Coordinated by CRHEA-CNRS research laboratory, this monthly newsletter is produced by Knowmade in collaboration with the managers of GANEXT groups. The newsletter presents a selection of newest scientific publications, patent applications and press releases related to Optoelectronics (LED, micro-LED, laser, photonics, etc.) and Electronics (Power, RF, advanced electronics, etc.) based on III-Nitride semiconductors (GaN, AlN, InN and alloys).

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Cluster of Excellence (Labex, 2020-2024)
GANEXT is a cluster gathering French research teams involved in GaN technology. The objective of GANEXT is to strengthen the position of French academic players in terms of knowledge and visibility, and reinforce the French industrial players in terms of know-how and market share. GANEXT replaces and succeed GANEX Cluster of Excellence (Labex 2012-2019).
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IMPORTANT NOTE:

The end of GaNeX Cluster of Excellence program (Labex 2012-2019) was scheduled on December 2019. However, the French government decided to expand the labex program for five additional years, in order to further strengthen the synergy between French academic research organizations and industrial players in the field of GaN optoelectronics and electronics. Therefore, GANEXT Cluster of Excellence program will replace and succeed GaNeX for the next five years (2020-2024).

Accordingly, the GANEXT newsletter will follow and adapt to the new program, focusing on scientific publications, patent applications and press releases related to optoelectronics (LED, µ-LED, laser, photonics, etc.) and electronics (power, RF, advanced electronics, etc.), ruling out publications which are not related to one of these two families of applications. For instance, publications dealing with MEMS, sensors, photovoltaics, nanostructures, semi-polar and non-polar materials, fundamental physics, etc. that do not obviously relate to optoelectronic or electronic applications will not be included in the GANEXT newsletter.

Besides, a panel of GANEXT experts will continue to interact with Knowmade team in order to select the most relevant publications of the month, consistently with GANEXT’s ongoing projects.

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**METHODOLOGY**

**SEARCH & SELECTION OF NOTEWORTHY INFORMATION**

- **Scientific publications**
  - Scientific Journal Editors: *nature*, *Elsevier*, *IEEE*, *AIP*, *Springer*, etc.
  - 250+ publications monthly

- **Press releases**
  - Specialized Press: *semiconductor Today*, *Micronews*, etc.
  - 30+ publications monthly

- **Patents**
  - Patent Database: *Questel*
  - 300+ publications monthly

**Segmentation by KnowMade analysts**

- OPTOELECTRONICS: LED / µ-LED, Laser, Optics, Photonics, etc.
- ELECTRONICS: Power electronics, RF electronics, Advanced electronics, etc.

**Refinement of the selection by KnowMade analysts**

**Exhaustive III-N publications database**

**Refinement of the selection by GANEXT experts**

**Monthly GANEXT newsletter**

- **New scientific III-N publications**
  - I. Optoelectronics
  - II. Electronics

- **Press releases**
  - (business, conference, ...)

- **Patent publications**
  - (IP players, notable inventions)
Influence of the Strain Relaxation on the Optical Property of AlGaN Quantum Wells

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physica status solidi b
https://doi.org/10.1002/pssb.201900582

The influence of strain relaxation on the optical properties of AlGaN quantum wells (QWs) is investigated. The relaxation ratio is controlled by changing the thickness of an AlGaN buffer layer. The relaxation ratio increases from 20% to 100% with increasing the AlGaN layer thickness from 0.5 to 6.0 μm. Photoluminescence (PL) intensity reaches maximum at a relaxation ratio of 36%, which implies competing effects in radiative and nonradiative recombinations. From the viewpoint of radiative recombination, strain relaxation increases the polarization field in the QW, which decreases the electron–hole overlap. The observed gradual decrease in PL may come from this effect. In terms of nonradiative recombination, the dislocation density is nearly constant up to 4.5 μm from the AlN/AlGaN interface, and decreases at 6.0 μm. Therefore, it is difficult to explain the observed PL intensity by the dislocation-related nonradiative pathways. Instead, relieved strain can decrease the point-defect density. Strain relaxation can reduce the vacancy concentration as a result of increased formation energy with the partial relief of compressive strain. The effect of strain on the band structure change is also discussed, where the relieved compressive strain increases the crystal-field split-off component in the valence band maximum, resulting in a decreased PL intensity.

