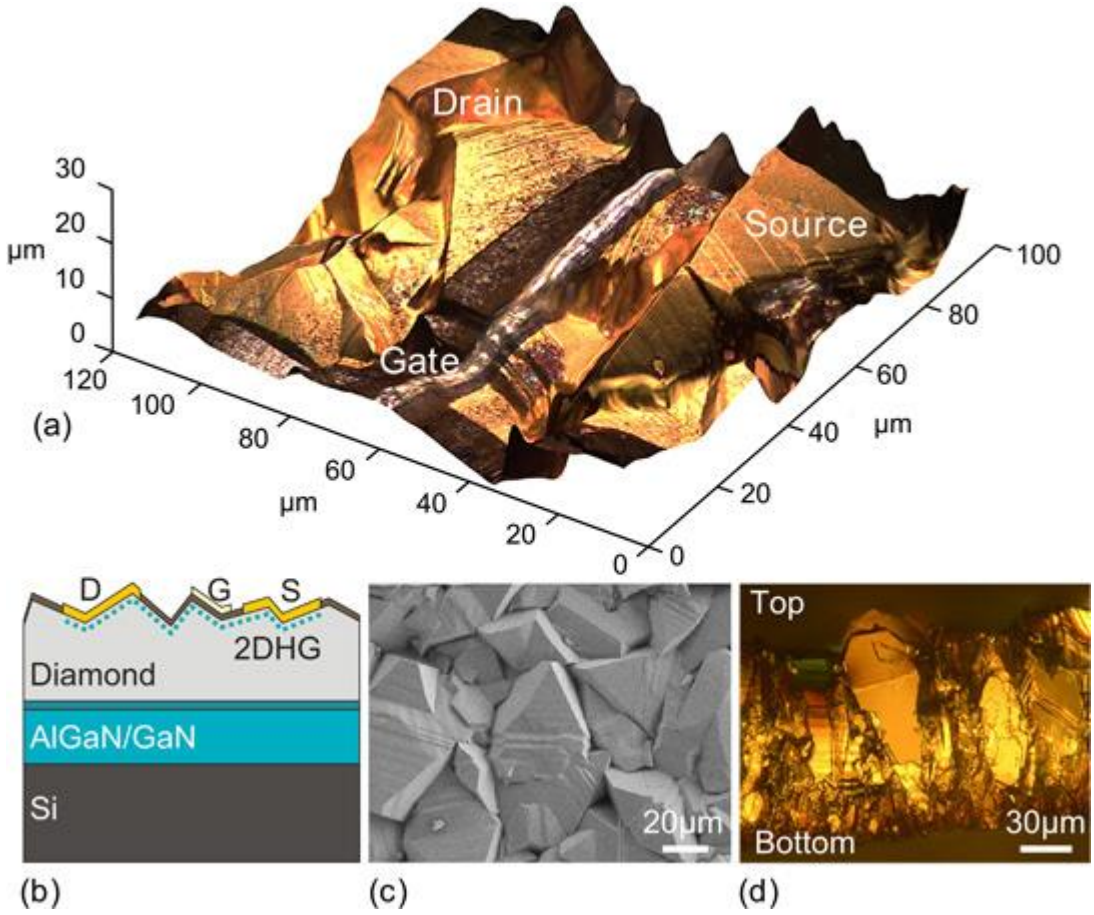


Figure 1: (a) Three-dimensional (3D) optical microscope image of fabricated HTDT, constructed using focus stacking. (b) Schematic of HTDTs. (c) Top-view SEM image of diamond surface. (d) Cross-sectional optical microscope image of diamond layer showing larger grain sizes at top.

The hydrogenation resulted in a p-type conductivity with ~1014/cm2 hole density, according to Hall measurements. The 1.3cm2/V-s mobility resulted in a sheet resistance of 50kΩ/square. The team comments: "The existence of many pits and edges in the unpolished diamond surface, serves as activation sites, resulting in a higher carrier density compared to the commonly reported values in the literature." The mobility was adversely affected by impurity scattering, the small grain sizes, and the rough surface – values of 3cm2/V-s have been measured for holes in single-crystal diamond.

The fabricated transistor with 4μm gate length achieved an on/off current ratio of 109. The source-gate and gate-drain distances were 2μm and 8μm, respectively. The on-current reached -60mA/mm. The specific on-resistance of 84mΩ-cm2 is described as "low". The leakage current was "very low" at less than 1μA/mm, even near breakdown.

The breakdown of the device occurred at -400V. The lateral critical field was estimated at 0.4MV/cm, according to studies using isolated contact pads separated by varying distances. The researchers report that monocrystalline diamond has achieved lateral breakdown fields of 1MV/cm.

The effective lateral conductivity came out at 900W/m-K in samples where the silicon substrate was removed from the backside of the diamond/GaN layers. The diamond grain size in the sample was 3µm on average.

The researchers comment: "Such excellent thermal conductivities can lead to very low thermal resistance and robust electrical performances in high-power-density applications. Moreover, this shows the potential of such high-quality CVD-deposited diamond layers for efficient thermal management of high-power GaN devices."

Comparing the performance with other polycrystalline and monocrystalline devices (Figure 2), the researchers observe that "there is still a gap between the performance of current HTDTs and their theoretical limits, which highlights the significant potential for improvement of this technology."

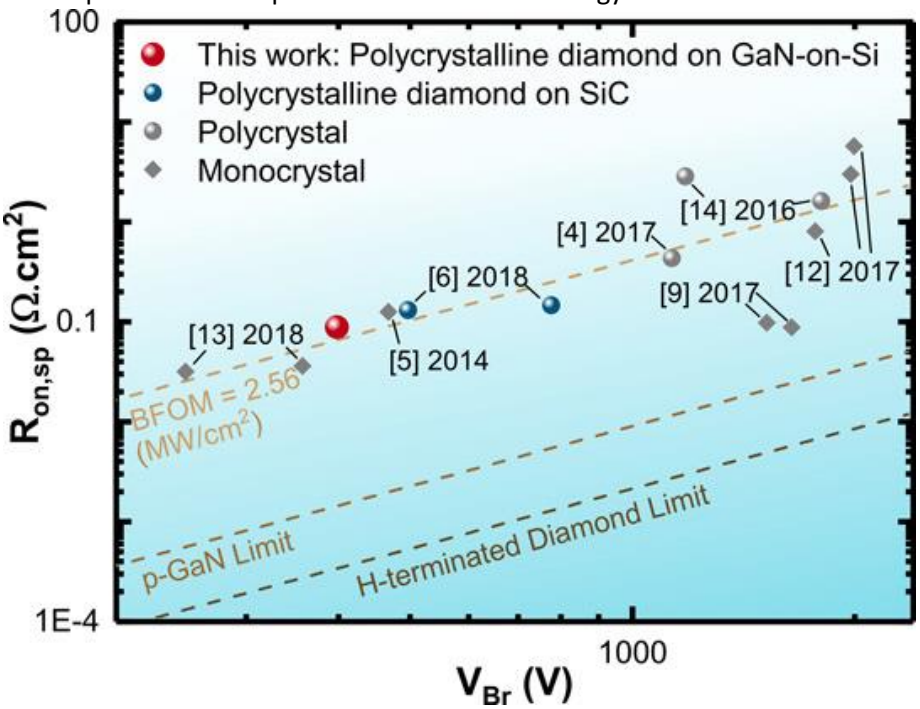


Figure 2: Benchmark of specific on-resistance (Ron,sp) and breakdown voltage (VBr) of this work with heteroepitaxial material on silicon carbide (SiC), as well as polycrystalline and monocrystalline substrate HTDTs.

At the same time, the device exceeds the performance of GaN-based p-channel transistors in terms of "6 times higher current density, 4 orders of magnitude higher on-off ratio and more than 6-times higher thermal conductivity". The researchers trace the improvement to the higher theoretical Baliga figure of merit of the diamond HTDT structure, compared with p-channel GaN devices.

Griffin unveils compact, fast USB-C wall chargers enhanced with power delivery and GaN technology

SemiconductorToday

At the Consumer Electronics Show (CES 2020) in Las Vegas (7–10 January), Griffin Technology of Irvine, CA, USA, a brand of Incipio Group, has unveiled a range of USB-C wall chargers equipped with power delivery (PD) and gallium nitride (GaN) technologies to deliver maximum fast charging power in an ultra-compact design. Engineered to provide a faster and safer charging experience in a smaller-sized package, Griffin's latest additions to its PowerBlock lineup includes three high-speed wall chargers powerful enough to charge most USB-C compatible smartphones, tablets and laptops.

"PD and GaN technologies deliver meaningful improvements in power adapter size, charging speed and safety," says Incipio Group's CEO Brian Stech. "As a brand with nearly 28 years of experience delivering dependable and

iconic solutions to better serve mobile users worldwide, we are thrilled to introduce a range of purpose-built charging solutions with industry-leading technology to further improve our customer's everyday lives," he adds.

Griffin's most powerful and versatile PowerBlock offering yet, each USB-C PD wall charger is equipped with power delivery to charge compatible smartphones, tablets and laptops at speeds up to 70% faster than standard chargers. With the integration of GaN technology, Griffin PowerBlock USB-C PD wall chargers are engineered with more efficient internal components than traditional silicon chargers to provide high-capacity power solutions with safer charging temperatures at a fraction of the size of traditional wall chargers.

By combining both technologies, Griffin's upcoming PowerBlock series allows users to save time charging while minimizing the number of chargers they need to power up all of their PD-compatible Apple and USB-C enabled smartphones, tablets and laptops.

Compared with most standard laptop chargers, GaN components allow the charger to be smaller (by 57%, 45% and 11%, respectively, for the 45W, 30W and 96W models), lighter and more efficient (which also provides safer temperatures while charging).

Power delivery provides high-speed charging; capable of charging a compatible device up to 70% faster than standard chargers for the PowerBlock 45W and PowerBlock 96W models, while the PowerBlock Dual 30W model allows charging of two devices simultaneously.

Available in second-quarter 2020, the PowerBlock USB-C PD wall chargers with GaN technology (costing $49.99 for the PowerBlock 45W, $69.99 for the the PowerBlock Dual 30W and $79.99 for the PowerBlock 96W) join the brand's growing range of USB-C PD wall and car chargers, wireless charging, portable power and connectivity solutions.

EPC's new ToF demo board drives lasers with currents up to 28A with 1.2ns pulses using automotive-qualified eGaN technology

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 announced the availability of the EPC9144, a 15V, 28A high-current pulsed laser diode driver demonstration board.

In time-of-flight (ToF) systems, speed and accuracy of object detection is critical. As demonstrated on this board, the rapid transition capability of the AEC Q101-qualified EPC2216 provides power pulses to drive laser diodes, vertical-cavity surface-emitting lasers (VCSELs) or light-emitting diodes (LEDs) up to ten times faster than an equivalent MOSFET, in a small fraction of the area, energy and cost, it is claimed.

eGaN FETs and integrated circuits are said to provide the high current pulses, extremely narrow pulse widths and small size that make affordable, high-performance light detection and ranging (LiDAR) possible. The short pulse width leads to higher resolution, and the small size and low cost make eGaN FETs suitable for time-of-flight applications from automotive to industrial, healthcare to smart advertising, gaming, and security.

The EPC9144 ships with an interposer board, which is a collection of break-away 5mm x 5mm square interposer PCBs with footprints to accommodate different lasers, RF connectors and a collection of other footprints designed for experimentation with different loads. The use of the interposers allows many different lasers or

other loads to be mounted, allowing users to test the performance with the load requirements that are appropriate to their application.

EPC says that GaN is a critical factor making affordable, high-performance LiDAR possible, so the use of GaN components further expands the number of applications where increased accuracy is vital. These include self-driving cars and other time-of-flight applications such as facial recognition, warehouse automation, drones and topological mapping. The EPC9144 can also be used for applications requiring a ground-referenced eGaN FET; for example in class E or similar circuits.

The EPC9144 demonstration board is priced at $378. The EPC2216 eGaN FET used on the EPC9144 demonstration board is priced at $0.532 each for 2.5Ku/reel.

II-VI wins Best Strategic Partner Award from Dynax for supplying SiC substrates for wireless RF devices

SemiconductorToday

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has won the Best Strategic Partner Award from China-based Dynax Semiconductor Inc as its supplier of silicon carbide (SiC) substrates for wireless RF devices.

Dynax's founder & CEO Dr Naiqian Zhang presented II-VI with the award for its outstanding supplier performance in quality, delivery and service. II-VI supplies Dynax with semi-insulating SiC substrates that enable gallium nitride-on-silicon carbide (GaN-on-SiC) RF power amplifiers deployed in 4G and 5G wireless base stations.