GaN microdisk with direct coupled waveguide for unidirectional whispering-gallery mode emission

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Optics Letters
https://doi.org/10.1364/OL.381767

Microdisks are excellent whispering-gallery mode (WGM) optical resonators, but their emissions are invariably in-plane isotropic due to their circularities and thus difficult to be extracted efficiently. In this work, a waveguide with a width of 0.16 μm directly coupled to a microdisk with a diameter of 10 μm is fabricated on a 0.77 μm thick GaN thin film containing InGaN/GaN multi-quantum wells. This eliminates the need for precision patterning required by evanescent coupling schemes in which coupling gaps of the order of tens of nanometers must be maintained. The fabrication was carried out using nanosphere and nanowire lithography. Non-evanescent coupling of WGMs to the waveguide from the microdisk is successfully demonstrated.

High Crystallinity and Highly Relaxed Al0.60Ga0.40N Films Using Growth Mode Control Fabricated on a Sputtered AlN Template with High-Temperature Annealing

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physica status solidi a
https://doi.org/10.1002/pssa.201900868

Herein, a method for growing AlGaN using an intermediate AlN molar fraction on a sputtered AlN template with high-temperature annealing via an AlN homoepitaxial layer is investigated. The growth mode dependence of AlGaN on the amount of Ga doping in the AlN homoepitaxial layer is examined in detail. As a result, homoepitaxial growth of AlN on sputtered AlN
improve the surface flatness. In addition, it is found that the macroscopic flatness is improved by increasing the amount of Ga doping, but this decreases the microscopic flatness. Moreover, when Al0.60Ga0.40N is grown on homoeptaxial AlN layers with different amounts of Ga doping, a difference in the growth mode is observed, and this reveals a remarkable difference in the dislocation density of Al0.60Ga0.40N. The dislocation density dependence of the lasing threshold power density in a UV–B optical pumped laser is also investigated. As a result, the lasing threshold power density is reduced from ≈220 to 50 kW cm−2 by reducing the dislocation density from 1.6 × 109 to 8.0 × 108 cm−2. It is confirmed that it is, therefore, essential to reduce the dislocation density to reduce the threshold power density of the UV–B laser.

UV light-emitting diodes grown on GaN templates with selective-area Si implantation
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Department of Photonics, National Cheng Kung University, Tainan 70101, Taiwan
Optics Express
https://doi.org/10.1364/OE.386512

This study demonstrates that selective-area Si implantation performed on the GaN templates instead of conventional dielectric layers, such as SiO2 or SiNx, serves as the mask layer for the epitaxial lateral overgrowth (ELOG) process. Although the substantial mask layer is absent on the templates, selective growth initially occurs on the implantation-free area and then evolves a lateral overgrowth on the Si-implanted area during the regrowth process. This selective growth is attributed to that the crystal structure of the Si-implanted area subjected to the high doses of ion bombardment produces an amorphous surface layer, thereby leading to a lattice mismatch to the regrown GaN layer. Microstructural analyses reveal that the density of the threading dislocations above the Si-implanted regions is markedly lower than the GaN layer in the implantation-free regions. Consequentially, UV LEDs fabricated on the Si-implanted GaN templates exhibit relatively higher light output and lower leakage current compared with those of LEDs grown on ELOG-free GaN templates.

Epitaxial Growth and Characterization of AlInN-Based Core-Shell Nanowire Light Emitting Diodes Operating in the Ultraviolet Spectrum
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Scientific Reports
https://doi.org/10.1038/s41598-020-59442-0

We report the demonstration of the first axial AlInN ultraviolet core-shell nanowire light-emitting diodes with highly stable emission in the ultraviolet wavelength range. During epitaxial growth of the AlInN layer, an AlInN shell is spontaneously formed, resulting in reduced nonradiative recombination on the nanowire surface. The AlInN nanowires exhibit a high internal quantum efficiency of ~52% at room temperature for emission at 295 nm. The peak emission wavelength can be varied from 290 nm to 355 nm by changing the growth conditions. Moreover, significantly strong transverse magnetic (TM) polarized emission is recorded, which is ~4 times stronger than the transverse electric (TE) polarized light at 295 nm. This study provides an alternative approach for the fabrication of new types of high-performance ultraviolet light emitters.