"Demand for GaN-on-SiC power amplifiers is increasing rapidly," notes Dr Gary Ruland, VP for II-VI's Wide Bandgap Semiconductors business unit. "II-VI continues to receive prestigious supplier and industry awards in China, demonstrating our strategic relationship with our customers in that region."

Semi-insulating SiC substrates enable RF power amplifiers for next-generation wireless networks operating over a wide frequency spectrum in the gigahertz range, including in the millimeter-wave bands. II-VI is a leading supplier of SiC substrates, with a strong technology portfolio of 30 active patents and with highly differentiated and proprietary manufacturing platforms and technologies including crystal growth, substrate fabrication, and polishing.

OPTOELECTRONICS

BluGlass and Luminus collaborating to evaluate RPCVD tunnel-junction-enabled cascade LED technology

SemiconductorToday

BluGlass Ltd of Silverwater, Australia (which was spun off from the III-nitride department of Macquarie University in 2005) and Luminus Devices Inc of Sunnyvale, CA, USA – which designs and makes LEDs and solid-state technology (SST) light sources for global illumination markets – have entered into a non-exclusive collaboration agreement to co-develop cascade LEDs for the rapidly growing entertainment, display and projector application markets.

Luminus aims to exploit the performance potential of BluGlass' tunnel-junction technology, developed using the firm's unique remote-plasma chemical vapor deposition (RPCVD) capabilities, to further improve its projector lighting technologies.

Projectors require ultra-high-performance LEDs and could benefit from the smaller form factor, higher-performance (intensity) and lower-cost benefits that RPCVD-enabled cascade LEDs potentially offer, says BluGlass. Projectors are also heat-sensitive devices, ideally operated at lower current densities to achieve peak efficiencies - a key benefit enabled by cascade LEDs. Traditional LEDs suffer from efficiency droop as current density is raised to drive higher light output intensities, resulting in significant performance losses in the form of heat.

Luminus develops LED technology for high-performance, high-value LEDs in industrial, medical, horticulture and entertainment applications. It works hand-in-hand with firms in the automotive, display and projection industries to illuminate everything from heads-up displays to projection systems for the next generation of vehicles and consumer technologies.

BluGlass is developing and commercializing RPCVD as a low-temperature, ammonia-free alternative to traditional manufacturing technologies. RPCVD is said to offer electronics manufacturers performance advantages including higher-performing, lower-cost devices. The firm recently demonstrated a technical breakthrough with its patented 'active as grown' RPCVD tunnel junctions for LED wafers, which provide a solution for the challenge of efficiency droop by combining multiple LEDs in a single vertical LED stack (with the potential to generate greater light output for less power).

The two firms will work together to combine their unique technologies to demonstrate high-performance LEDs for the entertainment, display and projection markets. Each party will bear their own costs for the initial trials. The purpose is to evaluate RPCVD tunnel junctions and demonstrate cascade LED performance in these markets.

Working with BluGlass to enhance its technology for ultra-high-performance LED specialty lighting markets will "give our customers more design flexibility to create even more unique and differentiated products," reckons Luminus' CEO Decai Sun.

"BluGlass is continuing to work with the world's leading innovators that are developing the next generation of lighting technologies in high-growth, high-value markets," says BluGlass' CEO & managing director Giles Bourne. The projection market represents "a strong fit" for the firm's RPCVD tunnel-junction technology, he concludes.

TowerJazz and Aledia agree process development partnership for nanowire-LED technology

SemiconductorToday

Specialty foundry TowerJazz of Migdal Haemek, Israel and Aledia S.A of Grenoble, France (a developer and manufacturer of 3D LEDs for display applications based on its gallium nitride nanowires-on-silicon platform) have announced a process development partnership to bring Aledia's nanowire-LED technology into commercialized volume production.

The development is based on Aledia's IP and utilizes TowerJazz's Transfer Optimization and Development Process Services (TOPS). Financed by Intel Capital among others, Aledia's nanowire-LED display technology offers solutions for the global display market's constant growing demand.

"We chose TowerJazz due to its vast expertise in the field of process development, its high-quality and extensive production capabilities, well serving our long-term production roadmap," says Aledia's CEO Giorgio Anania.

Aledia's 3D LED technology is said to enable high brightness (x1000 of today's average screen), high-resolution, low-power and cost-effective displays, all of which are key parameters in a variety of existing and future mobile display applications including laptops, tablets, mobile phones, augmented/virtual reality (AR/VR) and smart watches. With an ever-growing rate of consumers using their mobile screens in their daily lives, this market carries an enormous potential growth rate, it is reckoned.

TowerJazz's TOPS services should enable and facilitate quick transfer and manufacturability of Aledia's technology. The firm's global manufacturing capabilities - two manufacturing facilities in Israel (150mm and 200mm), two in the USA (200mm) and three in Japan (two 200mm and one 300mm) - provide volume production in scalable wafer sizes, which are claimed to enhance its cost competitiveness, capacity assurance and future roadmap alignment.

"This technology provides significant differentiators addressing all the main feature requirements of the micro-LED displays market and holds profound potential growth for both companies," comments Dani Ashkenazi, VP & general manager of TowerJazz's Transfer, Optimization and Development Process Services business unit (TOPS). "Bringing Aledia's solutions into volume production is a major step in establishing its role as a leading provider of next-generation display panel technology".

Monolithic optoelectronic integration of gallium nitride transistor

SemiconductorToday

Nanjing University of Posts and Telecommunications in China claims the first enhancement-mode metal-oxide-semiconductor field-effect transistors (MOSFETs) fabricated on a gallium nitride (GaN)-on-silicon light-emitting diode (LED) epitaxial wafer [Jiabin Yan et al, IEEE Electron Device Letters, published online 11 November 2019]. Enhancement-mode devices (that are 'normally-off' at 0V gate potential) are often preferred with respect to lower power consumption.

The research team also demonstrated the MOSFET's ability to control an indium gallium nitride (InGaN) LED on the same platform. The researchers hope that such monolithic optical electronic integrated circuits (OEICs) could lead to applications such as smart lighting, display, and visible light communication (VLC). The Nanjing group has been developing VLC systems on silicon for a while [see e.g. www.semiconductor-today.com/news_items/2019/jun/nupt-130619.shtml, which contains further links].

The team sees advan tages to the low-cost silicon platform as including integration with micro-electro-mechanical system (MEMS) batch fabrication processes. Although LEDs, photodiodes, waveguides, couplers and

other photonic structures are relatively easy to process, up to now GaN transistor structures are usually implemented using different epitaxial structures, impeding low-cost integration.

The III-nitride structure on silicon (Figure 1) included a 250nm InGaN/GaN multiple quantum well (MQW) layer sandwiched between n- and p-type GaN, as used in light-emitting diodes. The wafer was 2-inches in diameter. The silicon substrate was thinned to 300µm thick by grinding and polishing.

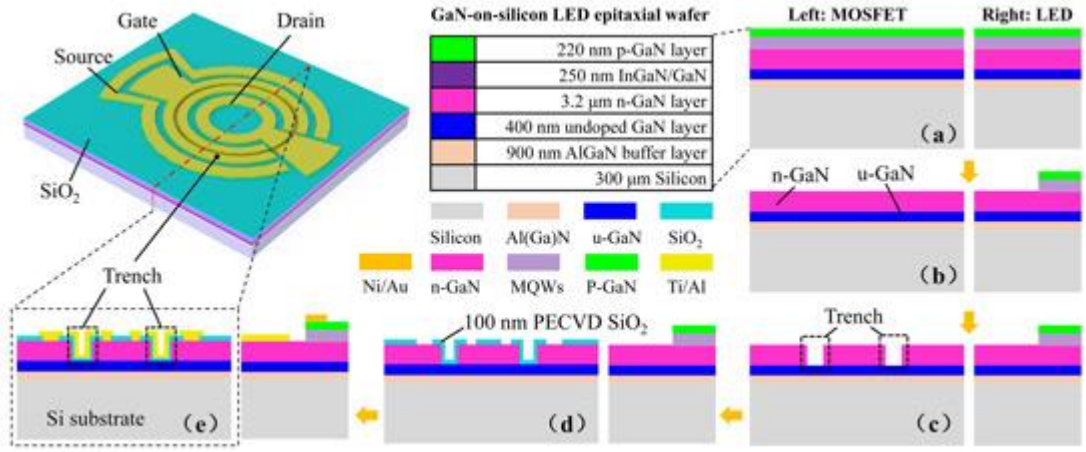


Figure 1: Schematic overview of proposed devices based on GaN-on-silicon platform and fabrication process steps.

The transistor was formed using the n-GaN as source and drain, while the channel was through the undoped GaN layer. Insulation and the gate dielectric consisted of 100nm silicon dioxide (SIO2). The gate metal was deposited in the trenches, covering the undoped GaN channel and the recess sidewalls. The electrodes were ring-shaped to increase the width/length ratio for a larger output current. The channel length was 20µm. The radius of the recess ring center was 135µm.

The fabrication began with removal of the p-GaN and InGaN/GaN layers using inductively coupled plasma reactive-ion etch from the transistor area. The gate recess also used a similar etch process, but at slow speed to ensure accurate depth with full removal of the n-GaN and non-removal of undoped GaN. Despite the slow etch, the sidewalls of the recess were rough.

The SiO2 was applied using plasma-enhanced chemical vapor deposition (PECVD) and patterned with reactive-ion etch. The transistor metals were titanium/aluminium, annealed to improve the source/drain ohmic contacts.

In DC testing the minimum on-resistance of 5Ω-m was achieved at 12V gate potential. The team comments: “Even though the output current is relatively low compared with that of some published GaN-based FETs, the proposed MOSFET can still meet the requirements of numerous low-power applications, especially the micro-LED for smart display (typical driving current from several µA to hundreds of µA).”

The subthreshold behavior was pretty poor with 2.78V/decade swing at 1V drain bias. This must be seen in the context that the theoretical minimum is 60mV/decade (0.06V/decade) at room temperature. Further, other reported GaN MOSFETs have achieved values as low as 218mV/decade. The researchers hope to improve the subthreshold behavior with tetramethylammonium hydroxide (TMAH) or fluorine treatments to reduce surface roughness of the recess sidewalls.

By contrast, the threshold voltage was a high 6.01V. The peak transconductance was 3.78µS/mm with the on-resistance at 7.96Ω-m. The drain bias was 0.1V. The gate and drain leakage currents were 120nA/mm (0V drain,

12V gate) and 5µA/mm (5V drain, 0V gate), respectively. An analysis of the parasitic capacitance suggests a cut-off frequency of the order of tens of megahertz. Reduced device dimensions would increase switching speed at the expense of drive current.

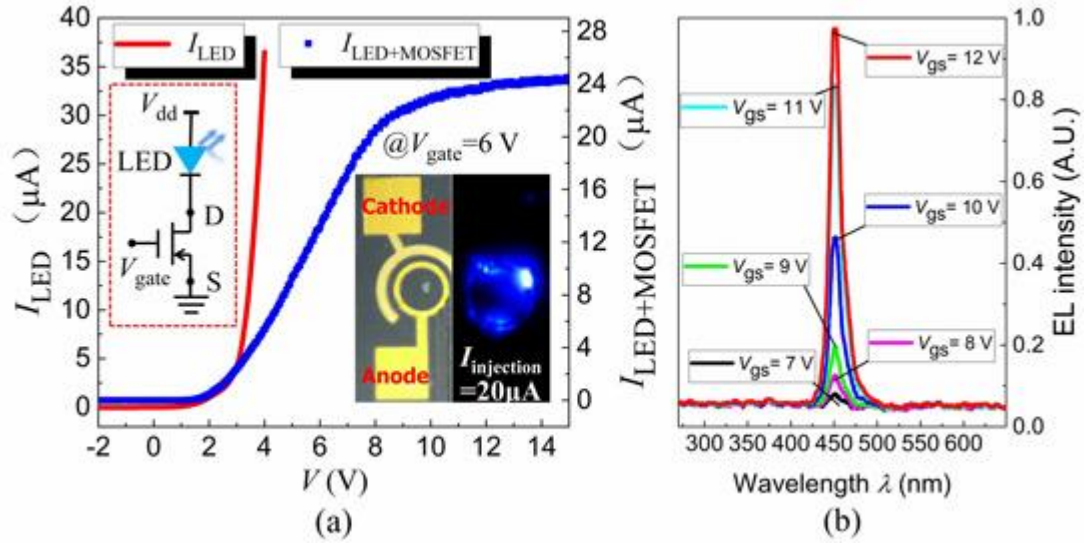


Figure 2: (a) Current-voltage (IV) characteristics of individual LED and LED-MOSFET (LED and MOSFET in series according to inset circuit diagram); (b) electroluminescence (EL) spectra of LED with different MOSFET gate voltages.

The researchers also integrated the MOSFET with an LED on the same substrate. The LED used titanium/aluminium and nickel/gold as cathode and anode electrodes, respectively. The MOSFET allowed control of the light output with increased gate potential (Figure 2).