High-power hybrid GaN-based green laser diodes with ITO cladding layer
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Photonics Research
https://doi.org/10.1364/PRJ.381262

Green laser diodes (LDs) still perform worst among the visible and near-infrared spectrum range, which is called the “green gap.” Poor performance of green LDs
is mainly related to the p-type AlGaN cladding layer, which on one hand imposes large thermal budget on InGaN quantum wells (QWs) during epitaxial growth, and on the other hand has poor electrical property especially when low growth temperature has to be used. We demonstrate in this work that a hybrid LD structure with an indium tin oxide (ITO) p-cladding layer can achieve threshold current density as low as 1.6 kA/cm², which is only one third of that of the conventional LD structure. The improvement is attributed to two benefits that are enabled by the ITO cladding layer. One is the reduced thermal budget imposed on QWs by reducing p-AlGaN layer thickness, and the other is the increasing hole concentration since a low Al content p-AlGaN cladding layer can be used in hybrid LD structures. Moreover, the slope efficiency is increased by 25% and the operation voltage is reduced by 0.6 V for hybrid green LDs. As a result, a 400 mW high-power green LD has been obtained. These results indicate that a hybrid LD structure can pave the way toward high-performance green LDs.

**Continuous-wave operation of DFB laser diodes based on GaN using 10th-order laterally coupled surface gratings**

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Institute of Solid State Physics, Technische Universität Berlin, 10623 Berlin, Germany

**Optics Letters**
https://doi.org/10.1364/OL.385002

Single longitudinal mode continuous-wave operation of distributed-feedback (DFB) laser diodes based on GaN is demonstrated using laterally coupled 10th-order surface Bragg gratings. The gratings consist of V-shaped grooves alongside a 1.5 µm wide p-contact stripe fabricated by using electron-beam lithography and plasma etching. By varying the period of the Bragg grating, the lasing wavelength could be adjusted between 404.8 and 408.5 nm. The feasibility of this device concept was confirmed by mode-hop-free operation up to an optical output power of 90 mW, a low temperature sensitivity of the lasing wavelength, and a Gaussian lateral far-field distribution.

**Status and prospects of AlN templates on sapphire for UV LEDs**

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physica status solidi a
https://doi.org/10.1002/pssa.201901022

The scope of this work is to give an overview over the current status of AlN/sapphire templates for UVB and UVC LEDs with focus on the work done by our group. Furthermore we discuss approaches to improve the properties of such AlN/sapphire templates by the combination of high temperature annealing (HTA) and patterned AlN/sapphire interfaces. While the beneficial effect of HTA is demonstrated for UVC LEDs, the growth of relaxed AlGaN buffer layers on HTA AlN is a challenge. To achieve relaxed AlGaN with low dislocation density we have started to investigate the applicability of HTA for AlGaN.

**Continuous-wave operation of DFB laser diodes based on GaN using 10th-order laterally coupled surface gratings**

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Institute of Solid State Physics, Technische Universität Berlin, 10623 Berlin, Germany

**Optics Letters**
https://doi.org/10.1364/OL.385002

Single longitudinal mode continuous-wave operation of distributed-feedback (DFB) laser diodes based on GaN is demonstrated using laterally coupled 10th-order surface Bragg gratings. The gratings consist of V-shaped grooves alongside a 1.5 µm wide p-contact stripe fabricated by using electron-beam lithography and plasma etching. By varying the period of the Bragg grating, the lasing wavelength could be adjusted between 404.8 and 408.5 nm. The feasibility of this device concept was confirmed by mode-hop-free operation up to an optical output power of 90 mW, a low temperature sensitivity of the lasing wavelength, and a Gaussian lateral far-field distribution.

**Enhanced injection efficiency and light output in bottom tunnel-junction light-emitting diodes**

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**Optics Express**
https://doi.org/10.1364/OE.384021

Recently, the use of bottom-TJ geometry in LEDs, which achieves N-polar-like alignment of polarization fields in conventional metal-polar orientations, has enabled enhancements in LED performance due to improved injection efficiency. Here, we elucidate the root causes behind the enhanced injection efficiency by employing mature laser diode structures with optimized heterojunction GaN/In0.17Ga0.83N/GaN TJs and UID GaN spacers to separate the optical mode from the heavily doped absorbing p-cladding regions. In such laser structures, polarization offsets at the
electron blocking layer, spacer, and quantum barrier interfaces play discernable roles in carrier transport. By comparing a top-TJ structure to a bottom-TJ structure, and correlating features in the electroluminescence, capacitance-voltage, and current-voltage characteristics to unique signatures of the N- and Ga-polar polarization heterointerfaces in energy band diagram simulations, we identify that improved hole injection at low currents, and improved electron blocking at high currents, leads to higher injection efficiency and higher output power for the bottom-TJ device throughout 5 orders of current density (0.015–1000 A/cm²). Moreover, even with the addition of a UID GaN spacer, differential resistances are state-of-the-art, below $7 \times 10^{-4} \, \Omega$ cm². These results highlight the virtues of the bottom-TJ geometry for use in high-efficiency laser diodes.

**GaN:Eu,O-based resonant-cavity light emitting diodes with conductive AlInN/GaN distributed Bragg reflectors**

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ACS Appl. Electron. Mater. 9b00806

We demonstrate a GaN:Eu,O-based resonant-cavity light emitting diode (RCLED) fabricated with n-type conductive Al0.82In0.18N/GaN bottom-distributed-Bragg-reflectors (DBBR) and ZrO2/SiO2 top-DBRs, and made in order to manipulate both the radiative transition probability of Eu³⁺ ions and the light extraction efficiency. Shortening of the lifetime of Eu luminescence, along with an improved directionality of the light output is observed from the RCLED. These factors lead to a 4.8-times enhancement of the output power at room temperature as well as a peak enhancement of the electroluminescence intensity of 10.9 as compared to a conventional GaN:Eu,O-based LED. This is the first demonstration of red RCLED based on rare-earth-doped GaN and enables a significant enhancement of Eu luminescence of GaN:Eu,O-based red LED with a high color purity and temperature insensitive emission wavelength.

**High Responsivity and Wavelength Selectivity of GaN-Based Resonant Cavity Photodiodes**

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Advanced Optical Materials https://doi.org/10.1002/adom.201901276

The implementation of blue-light photodiodes based on InGaN in emerging technologies, such as free-space visible light communication (VLC), requires transformative approaches toward enhanced performance, miniaturization, and integration beyond current Si-based technologies. This work reports on the design and realization of high-performance InGaN-based resonant cavity photodiodes with high-reflectivity lateral porous GaN distributed Bragg reflectors. The well-controlled porosification of GaN on the 2-inch wafers enables design and fabrication of optical components, unlocking the potential of nitride semiconductors for several applications. These resonant-cavity-enhanced photodiodes, which have a 12 nm-thick optically active region, exhibit a high responsivity (≈0.1 A W⁻¹) to blue-light even without any externally applied voltage. Furthermore, the device can operate as both an emitter and a detector of visible light at well-defined wavelengths with spectral overlap between the electroluminescence emission and photocurrent responsivity, meeting the requirement of wavelength selectivity, thermal stability, and low-power consumption for VLC, with potential for integration of different functionalities, that is, light emission and detection, on a single chip without additional light filters.
High-Temperature Analysis of GaN-based MQW Photodetector for Optical Galvanic Isolations in High-Density Integrated Power Modules

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IEEE Journal of Emerging and Selected Topics in Power Electronics
https://doi.org/10.1109/JESTPE.2020.2974788