Deep UV aluminium gallium nitride laser diode at 271.8nm wavelength

SemiconductorToday

Researchers from Japan and the USA claim the shortest wavelength so far reported for current-injection laser diodes (LDs) [Ziyi Zhang et al, Appl. Phys. Express, vol12, p124003, 2019]. The emission wavelength of 271.8nm places it in the deep ultraviolet (UV-C) 100-280nm range. Previous UV laser diode reports have been restricted to the 315-400nm UV-A range.

Asahi Kasei Corp and Nagoya University in Japan and Crystal IS in the USA collaborated on the device, which used low-dislocation-density aluminium nitride (AlN) substrates to grow layers of aluminium gallium nitride (AlGaN). Most reported short-wavelength laser diodes use silicon carbide, sapphire or freestanding gallium nitride as the growth substrate.

The team used an unintentionally doped distributed polarization-induced doping (DPD) cladding layer on the p-side, aiming for low internal loss, high hole conductivity and high hole injection. The usual magnesium doping of AlGaN has very poor performance in terms of generating mobile holes. Further, the use of ionized impurities creates scattering centers for light and charged carriers, which adversely impact performance.

UV-C emitting devices could have a wide range of applications: biochemical sensing, small-particle detection, disinfection, medical treatment and surface monitoring are mentioned in the paper. These very short wavelengths are able to disrupt biochemicals such as DNA with potential for disinfection and water purification of bacterial and viral pathogens.

The researchers grew the laser diode structure (Figure 1) on 2inch-diameter (0001) AlN substrates using metal-organic chemical vapor deposition (MOCVD). The dislocation density in the single-crystal substrate from Crystal IS was in the range 103-104/cm2. The 9nm light-emitting single quantum well was designed to emit 270nm wavelength UV-C light.

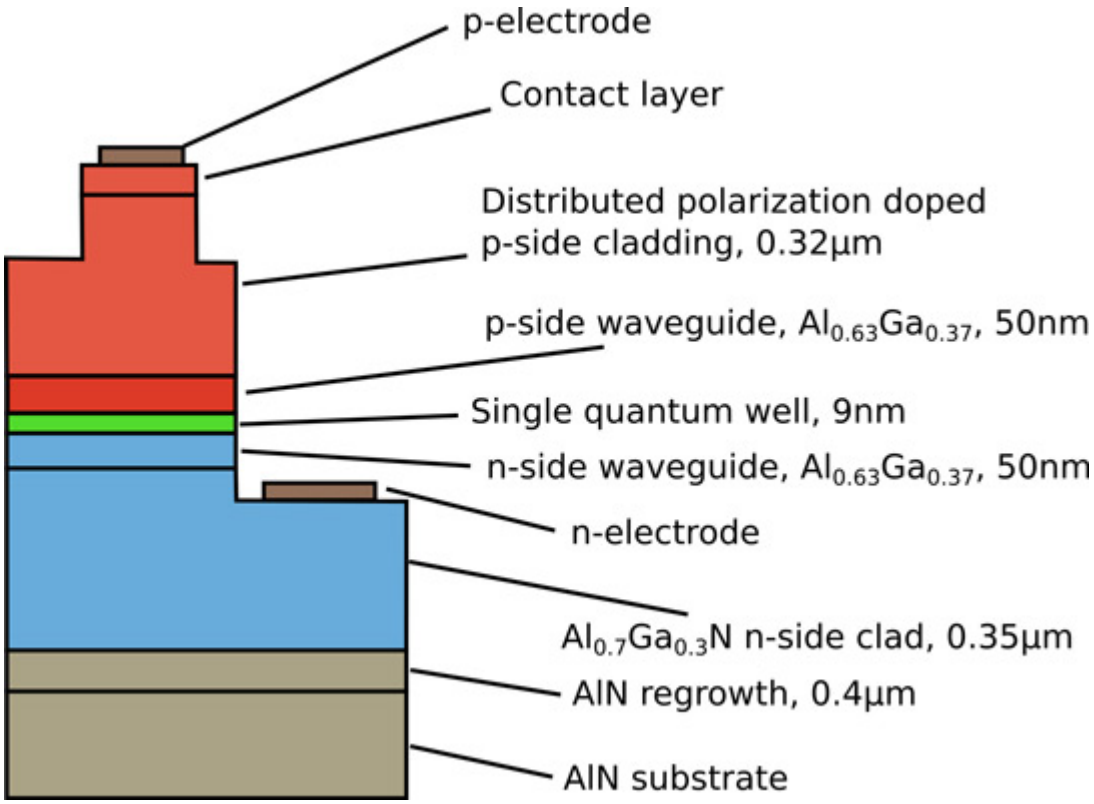


Figure 1: Schematic of fabricated UV-C laser diode structure.

The 0.32µm distributed polarization doped p-side cladding consisted of AlxGa1-xN graded from 100% to 70% Al content. The grading effects a charge polarization gradient that creates and conducts mobile holes. The p-contact region consisted of magnesium-doped AlGaN further graded down to pure GaN. The n-side of the device was doped with silicon using an impurity concentration of more than 1x1019/cm3 in both contact and cladding layers. The epitaxial layers were strained pseudomorphically with the underlying AlN substrate.

Laser diode devices were fabricated with 4µm-wide ridge waveguides. The ridge etch exposed the n-contact layer on which vanadium-based metal was deposited. Silicon dioxide passivation was applied before the n-contact metal. The p-contact and other wiring and probe pads consisted of nickel/gold metal.

The fabricated laser diodes were cleaved along the <11-20> direction into 400µm-long cavities. The resulting (1-100)-plane facets were coated with five dielectric layer pairs consisting of hafnium dioxide and silicon dioxide. The reflectivity of the coatings were more than 90%, according to the researchers. The high reflectivity was a key factor in reducing threshold current.

The laser diodes were tested under pulsed operation with 50ns width and 0.01% duty cycle. The light output power increased non-linearly at around 0.4A injection, 25kA/cm2 density relative to the p-electrode area. Above this threshold a sharp spectral peak emerged around 271.8nm wavelength. The threshold occurred with a forward voltage of 13.8V.

The optical polarization of the emission was transverse electric (TE): while the transverse magnetic (TM) component had a constant 11nm full-width at half maximum (FWHM) between 0.2A and 0.5A, the TE values were 6.6nm and 0.41nm, respectively (Figure 2).

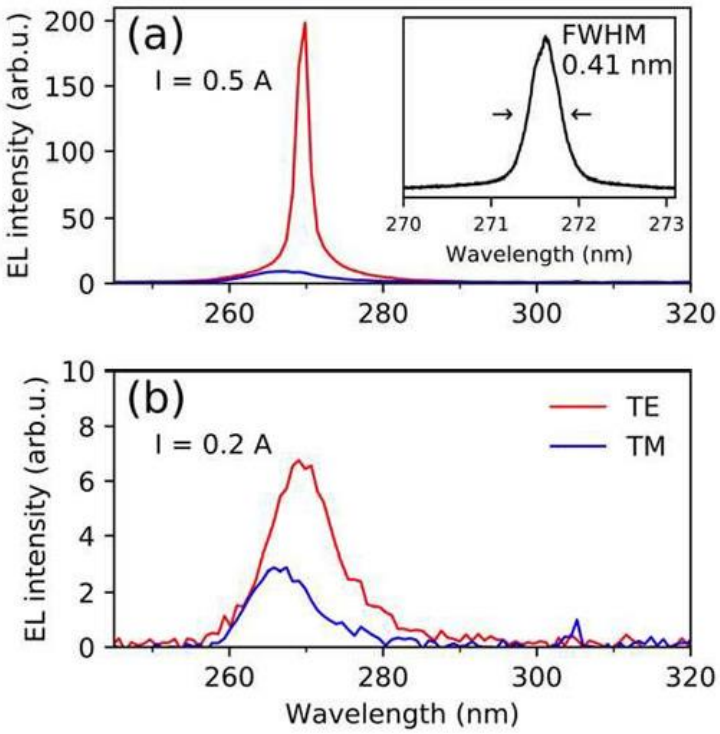


Figure 2: Edge emission spectra with TE and TM polarization at (a) 0.5A and (b) 0.2A forward current. Inset in (a) shows spectrum of TE mode at 0.5A with highest wavelength resolution.

The researchers attributed the "remarkably low" threshold voltage of 13.8V to the DPD structure giving a flat valence band profile on the p-side, allowing injection of the holes without a barrier. They also speculate that the high-Al-content material on the p-side of the waveguide layer created an electron-blocking barrier in the conduction band.

The team comments: "The pseudomorphic growth of the whole structure, including the DPD on the single-crystal AlN substrate, maximized the polarization-induced charge to achieve high hole conductivity, considering that relaxation of the graded structure can also hinder polarization doping."

One problem was found in the MOCVD growth process: convex, hexagonal pyramid-shaped hillocks on the surface with a density of 6x103/cm2. The hillocks seemed to contribute an additional emission peak around 278nm wavelength. In devices that included one of these hillocks, lasing was not achieved.

The researchers believe, based on transmission electron microscope analysis, that the hillocks originate from pre-existing threading dislocations in the AlN substrate. Threading dislocations offer non-radiative routes to carrier recombination and can adversely affect current flow patterns.

For lasing, the hillocks also affect the optical structure, scattering light out of the waveguide mode. "A high-quality AlN substrate with low dislocation density appears to be fundamental to the development of a UV-C LD," the team concludes.

Rohinni and BOE launch JV to develop mini- and micro-LED-based LCD displays and video walls

SemiconductorToday

Semiconductor display maker BOE Technology Group Co Ltd of Beijing, China (the world's biggest manufacturer of TFT-LCD panels for mobile phones, tablets, notebooks, monitors and TVs) and Rohinni LLC of Coeur d'Alene, ID, USA (which has developed a proprietary method for transferring mini- and micro-LEDs to substrates) have officially launched the joint venture BOE Pixey, aiming to bring the power and brilliance of micron-scale LEDs to mass-market fruition.

In development for more than two years, BOE Pixey will design and build LCD display backlights, direct-emission displays and display-related sensors for high-performance televisions, video walls and other large-format end products. The JV rolls out at Consumer Electronics Show (CES 2020) in Las Vegas (7–10 January), with demonstrations offering visitors a glimpse of the future of high-performance display products.

BOE Pixey is integrating Rohinni's high-speed and high-accuracy mini- and micro LED manufacturing process with BOE's display panel expertise to create ultra-thin high-performance displays. Consumer devices utilizing BOE Pixey mini- and micro-LED-based displays are expected to become available for purchase in second-half 2020.

"With BOE Pixey, consumer electronics developers can now have more opportunities to design unique, cutting-edge end products that feature displays made with our technology," says BOE Pixey chairman Dong Xue.

LCDs using mini-LED backlights outperform other LCD technologies in a range of parameters including thickness, contrast ratio, brightness and consistency. Direct-emission displays based on mini- and micro-LEDs, including video walls, are made by precisely placing hundreds of thousands of mini- or micro-LEDs directly on a substrate using BOE Pixey's approach, and are said to offer much better viewing than existing video walls made from packaged LEDs.

"Mini- and micro-LEDs' promise has long been touted, but they have not been commercialized for these kinds of products before because making them in high volumes wasn't possible," says Rohinni's CEO Matthew Gerber. The combination of expertise of the two companies will bring new development opportunities to the display industry, he reckons.

As BOE Pixey ramps its production capabilities, the team aims to implement plans for new advances that will further enable customers to develop next-generation products, including faster LED placement, integration of new substrate materials, and addressing a wider range of form factors

Toward photodetector arrays based on indium gallium nitride µLEDs

SemiconductorToday

Fudan University in China and University of Toronto in Canada have been exploring the use of indium gallium nitride (InGaN) micro light-emitting diode (µLED) arrays in photodiode (PD) mode for multiple input, multiple output (MIMO) visible light communications (VLC) [Xiaoyan Liu et al, ACS Photonics, published online 31 October 2019]. The team suggests that the technology could lead to integration of display, fast data transmission and photodetectors, powered photovoltaically either through the signal itself or through solar illumination.

The researchers comment: "Such a multifunctional µLED information display is very useful for applications where high-speed wireless network and considerable electrical power are required, for instance information display chips for wearable virtual reality/augmented reality (VR/AR) devices, and outdoor large-screen display."

VLC is seen as a wireless communication technology that could be deployed in environments where electromagnetic interference from radio frequencies could be problematic such as aircraft or hospitals.

The small size of µLEDs is expected to result in higher bandwidths due to smaller parasitic resistances and capacitances. Although single µLED photodetectors have been studied, the researchers report that parallel array structures of such devices have not been presented up to now.