The InGaN/GaN MQW structure is demonstrated as a possible solution for high-temperature photodiode applications. High temperature spectral and noise analysis of InGaN/GaN MQW structure are performed for the potential integration as a detector in future power electronics applications. The spectral response was measured under photovoltaic and bias modes for the temperature range of 77 - 800 K. A peak spectral responsivity of 27.0 mA/W at 440 nm at 500 K is recorded. The peak external quantum efficiency of the device was calculated to be in the range of 5 - 8 % in the temperature range 77 - 800 K. The photodetector sensitivity of the structure is quantified using the material figure of merit parameter, D* for different temperature and biased voltages. A peak detectivity of 4 x 108 cmHz1/2W-1 is observed at 800 K with zero bias at 440 nm.

Molecular beam epitaxial growth and optical characterization of AlGaN nanowires with reduced substrate temperature

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AIP Advances
https://doi.org/10.1063/1.5140572

The requirement of high growth temperature for high-quality epitaxial AlGaN, which is typically around 100 °C higher than the growth temperature of GaN, is unfavorable for p-type dopant (Mg) incorporation, representing a grand challenge for AlGaN deep ultraviolet (UV) light-emitting devices. In this context, we show high-quality AlGaN nanowires emitting in the deep UV band grown at merely the growth temperature of GaN nanowires by molecular beam epitaxy. This is enabled by the discovery of a narrow GaN nanowire template growth window. We have further compared the room-temperature internal quantum efficiency of the samples emitting around 255 nm grown in the low-temperature regime and high-temperature regime. It is found that the sample grown in the low-temperature regime can possess optical quality close to the sample grown in the high-temperature regime. This study, therefore, suggests that even with a low growth temperature, using nanowire structures can still lead to AlGaN alloys with a relatively high optical quality, and the use of low substrate temperature could be beneficial for p-type doping.

InGaN Nanohole Arrays Coated by Lead Halide Perovskite Nanocrystals for Solid-State Lighting

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ACS Appl. Nano Mater.
https://doi.org/10.1021/acsanm.9b02154

Down-conversion of light via phosphors is central to the generation of white and multi-color emission for solid-state lighting. Lead halide perovskite nanocrystals (NCs) are viable contenders to phosphors as they offer higher emission yields with narrower linewidth and facile synthesis and compositional tunability across the visible. Herein, we employ green-emitting CsPbBr3 and FAPbBr3 and near infrared-emitting FAPbI3 NCs to efficiently down-convert the emission of InGaN/GaN structures. The nitride wafers are patterned into nanohole arrays which are filled by the perovskite NCs to minimize the nitride-NC separation while increasing the heterointerfacial area, thus improving light conversion via both non-radiative resonant and radiative energy transfer. The efficient
quenching of the nitride emission dynamics in the presence of the NC overlayers accompanied by a concurrent increase of the NC emission, provides evidence of efficient light down-conversion with efficiencies as high as ~83±6% in the green and ~74±5% in the near-IR.

**Widely separated optical Kerr parametric oscillation in AlN microrings**
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Optics Letters
https://doi.org/10.1364/OL.384317

Here, we report χ(3)-based optical parametric oscillation (OPO) with widely separated signal–idler frequencies from crystalline aluminum nitride microrings pumped at 2μm. By tailoring the width of the microring, OPO reaching toward the telecom and mid-infrared bands with a frequency separation of 64.2 THz is achieved. While dispersion engineering through changing the microring width is capable of shifting the OPO sideband by >9THz, the OPO frequency can also be agiley tuned in the ranges of 1 and 0.1 THz, respectively, by shifting the pump wavelength and controlling the chip’s temperature. At high pump powers, the OPO sidebands further evolve into localized frequency comb lines. Such large-frequency-shift OPO with flexible wavelength tunability will lead to enhanced chip-scale light sources.