The 2x2 MIMO system consisted of transmissions from 405nm violet laser diodes (LDs) transmitted over a free-space distance of 1m onto 450nm blue µLED structures used as photodetectors (Figure 1). The laser diodes were used due to reduced crosstalk between the two signal sources with reduced divergence angle of the beams. The laser light was collimated using lens systems.

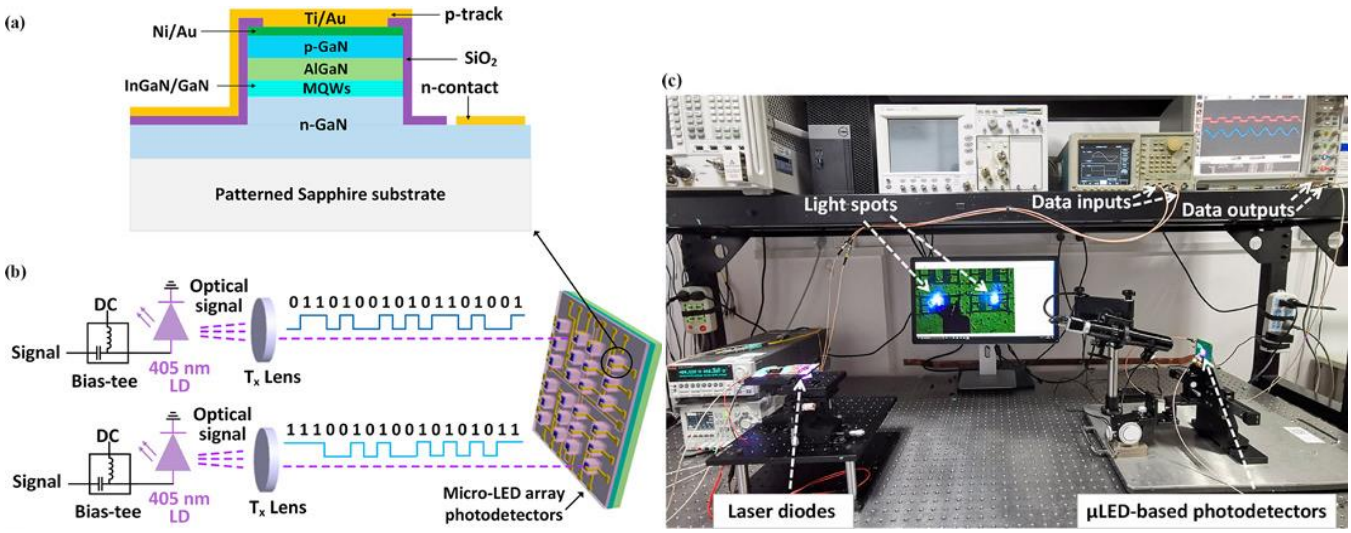


Figure 1: (a) Schematic diagram of µLED, (b) setup for MIMO VLC, and (c) photograph of experiment.

The researchers fabricated their devices using commercial metal-organic chemical vapor deposition (MOCVD) material grown on patterned sapphire substrates. The light-sensitive region was indium gallium nitride (InGaN) multiple quantum wells (MQWs) with GaN barriers. An aluminium gallium nitride (AlGaN) electron-blocking layer was included in the structure. The silicon dioxide (SiO2) insulation was applied using plasma-enhanced chemical vapor deposition (PECVD). Nickel/gold (Ni/Au) was used for current spreading. The n- and p-contact pads consisted of titanium/gold (Ti/Au).

The photodetector diameters varied between 40µm and 100µm. At zero bias, the photo/dark current ratio, or 'photosensitivity', was of order 109. This high value resulted from the very low dark current at zero bias of 10-14A. The laser diode power density reached as high as 11.0W/cm2.

With the devices biased at -5V, the photo/dark current ratio was 107 for the smaller devices, and 108 for the larger. The researchers say that these values match the best reported results and are "higher than previously reported values of the GaN photodetectors with photoconductive, p–i–n, or heterojunction structures". The team expects the high values to benefit the signal/noise ratio and minimum detection limits of the devices.

When the illumination was at 11.0W/cm2, the short-circuit current was 27.4µA for the 40µm-diameter µLED. This increased to 188µA for 100µm diameters. The open-circuit voltages were all 2.6V. This photovoltaic effect could be used to power other parts of a circuit. The researchers report that they have used such harvested energy to power a 660nm laser diode. The team sees potential for such setups to be used in powering systems in hazardous and harsh environments.

The responsivity of the self-powered µLEDs with 11.0W/cm2 laser power density was 0.24A/W for 40µm diameters, and 0.21A/W for 100µm. A 60µm-diameter µLED achieved 0.29A/W response. The researchers estimate the quantum efficiency to be 74%, 88% and 62% for 40µm-, 60µm- and 100µm-diameter µLEDs, respectively.

Biasing the devices at -5V gives corresponding responses of 0.27, 0.31 and 0.24A/W – and quantum efficiencies of, in the same order, 82%, 96% and 73%. The researchers attribute the increased performance to the enhanced separation and collection of electrons and holes under reverse bias.

The team comments: "The values of responsivities are higher than that of a commercial Si-PIN photodetector at the wavelength of 405nm and are slightly better than the GaN-based photodetectors in previous reports without internal photocurrent gain."

The specific detectivity that measures the effects of bandwidth and noise on the µLED-PD was around 1013Jones (cm-Hz1/2/W) at zero bias – 7.5x1012Jones for 40µm diameters and 1.5x1013Jones for 60µm. The values decreased somewhat for -5V bias due to increased dark current – 1.11x1011Jones for 40µm and 2.3x1012Jones for 60µm diameters.

For high-speed communications, fast response to changes in illumination are needed. Smaller devices are likely to have faster rise and fall times. At zero bias, the rise and fall times in response to 11.7W/cm2 laser diode illumination were 22.0ns and 23.7ns, respectively, for the 40µm-diameter µLED. These times reduced with -5V reverse bias to 13.2ns and 13.7ns, respectively.

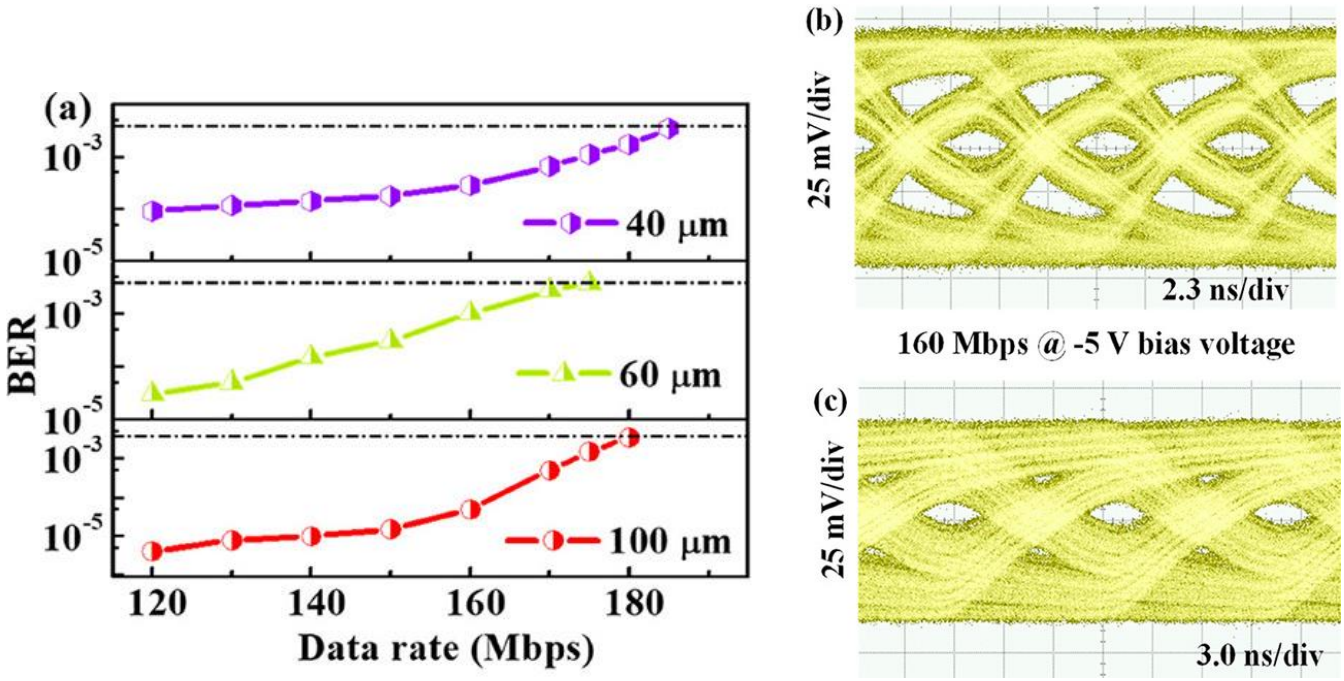


Figure 2: (a) BER versus data rate at -5V bias for µLED-based photodetectors with various diameters. Black solid line and black dash line represent -3dB bandwidth and FEC threshold, respectively. Eye diagrams captured at data rates of 160 (b) and 100Mbps (c) for 60µm µLED-based photodetector at -5V and 0V bias, respectively.

The researchers explain: "In comparison with 0V bias, the photoresponse time turns out to be shorter at a -5V bias, which is attributed to the increase of drift speed of carriers under reverse bias.

In fact, the 60µm-diameter µLED had improved rise/fall times: 17.2n/20.2ns at zero bias, and 12.2ns/12.7ns at -5V.

The -3db electrical-to-optical modulation bandwidths at -5V reverse bias were 56.8, 56.2 and 53.5MHz, respectively, for the 40µm, 60µm and 100µm devices. These values reduced at zero bias with corresponding values of 40.3, 41.2 and 38.6MHz.

In on-off keying (OOK) modulation transmissions, the researchers achieved 185 megabits per second (Mbps) with the 100µm device reverse biased at -5V (Figure 2). The bit error rate (BER) was 3.5x10-3, lower than the 3.8x10-3 upper limit for forward error correction (FEC) to be possible.

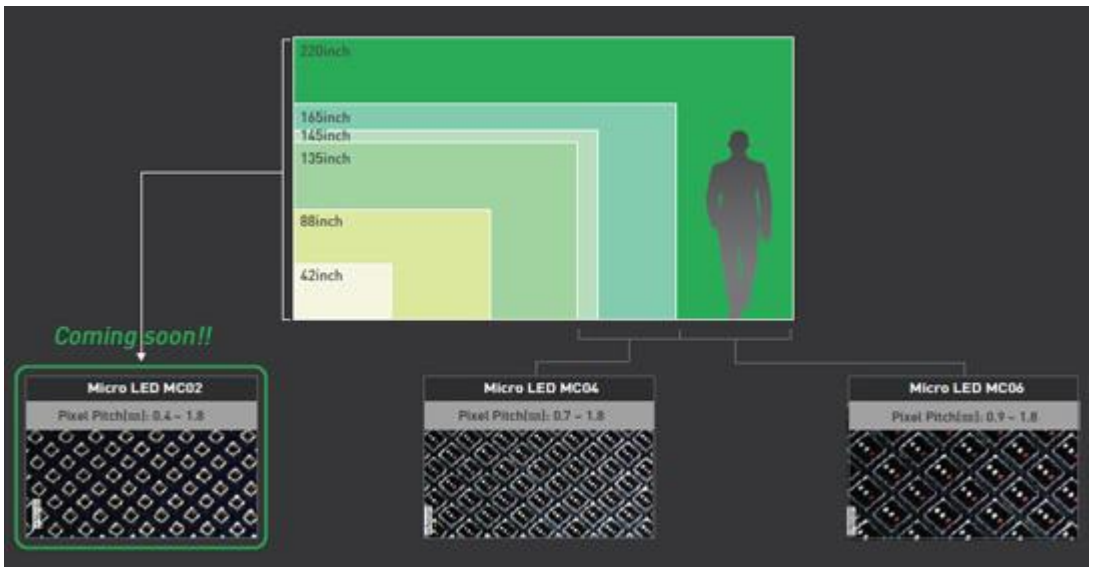
The 60µm device achieved 120Mbps with zero bias and 3.6x10-3 BER. Under -5V reverse bias, the same devices achieved 175Mbps and 3.7x10-3 BER. The researchers comment: "In the proposed 2x2 MIMO VLC, ideal real-time data rates of 350Mbps (under a −5V bias) and 240Mbps (under zero-bias) can be accomplished using 60µm µLED-based photodetectors as optical receivers."

Applying scaling arguments, the team suggests that 18Gbps could be achieved with 10x10 arrays, and several terabits per second with 128x128 setups. However, "it is worth noting that there are significant challenges to achieve such extension to multi-Gbps transmission in practical applications because of the inevitable crosstalk and collimation difficulty for more and more arrays," the team warns.

Seoul Semiconductor and Viosys showcase first 1-pixel µLED enabling 42-220" 4K-resolution TV

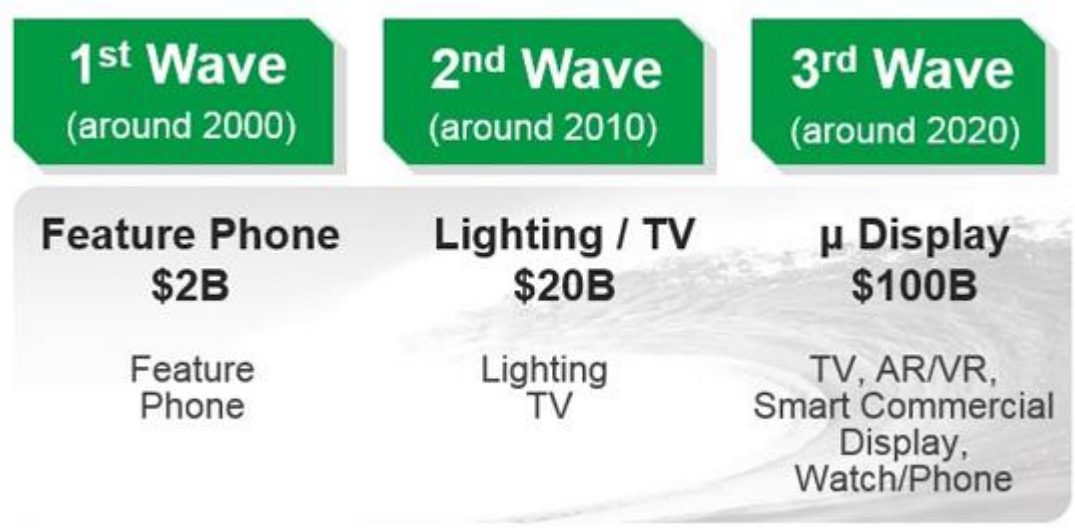
SemiconductorToday

At the Consumer Electronics Show (CES 2020) in Las Vegas (7-10 January), South Korean LED maker Seoul Semiconductor Co Ltd has unveiled the new concept display 'Micro Clean LED' - developed by its ultraviolet (UV) LED product manufacturing subsidiary Seoul Viosys Co Ltd and ready for mass production - which realizes 4K-resolution TV sizes from 42-inch to 220-inch with one RGB LED per pixel. Also at CES, the Micro Clean LED solutions for a smart watch display is also being demonstrated to main strategic partners by appointment.



The firm says that Seoul Viosys possesses the necessary technologies, from metal-organic chemical vapor deposition (MOCVD) for epitaxial growth of all three colors (RGB) to the transfer of small-sized micron-scale RGB chips. Seoul Semiconductor also possesses the tiling technology and substrate connectivity technology for large-

screen displays due to readying surface-mount technology (SMT) manufacturing processes at the customer's request in its own factory.



Furthermore, since it is developed as 1 pixel, it resolves three main challenges for micro-LEDs, which are the transfer technology, color mixing and the individual color and intensity of light control. By resolving these three challenges, costs can be reduced by a third, it is reckoned. Also, product reliability testing has been completed.

Seoul Semiconductor notes that, in the LED market, the first wave was the adoption of LED technology in mobile phone applications in the 2000s. The second wave was LED TV and lighting applications in the 2010s. As the third wave grows to a $100bn market with LCD and OLED displays, micro-LED are expected to capture a significant portion of the next generation display market. They are also suitable for light sources in the virtual reality/augmented reality (VR/AR) and mixed reality (MR) sectors. The micro-LED is reckoned to be the only light source that can deliver 1000 times faster response times, a 30% reduction in internal and external power consumption, and infinite contrast range compared with existing LCD and OLED displays.

Thermal droop in indium gallium nitride light-emitting diodes

SemiconductorToday

A study of indium gallium nitride (InGaN) light-emitting diodes (LEDs) suggests that the thermal droop in external quantum efficiency (EQE) is mainly caused by transport effects such as carrier overshoot, according to researchers at Soraa Inc in the USA [Aurelien David et al, Appl. Phys. Lett., vol115, p223502, 2019].

Thermal droop refers to the loss in efficiency when the junction is heated either by high-temperature operation or due to poor heat dissipation in continuously operating devices ('Joule heating'). This is in contrast to current droop, which refers to an efficiency loss at high current injection. Often current droop is isolated by pulsed operation designed to avoid heat build up in LED junctions.

The researchers used material grown by metal-organic chemical vapor deposition (MOCVD) on c-plane bulk GaN. The light emissions came from 13% indium-content InGaN single or multiple quantum wells (SQW/MQW). The use of expensive bulk GaN substrates gives best-case devices with low defect levels that should reduce leakage currents through dislocations.

Photoluminescence (PL) experiments on a SQW in the 25-160°C temperature range suggested a peak internal quantum efficiency (IQE) of 84%. The structure that was tested consisted of the SQW lodged in 200nm of intrinsic GaN material. The IQE response to the laser pumping was fairly consistent across the temperature range. The researchers even suggest that, allowing for differences in absorption, the peak IQE increased slightly at higher temperatures.

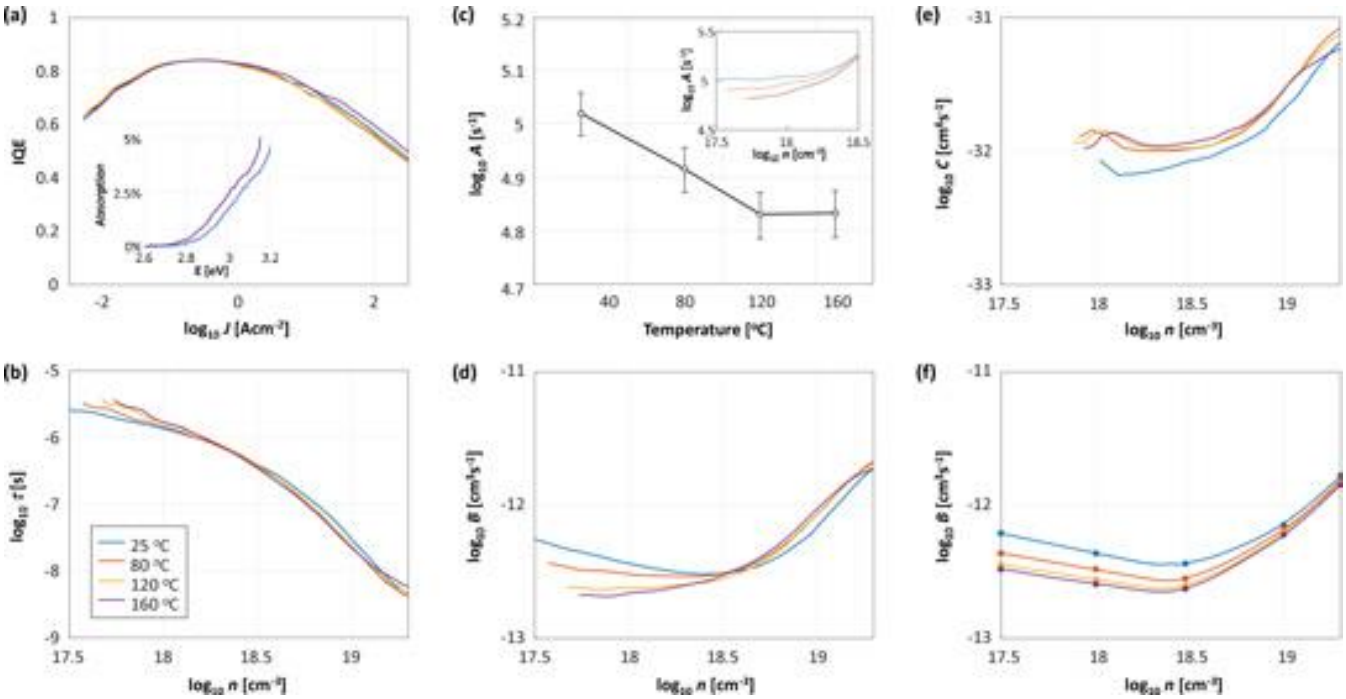


Figure 1: PL measurements of thermal droop on SQW sample: (a) IQE, (b) differential lifetime versus carrier concentration. (c) Extracted SRH coefficient A. Inset: non-radiative current divided by carrier density: A value extracted from low-current plateau. (d) Radiative coefficient B. (e) Auger coefficient C. (f) Calculated value of B (considering many-body effects and alloy disorder) shows trend qualitatively similar to experimental data of (d).

The researchers used an optical differential lifetime technique to derive the various parameters of the standard ABC model. The separate terms of the model – Shockley-Read-Hall (A), radiative (B) and Auger (C) – can be extracted by studying the luminescence at different carrier levels generated by different pump laser powers.

The team explains: "A diode laser having a time-dependent output excites the QW resonantly; the PL signal is collected by an avalanche photodiode connected to a network analyzer, which determines the phase and amplitude response of the PL signal, from which the differential carrier lifetime is derived. This technique directly probes the carrier lifetime in the active region and therefore circumvents transport effects."

Analysis of the carrier lifetime behavior allows extraction of the current-dependent ABC coefficients, along with IQE.

The total recombination lifetime was found to be only weakly dependent on temperature with the 'A' portion attributed to non-radiative Shockley-Read-Hall (SRH) transitions through mid-gap levels slightly decreasing at high temperature against expectations, according to the researchers' analysis based on the ABC model.

The team suggests that temperature-dependent effects reported previously can be attributed to two factors: "(1) in heteroepitaxy samples, additional dislocation-related effects may lead to a different thermal activation

(especially for A); (2) previous studies have derived lifetimes from EL [electroluminescence] measurements, where recombination effects and transport effects were not disentangled. Our measurements directly probe active-region recombinations in low-defect material and therefore provide a more direct insight into the intrinsic nature of thermal droop."

The researchers believe therefore that thermal droop in their LEDs' EL performance is not due to recombination problems in the active QW region of the devices. The SQW LEDs consisted of 30nm p-i-n structures with a magnesium-doped aluminium gallium nitride (AlGaN) electron-blocking layer. The LED was assembled with the chip flipped onto a silver p-contact. One aim of the silver contact was high light extraction efficiency, presumably through reflection back to the top of the device.

Thermal droop is attributed to transport effects, such as electrons escaping from the active region by crossing the electron-blocking layer into the p-contact layer and recombining non-radiatively. The researchers performed a time-resolved study that allowed measurement of carrier escape time from the QW. The exponential temperature dependence was consistent with thermionic emission.

The researchers found that an optimized MQW structure enabled higher EQE and hot/cold (HC) ratio values (Figure 2). 'Cold' refers to room-temperature performance. The team observes that the HC ratio "reaches near-unity at a temperature of 100°C and at operating current density—a higher value than typically observed in commercial LED samples. Crucially, this improvement in the HC ratio is not obtained at the expense of peak EQE (instead, the room-temperature peak EQE of the MQW structure reaches a state-of-the-art value of 80%, surpassing that of the SQW structure). This reveals that thermal droop is not a fundamental limit to LED performance."

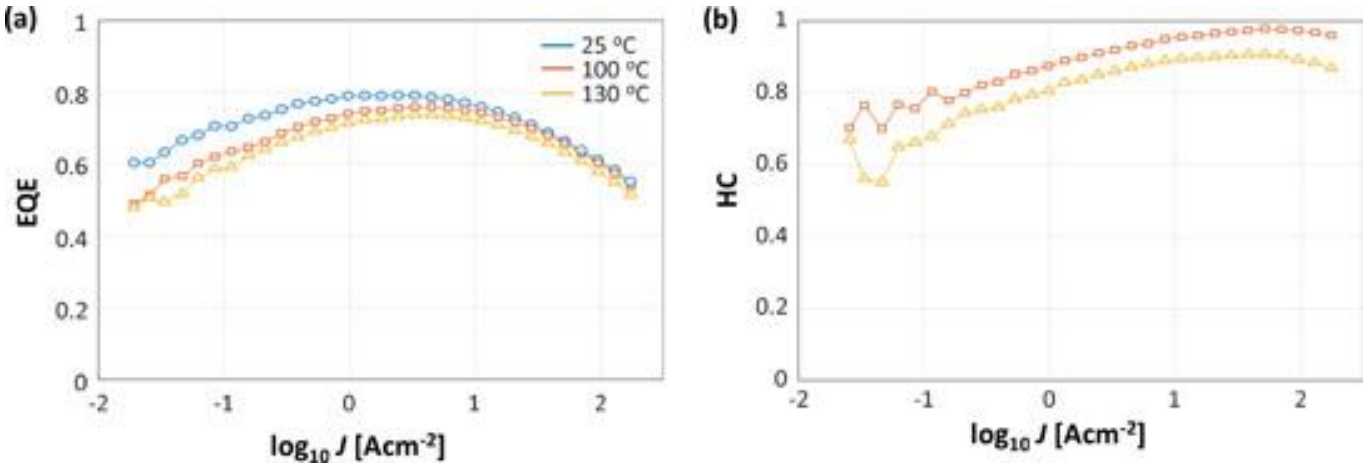


Figure 2: Electroluminescence thermal droop in MQW LED: (a) EQE and (b) HC ratio.