**Deep ultraviolet monolayer GaN/AlN disk-in-nanowire array photodiode on silicon**
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Applied Physics Letters
https://doi.org/10.1063/1.5135570

Extreme confinement of carriers in GaN layers of thickness of the order of a monolayer leads to a large quantum confinement energy and very large electronic and optical bandgaps. We have exploited this to realize a photodiode with AlN nanowire arrays, grown on silicon substrates by plasma-enhanced molecular beam epitaxy, wherein multiple ~2 monolayer disks are inserted as the light absorbing region. Photoluminescence and photocurrent spectra confirm the optical gaps of the monolayer GaN. The photocurrent spectra show a peak at ~240 nm in the deep-ultraviolet region of the optical spectrum. The dark current of the photodiodes is ~10 nA at −6 V at room temperature. The peak quantum efficiency is 0.6%, and the noise-equivalent power is estimated to be 4.3 × 10−11W/Hz1/2. The bandwidth of the device is estimated to be limited to ~3 MHz by the series resistance and diode capacitance.

**Near-Strain-Free GaN/AlGaN Narrow Line Width UV Light Emission with Very Stable Wavelength on Excitation Power by Using Superlattices**
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https://doi.org/10.1021/acsaelm.9b00813

Because of the strong strain in nitrides, superlattice layers have been used to release the strain in the QW and reduce the quantum confined Stark effect. However, few reports discuss comprehensively the strain relaxation behavior and optical performance of a GaN/AlGaN single quantum well (QW) with inserted GaN/AlGaN superlattices (SLs). In this work, we examined a group of graded Al content GaN/AlxGa1−xN SL layers under the GaN/Al0.3Ga0.7N single QW grown on c-plane sapphire. Both the excitation power and temperature dependence of the time-integrated micro-photoluminescence (μ-PL) and time-resolved μ-PL were measured. The samples exhibited very narrow UV emission and had almost unchanged emission wavelength and stable line width behavior with excitation power as well as “S-shape” and weak “W-shape” characteristics with temperature due to the localization. The temperature-dependent PL lifetime was measured from 5 to 300 K, and the relatively fast recombination lifetime of the two samples was examined. Micro-Raman spectroscopy was also
conducted to probe the strain state. All the results showed that adopting SLs around the QW structure produced a much more stable and desirable performance, which can be attributed to an effective relaxation of the strain in the QW.

**Electrically injected GaN-based vertical-cavity surface-emitting lasers with TiO2 high-index-contrast grating reflectors**

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ACS Photonics

https://doi.org/10.1021/acsphotonics.9b01636

We demonstrate the first electrically injected GaN-based vertical-cavity surface-emitting lasers (VCSELs) with a TiO2 high-index-contrast grating (HCG) as the top mirror. Replacing the top distributed Bragg reflector (DBR) with an HCG offers substantial thickness reduction, polarization-pinning and setting of the resonance wavelength by the grating parameters. Conventional HCGs are usually suspended in the low refractive index material such as air in order to create the largest refractive index contrast. However, the mechanical stability of such structures can be questioned and creating free-hanging GaN-membrane on top of GaN is problematic. We have therefore fabricated TiO2-HCGs resting directly on GaN without an air-gap. No DBR layers are used below the HCG to boost the reflectivity. A VCSEL with an aperture diameter of 10 μm shows a threshold current of 25 mA under pulsed operation at room temperature. The lasing modes locate around 400 nm and are transversely electrically -polarized with a linewidth of 0.5 nm. The full-width half-maximum beam divergence is 10°. This demonstration of a TiO2-HCG VCSEL offers a new route to achieve polarization pinning and could also allow additional benefits such as post-growth setting of the resonance wavelength.

**High gain, large area, and solar blind avalanche photodiodes based on Al-rich AlGaN grown on AlN substrates**

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Department of Electrical and Computer Engineering, North Carolina State University, Raleigh, North Carolina 27695-7919, USA

Applied Physics Letters

https://doi.org/10.1063/1.5138127

We demonstrate large area (25 000 μm2) Al-rich AlGaN-based avalanche photodiodes (APDs) grown on single crystal AlN substrates operating with differential (the difference in photocurrent and dark current) signal gain of 100 000 at 90 pW (<1 μW cm−2) illumination with very low dark currents <0.1 pA at room temperature under ambient light. The high gain in large area AlGaN APDs is attributed to a high breakdown voltage at 340 V, corresponding to very high breakdown fields ~9 MV cm−1 as a consequence of low threading and screw dislocation densities <103 cm−2. The maximum charge collection efficiency of 30% was determined at 255 nm, corresponding to the bandgap of Al0.65Ga0.35N, with a response of 0.06 A/W. No response was detected for λ > 280 nm, establishing solar blindness of the device.