The team suggests that the MQW structure reduces escape from the active region into the p-contact region. If the electron is not captured by one QW it may be by the next. However, there may also be a compensation effect going on, where higher temperatures enable broader use of the QWs in the MQW structure. Some studies have found that the MQW structures under EL testing have very non-uniform emissions, with most light coming from wells near the p-end of the device, since holes tend to have more sluggish transport properties.

This compensation may partially explain the HC performance, but not that of the EQE. The SQW LEDs showed a relative drop in peak EQE of 15% at 100°C, compared with 5% for the MQW structure. The researchers claim that the drop is not influenced by carrier spreading since it is the peak EQE being considered, regardless of current). The team adds that this "indicates that a majority of the HC improvement has a separate cause."

MICLEDI raises €4.5m from imec.xpand, PMV and FIDIMEC

SemiconductorToday

MICLEDI Microdisplays BV of Leuven, Belgium, a spin-off from nanoelectronics research centre imec, has raised €4.5m seed capital from imec.xpand, with participation from Brussels-based PMV (which funds start-ups in Flanders) and FIDIMEC (imec's investment arm, supporting the creation and growth of its spin-off companies). The funding will be used to develop micro-LED displays for next-generation augmented reality (AR) glasses.

MICLEDI says that its vision is to enable AR for everyday personal use - smart glasses that are small, lightweight, with long battery life, and at reasonable cost. The firm is hence developing what are targeted to be the world smallest and brightest displays. The key innovation is the new integration technology for micro-LEDs on 300mm wafers developed in collaboration with imec.

The MICLEDI team: co-founder & CTO Dr Soeren Steudel, co-founder & COO Dr Alexander Mityashin, and CEO Sean Lord.

MICLEDI was founded by chief technology officer Dr Soeren Steudel and chief operating officer Dr Alexander Mityashin, both researchers from imec with expertise in R&D and display development. They are joined by experienced semiconductor industry Sean Lord as CEO.

"AR glasses may replace our smartphones in the future, and display technology is a key enabler for such a transition," says Steudel. "Today's display technologies cannot fulfil the specifications needed for next-generation AR glasses," he adds. "At MICLEDI we are tackling this challenge and have developed displays that are 100x brighter than commercial alternatives."

To implement the vision that future consumer AR devices will be powered by a tiny display, MICLEDI has raised the €4.5m seed investment from imec.xpand, PMV and FIDIMEC. "We look forward to working with them and to enable technology that will be at the core of future AR devices and will change how digital information is presented to consumers," comments Cyril Vančura, a partner at imec.xpand.

MICLEDI's will develop its micro-LED technology and first prototypes on imec's 300mm pilot-line infrastructure.

"Hardware development takes courage, capital and time. We are proud of the entrepreneurship of our engineers to bring promising technology developments originating from our R&D to the market," says imec's president & CEO Luc Van den hove. "Based on an original concept launched now more than two years ago by the MICLEDI team, imec together with imec.xpand incubated this into a promising technology base and exciting business case. It leverages imec's extensive R&D in organic displays, 300mm integration and wafer-scale optics technologies," he adds.

"MICLEDI's new-generation display for AR glasses fits in PMV's strategy of supporting early-stage technology with a large-scale international potential, hence strengthening Flanders' position as a top region," states Roald Borré, head of equity investments at PMV.

Osram boosts Ostar Projection Power LED family beyond 3000 ANSI lumens, rivaling high-pressure discharge lamps

SemiconductorToday

As projectors have become more and more popular in home entertainment systems, so have the expectations of users. In addition to ever-higher resolution, the focus is also on richer colors, contrasts and higher brightness. Osram Opto Semiconductors GmbH of Regensburg, Germany says that, with the Ostar Projection Power family,

it has succeeded for the first time in achieving projector brightness levels beyond the 3000 ANSI lumen barrier using LEDs instead of conventional lamps, making them accessible to a broad market.

Depending on the ambient light conditions and the distance to the projection surface, requirements differ for the light source. Osram says that, with 12 new products, it can now offer three different power classes for RGB solutions in deep blue (440nm), blue (456nm), converted green (520nm) and amber (614nm) wavelengths. In the lowest power class, two chips of the same color per component provide projector brightness of up to 1500 ANSI lm. In the mid-power class, four chips of the same color per component can achieve 2500 ANSI lm. In the highest-power class, six chips of the same color per LED can achieve more than 3000 ANSI lm. As a result, products from the Ostar Projection Power family present an alternative to the high-pressure discharge lamps previously used in projectors above 2000 ANSI lm.

Osram says that this leap in performance was achieved by, among other things, improved chip and package technology. The developers have fundamentally modified the individual LED chips, allowing them to be electrically connected in a series on the copper board. The system designer benefits not only from a significantly lower operating current (with the same power consumption) and reduced complexity of the LED driver but also from the much simpler contacting of the component, says the firm. In addition, direct coupling of the LEDs to a heat sink is possible, without additional isolation costs.

The mechanical design remains largely unchanged compared to previous products, enabling fast and uncomplicated exchange of the products in existing projector systems.

“With products from the Osram Ostar Projection Power family, we have successfully crossed the 3000 ANSI lumens barrier using LED technology,” says Wolfgang Schnabel, product manager in the Visualization & Laser division. “Our customers can easily integrate the new components in their desired power class into their system design and replace conventional lamps with state-of-the-art LED systems,” he adds.

OTHER

JST’s NexTEP program yields bulk GaN crystal growth equipment based on THVPE

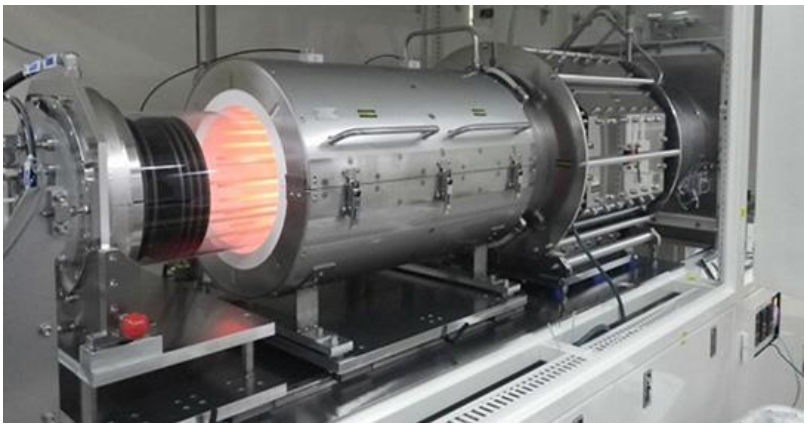
SemiconductorToday

The Japan Science and Technology Agency (JST) has developed bulk gallium nitide (GaN) growth equipment based on the tri-halide vapor phase epitaxy (THVPE) method, a development topic of NexTEP (the ‘Newly extended Technology transfer Program’). Development towards commercial application was carried out by the Innovation and R&D Division of Taiyo Nippon Sanso from August 2013 to March 2019, based on the research of professor Akinori Koukitsu of the Tokyo University of Agriculture and Technology. The team has hence developed GaN crystal manufacturing equipment that achieves high speed, high quality and continuous growth.

Most GaN substrates used in electronic devices are manufactured using hydride vapor phase epitaxy (HVPE). Compared with other practical vapor deposition methods such as metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE), HVPE offers a faster growth rate (100 microns per hour) together with the benefit of fewer carbon impurities.

However, it is difficult to produce thick GaN crystals using HVPE due to distortions in the crystal, and GaN crystals are grown on a heterogeneous seed crystal substrate, then repeatedly peeled off at a thickness of less than 1mm for use. Commercially practical manufacturing of GaN crystals has hence not been possible so far due

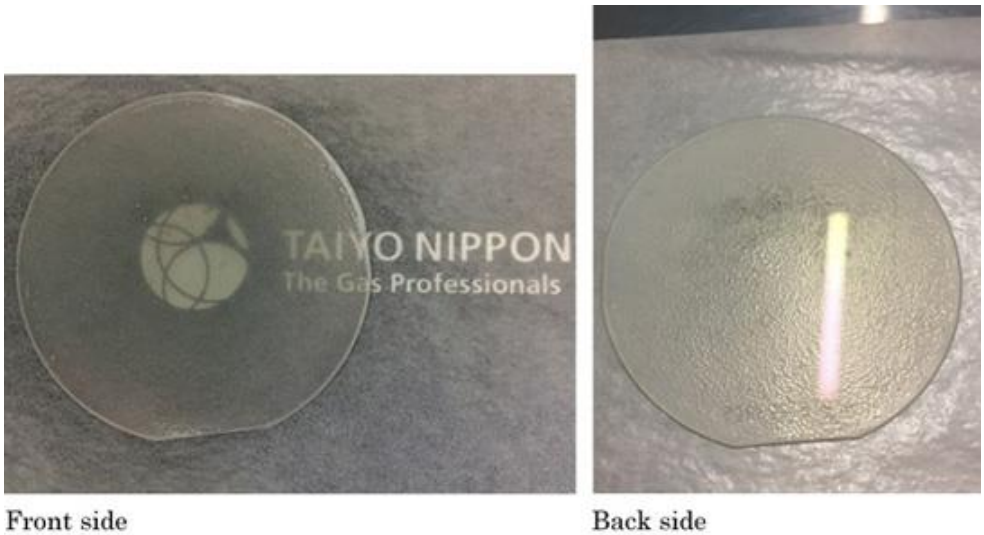
to the cost and crystal quality, particularly in the light of the pre- and post-work required in the process, such as cleaning the furnace.



Picture: THVPE crystal growth furnace. ©Taiyo Nippon Sanso Co.

Taiyo Nippon Sanso has advanced the HVPE method to develop a GaN crystal production system that achieves high-speed, high-quality, continuous growth through the tri-halide vapor phase epitaxy method utilizing a gallium trichloride-ammonia reaction system. THVPE succeeds in forming high-quality crystals at a high growth rate three times faster than conventional methods, with only one-fifth the existing density of dislocation defects. The new THVPE method is also said to offer cost advantages over existing techniques, such as not degrading the quartz glass tube of the reactor, avoiding the reduction of crystal growth area, and reducing the occurrence of unnecessary polycrystals.

In particular, when using the standard HVPE method to grow GaN crystals, a particular surface on the crystal will begin growing at a faster rate, and the crystal will continue growing from that surface point as it thickens. The crystal growth area hence decreases as it grows, leading to a turret-like shape. In contrast, THVPE uses the N-polar surface for crystal growth, opposite to the Ga surface. This leads to the reverse phenomenon, and the uppermost growth surface does not decrease even as the crystal grows.



Picture: Front side: transparent - no unnecessary polycrystals are generated on the wafer edge. Back side: since the surface is smooth, the fluorescent light is reflected.

If the THVPE technique can be further developed to achieve production of thick GaN crystals, it should allow the mass production of GaN crystal substrates through slicing. The new technique is reckoned to hold strong promise for achieving a breakthrough in the development of low-cost, high-performance GaN devices.

Korean GaN epi foundry IVWorks raises $6.7m in Series B funding

SemiconductorToday

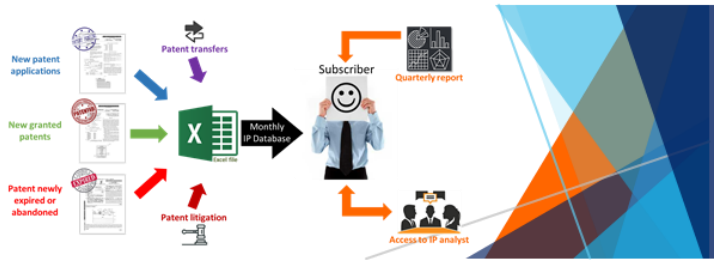
South Korea-based IVWorks, which manufactures gallium nitride (GaN) epitaxial wafers, has raised $6.7m in Series B funding, including follow-on funding from seed-round investor Samsung Venture Investment, joined by new investors such as KB Investment, KDB Bank and Dt&Investment. This boosts total funding to $10m.

IVWorks, which claims to be the first South Korean GaN epiwafer foundry to develop 8-inch GaN-on-Si epiwafers and 4-inch GaN-on-SiC epiwafers, says that it has recently entered into ODM (original design manufacturer) contracts with USA and Korean semiconductor companies and begun mass production.
The proceeds are expected to be used for ODM production and a planned capacity expansion, as well as upgrading the firm's artificial intelligence (AI)-based epitaxy production system.

Picture: IVWorks' GaN epitaxy facility.

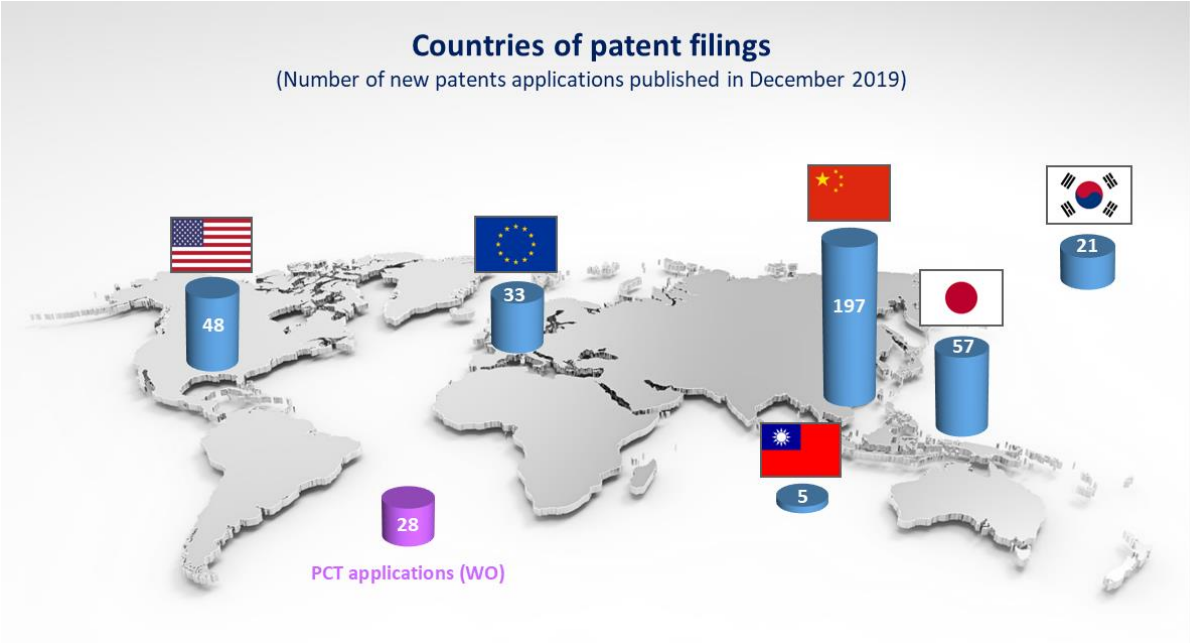
"We highly value its technological advantages, including the cost competitiveness it has secured through the advanced equipment technology and the defect reduction technology, as well as the revolutionary AI epitaxy technology," comments Samsung Venture Investment about IVWorks.

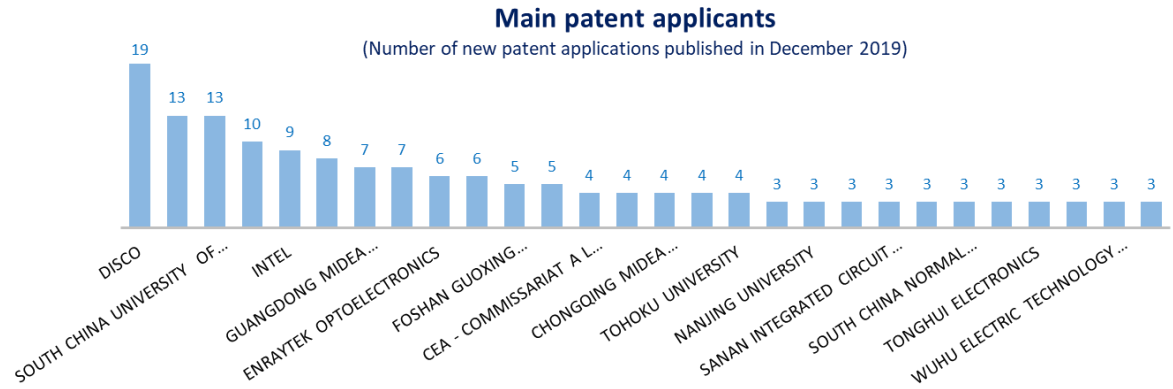
"GaN power devices, which are more efficient than existing silicon power devices and which can be miniaturized, are being applied to high-speed chargers, data-server power supplies, LiDAR sensors, etc, thereby rapidly replacing silicon power devices," says IVWorks' CEO Young-kyun Noh. "Additionally, as GaN RF devices are being used as an essential component in 5G communication base stations, the demand for GaN epiwafers, which is a core material in GaN RF devices, is also rapidly rising," he adds. "We expect to expand our market share rapidly through the supply of the contracted ODM volume and preemptive capacity expansion."



PATENT APPLICATIONS

More than 300+ **new patent families (inventions)** were published in **December 2019**.





Other patent applicants Disco, Midea, South China University of Technology, Xidian University, Intel, Mitsubishi Electric, Guangdong Midea Refrigeration Equipment, Zhong Zheng Bo Xin Semiconductor, Enraytek Optoelectronics, Zhongshan Institute of Modern Industrial Technology South China University of Technology, Foshan Guoxing Semiconductor Technology, Suzhou Institute of Nano Technology & Nano Bionics Chinese Academy of Sciences, Cea - Commissariat à l'Energie Atomique & Aux Energies Alternatives, Central South University, Chongqing Midea Refrigeration Equipment, Stanley Electric, Tohoku University, Huazhong University of Science & Technology, Nanjing University, Nikkiso, Sanan Integrated Circuit Manufacturing, Shenzhen Wins Semiconductor Research Institute, South China Normal University, Sun Yat Sen University, Tonghui Electronics, Vishay Siliconix, Wuhu Electric Technology Optical Electronic, Xiangneng Hualei Optoelectronic Corppration, Akoustis, Beijing University of Technology, Chip Foundation Technology, Datong Xincheng New Material, Efficient Power Conversion, GD Midea Air Conditioning Equipment, Hamamatsu Photonics, Hanyang University Industry University Cooperation Foundation, Hebei University of Technology, Hunan University, IBM, Jade Bird Display, Macom Technology Solutions Holdings, Nanjing Xinyun Electronic Technology, Rohm, Sciocs, Semiconductor Components Industries, Seoul Viosys, Siemens Mobility, Sumitomo Chemical, Suzhou Zican Technology, TCL, Toshiba,

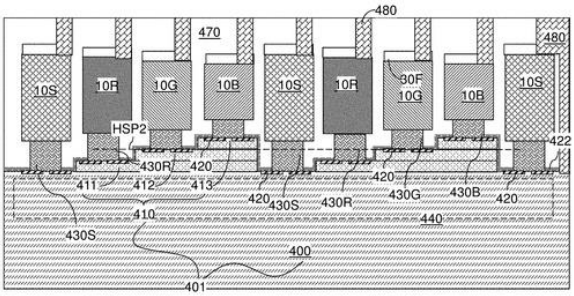
University of California, University of Electronic Science & Technology of China, University of Science & Technology of China, Vanguard International Semiconductor, Xiamen Changelight, 13th Research Institute of China Electronics Technology, Actron Technology, Advanced Micro Fabrication Equipment, Aixtron, Anhui Huaxin Electric Polytron Technologies, Anyang Normal University, Beijing Hurricane Core Technology, BOE Technology, Changchun Institute of Optics Fine Mechanics & Physics Chinese Academy of Sciences, Chemical Technology Academy of Shandong Province, China Electronics Technology, Conary Enterprise, Cree, Dale Electronics, Delta Electronics, Denso, Dongguan Institute of Opto Electronics Peking University, Dongguan University of Technology, Engine Techwin, Epistar, Excelliance MOS, Facebook Technologies, Fairchild Semiconductor, Faraday Semi, Filnex, Fudan University, Fuzhou Internet of Things Open Laboratory, Fuzhou University, Gemini Semiconductor Manufacturing, Glo, Gloria Technology, Gpower Semiconductor, Guangdong University of Technology, Guangdong Vital Materials, Gwangju Institute of Science & Technology, Haidike Photoelectric Science & Technology, Hauni Maschinenbau, Hefei Irico Epilight Technology, Hefei Jingdongfang Zhuoying Technology, Huaiyin Teachers College, Hubei Duvtek, Indian Institute of Science, Indian Institute of Technology Bombay, Innoscience Technology

Notable new patent applications

Epitaxial gallium nitride-based light emitting diode and method of making thereof

Publication Number: US20190386173, WO2019/240894
Patent Applicant: glo

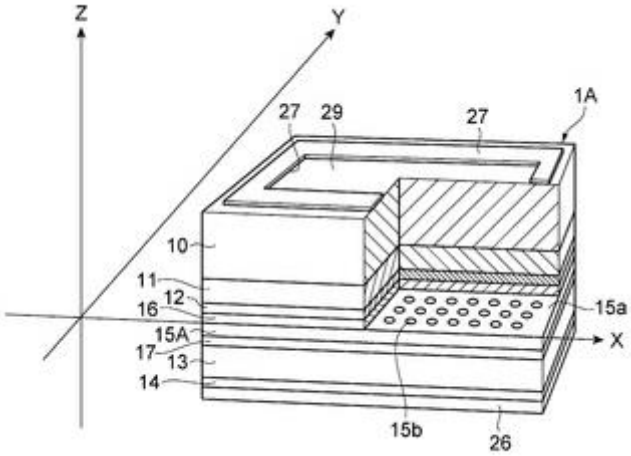
A light emitting diode includes a n-doped region, a p-doped region, and a light emitting region located between the n-doped region and a p-doped region. The n-doped region includes a first GaN layer, at least one n-doped second GaN layer located over the first GaN layer, an AlGaN dislocation blocking layer located over the at least one n-doped second GaN layer, and a n-doped third GaN layer located over the AlGaN dislocation blocking film.



Light-emitting device

Publication Number: JP2019220574, WO2019/244943
Patent Applicant: Hamamatsu Photonics

A light-emitting device according to an embodiment of the present invention is provided with a structure for increasing the light confinement factor in a layer forming a resonance mode. Said light-emitting device is provided with: a first clad layer; an active layer; a second clad layer; a resonance-mode forming layer, and a high-refractive-index layer. The first clad layer, the active layer, the second clad layer, the resonance-mode forming layer, and the high-refractive-index layer mainly contain nitride semiconductors. The high-refractive-index layer has a refractive index that is greater than the refractive index of any one of the first clad layer, the active layer, the second clad layer, and the resonance-mode forming layer, and has a superlattice structure in which two or more layers having refractive indexes that are different from each other are repeatedly laminated.



Parasitic capacitance reduction in GaN-on-Silicon devices

Publication Number: WO2019/236702
Patent Applicant: Macom

A method for making a semiconductor structure includes defining one or more device areas and one or more interconnect areas on a silicon substrate, forming trenches in the interconnect areas of the silicon substrate, oxidizing the silicon substrate in the trenches to form silicon dioxide regions, forming a Ill-nitride material layer on the surface of the silicon substrate, forming devices in the device areas of the gallium nitride layer, and forming interconnects in the interconnect areas. The silicon dioxide regions reduce parasitic capacitance between the interconnects and ground.

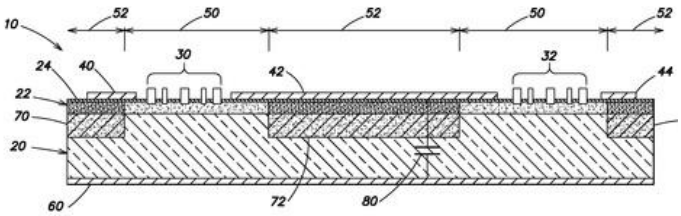


FIG. 1

Scalable multi-level power converter

Publication Number: WO2019/236861
Patent Applicant: Magna International, University of Windsor

A multilevel power converter, or inverter, for converting a direct current electrical power to an alternating current electrical power includes one or more 2-level converters each including gallium nitride (GaN) transistors configured to switch two input lines to a three-phase output line. The multilevel power converter may be used in a motor drive circuit, which may provide a 3-phase AC supply. Two power converters, which may be 2-level or 3-level power converters, may be alternately switched to provide the AC power to an AC motor by an output stage including bi-directional switching transistors configured to switch a corresponding three-phase output lines from the multilevel power converters. The multilevel power converters switch input lines from a neutral-point clamped input stage including capacitors connected in series across input terminals having a DC voltage therebetween to energize a midpoint terminal with an intermediate voltage half of the voltage between the input terminals.

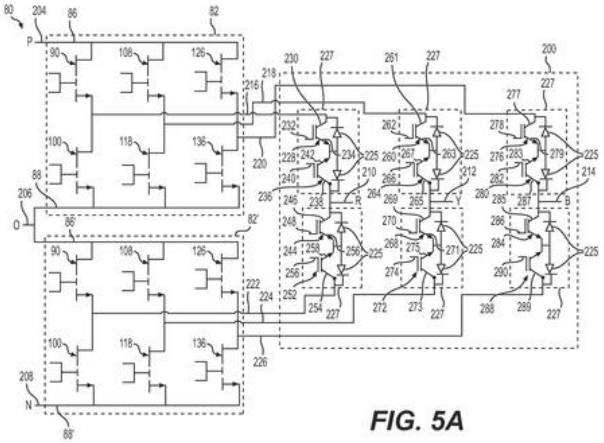
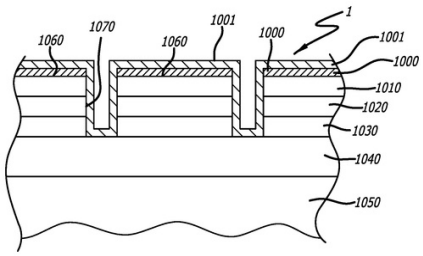


FIG. 5A

Device and method for III-V light emitting micropixel array device having hydrogen diffusion barrier layer

Publication Number: US20190378957, WO2019/241159
Patent Applicant: Ostendo

Solid state light emitting micropixels array structures having hydrogen barrier layers to minimize or eliminate undesirable passivation of doped GaN structures due to hydrogen diffusion.



Gallium nitride power amplifier integration with metaloxide-semiconductor devices

Publication Number: WO2019/236231
Patent Applicant: Qualcomm

Certain aspects of the present disclosure provide a semiconductor device (100). One example semiconductor device generally includes a substrate, a semiconductor region disposed adjacent to the substrate, first fin(s) (106) disposed adjacent to the semiconductor region, first gate region(s) (112) disposed adjacent to the first fin(s), first drain contact(s) (116) disposed above the first fin(s), first source contact(s) (118) disposed below the substrate, a second fin (132) disposed above the semiconductor region, and a second gate region (136, 140), second source contact and second drain contact disposed adjacent to the second fin and above the semiconductor region. First path(s) (120) are formed between the first drain contact(s) and the first source contact(s) for current flow(s) through the first fin(s) in a vertical direction along the first path(s). A second path (144) is formed between the second source contact and the second drain contact for current flow through the second fin in a horizontal direction along the second path.

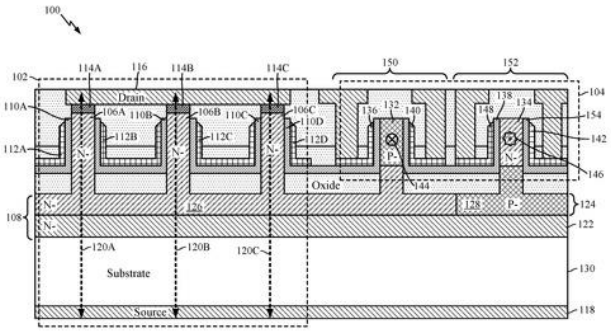
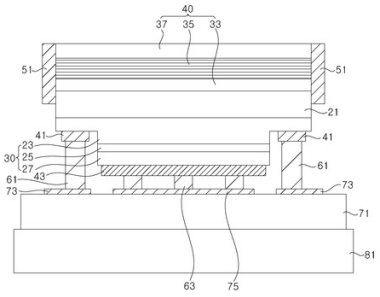


FIG. 1

Group III-V light-emitting diode

Publication Number: WO2019/240428
Patent Applicant: Seoul Viosys

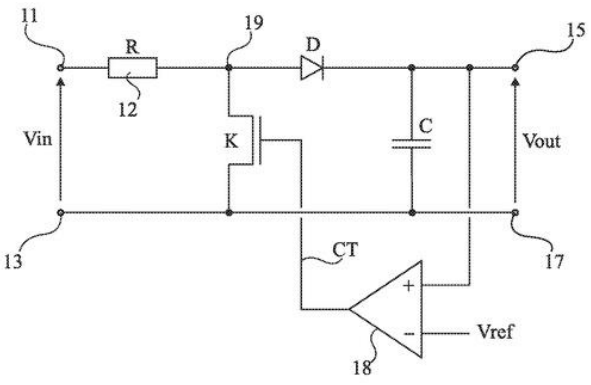
A group III-V light-emitting diode is provided. The light-emitting diode comprises: a light generating unit including an active layer interposed between a first conductive semiconductor layer and a second conductive semiconductor layer to generate light; an optical trap unit disposed on a propagation path of the light generated in the active layer and including a light absorbing layer interposed between light guide layers; and a side reflector disposed on a side of the optical trap unit.



Voltage down-converter

Publication Number: FR3083037, US20190393781, EP3588760
Patent Applicant: Cea

The present disclosure concerns a DC voltage step-down converter, including: at least one first resistive element (12) in series with a first switch (K) between a first terminal (11) and a second terminal (13) of application of a first DC voltage (Vin); and a capacitive element (C) between a third terminal (15) and a fourth terminal (17) for supplying a second DC voltage (Vout) smaller than the first one, the node (19) between said first resistive element (12) and the first switch (K) being coupled by a diode to said third terminal, said first switch (K) being turned on when the second voltage (Vout) is greater than a reference voltage (Vref) of the second voltage.

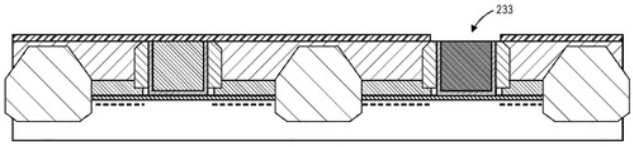


Work function based approaches to transistor threshold voltage tuning

Publication Number: US20190393332, DE102019110235, CN110634941

Patent Applicant: Intel

A semiconductor device is disclosed. The semiconductor device includes a substrate, an epitaxial layer on the substrate, a semiconductor interlayer on top of the epitaxial layer, a gate conductor above the semiconductor interlayer, a gate insulator on the bottom and sides of the gate conductor and contacting the top surface of the semiconductor interlayer, a source region extending into the epitaxial layer, and a drain region extending into the epitaxial layer. The semiconductor device also includes a first polarization layer on the semiconductor interlayer between the source region and the gate conductor and a second polarization layer on the semiconductor interlayer between the drain region and the gate conductor.

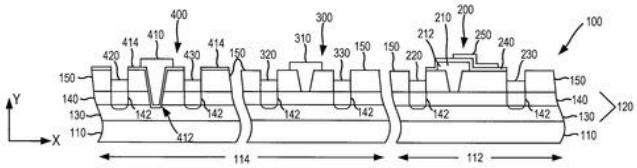


Monolithic microwave integrated circuits having both enhancement-mode and depletion mode transistors

Publication Number: US10516043

Patent Applicant: Cree

A gallium nitride based monolithic microwave integrated circuit includes a substrate, a channel layer on the substrate and a barrier layer on the channel layer. A recess is provided in a top surface of the barrier layer. First gate, source and drain electrodes are provided on the barrier layer opposite the channel layer, with a bottom surface of the first gate electrode in direct contact with the barrier layer. Second gate, source and drain electrodes are also provided on the barrier layer opposite the channel layer. A gate insulating layer is provided in the recess in the barrier layer, and the second gate electrode is on the gate insulating layer opposite the barrier layer and extending into the recess. The first gate, source and drain electrodes comprise the electrodes of a depletion mode transistor, and the second gate, source and drain electrodes comprise the electrodes of an enhancement mode transistor.

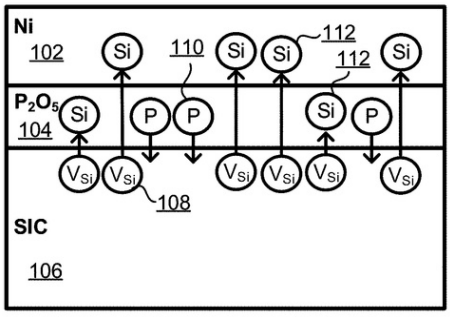


Gallidation-assisted impurity doping

Publication Number: US20190393038

Patent Applicant: Lawrence Livermore National Security

In one embodiment, a product includes a structure comprising a material of a Group-III-nitride having a dopant, where a concentration of the dopant in the structure has a concentration gradient characteristic of diffusion of the dopant inward from at least a portion of a surface of the structure in a direction substantially normal to the portion of the surface. The structure has less than 1% decomposition of the Group-III-nitride at the surface of the structure.

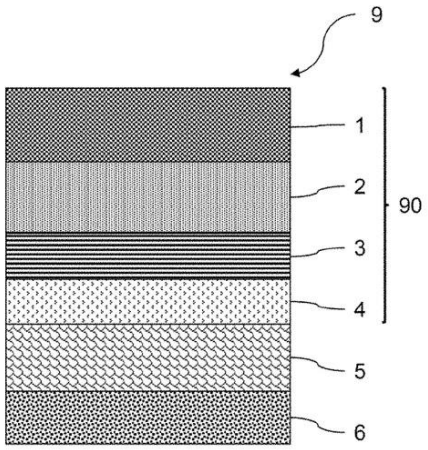


Method for manufacturing a GaN type light-emitting diode

Publication Number: FR3082053, EP3576165, US20190371963, KR10-2019-0135944

Patent Applicant: Cea

A method for manufacturing a light-emitting diode is provided, including the following steps in succession, while maintaining a substrate in a vapour-phase epitaxial growth chamber: epitaxial deposition, with an atmosphere having a first non-zero concentration of ammonia in the chamber, of a first GaN alloy layer P-doped with magnesium; epitaxial deposition, on the first GaN alloy layer, of a sacrificial GaN alloy layer in a second atmosphere in the chamber that is not supplied with magnesium; placing the second atmosphere inside the chamber under conditions with a second concentration of ammonia that is at least equal to a third of the first non-zero concentration so as to remove the sacrificial GaN layer; and then epitaxial deposition of a second N-type doped GaN alloy layer so as to form a tunnel junction with the first GaN alloy layer.

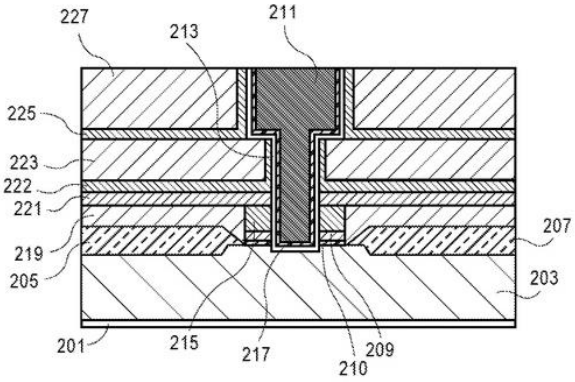


Methods of transistor gate structuring using single operation dummy gate removal

Publication Number: US20190393041, EP3584841, CN110620144

Patent Applicant: Intel

A transistor gate is disclosed. The transistor gate includes a first part above a substrate that has a first width and a second part above the first part that is centered with respect to the first part and that has a second width that is greater than the first width. The first part and the second part form a single monolithic T-gate structure.

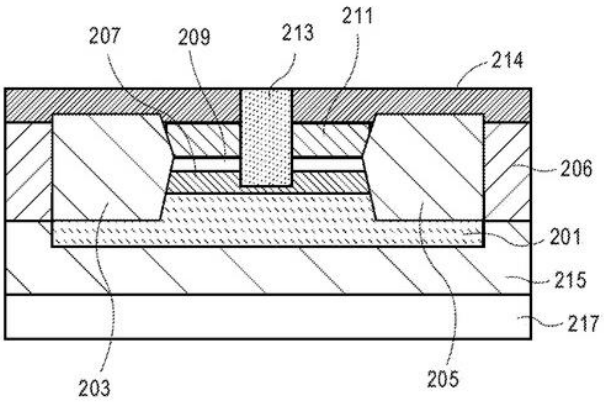


Implants to enlarge schottky diode cross-sectional area for lateral current conduction

Publication Number: US20190393210, CN110634859, DE102019116910

Patent Applicant: Intel

A semiconductor device is disclosed. The semiconductor device includes a substrate, an epitaxial layer above the substrate, a Schottky barrier material on the epitaxial layer, a Schottky metal contact extending into the Schottky barrier material, a fin structure that extends in a first direction, a first angled implant in a first side of the fin structure that has an orientation that is orthogonal to the first direction, and a second angled implant in a second side of the fin structure that has an orientation that is orthogonal to the first direction. The second side is opposite to the first side. A first cathode region and a second cathode region are coupled by parts of the first angled implant and the second angled implant that extend in the first direction.



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