**Ultra-High Sensitivity Graphene/Nanoporous GaN Ultraviolet Photodetectors**

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ACS Appl. Mater. Interfaces

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Integration of graphene with three-dimensional semiconductors can introduce unique optical and electrical properties that overcome intrinsic limitation of the materials. Here, we report on the high
sensitivity ultraviolet (UV) photodetectors based on monolayer graphene/nanoporous GaN heterojunctions. By investigating the reflectivity, PL and Raman spectral characteristics of nanoporous GaN, we find that the increase of the porosity can help to improve its optical properties. The device based on the highest-porosity nanoporous GaN demonstrates rapid and linear response to UV photons, with an ultra-high detectivity of 1.0×10¹⁷ Jones and UV-visible rejection ratio of 4.8 × 10⁷ at V = -1.5 V. We attribute such high sensitivity to the combination of the significantly enhanced light harvesting of high-porosity nanoporous GaN, and the unique UV absorption, high mobility and finite density of states of monolayer graphene. The high performance together with a simple and low-cost fabrication process endow these graphene/nanoporous GaN heterojunctions with great potential for future selective detection of weak UV optical signals.

Comparison of size-dependent characteristics of blue and green InGaN microLEDs down to 1 μm in diameter

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There is growing interest in microLED devices with lateral dimensions between 1 and 10 μm. However, reductions in external quantum efficiency (EQE) due to increased nonradiative recombination at the surface become an issue at these sizes. Previous attempts to study size-dependent EQE trends have been limited to dimensions above 5 μm, partly due to fabrication challenges. Here, we present size-dependent EQE data for InGaN microLEDs down to 1 μm in diameter fabricated using a process that only utilizes standard semiconductor processing techniques (i.e., lithography and etching). Furthermore, differences in EQE trends for blue and green InGaN microLEDs are compared. Green wavelength devices prove to be less susceptible to reductions in efficiency with the decreasing size; consequently, green devices attain higher EQEs than blue devices below 10 μm despite lower internal quantum efficiencies in the bulk material. This is explained by smaller surface recombination velocities with the increasing indium content due to enhanced carrier localization.

Back-illuminated AlGaN heterostructure solar-blind avalanche photodiodes with one-dimensional photonic crystal filter

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AlGaN heterostructure solar-blind avalanche photodiodes (APDs) were fabricated on a double-polished AlN/sapphire template based on a separate absorption and multiplication (SAM) back-illuminated configuration. By employing AlGaN heterostructures with different Al compositions across the entire device, the SAM APD achieved an avalanche gain of over 1×10⁵ at an operated reverse bias of 92 V and a low dark current of 0.5 nA at the onset point of breakdown. These excellent performances were attributed to the acceleration of holes by the polarization electric field with the same direction as the reverse bias and higher impact ionization coefficient of the low-Al-content Al0.2Ga0.8N in the multiplication region. However, the Al0.2Ga0.8N layer produced a photocurrent response in the out of the solar-blind band. To retain the solar-blind detecting characteristic, a periodic Si3N4/SiO2 photonic crystal was deposited on the back of the AlN/sapphire template as an optical filter. This significantly improved the solar-blind characteristic of the device.
Unidirectional emission of GaN-based eccentric microring laser with low threshold
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To reduce the threshold and achieve unidirectional lasing emission in a whispering gallery mode microcavity, we propose and demonstrate a GaN-based eccentric microring with an inner hole located off the center. Compared to microdisk with the same outer diameter, the eccentric microring structure exhibits a remarkable reduction of lasing threshold by up to 53%. The introduction of the hole disturbs and eventually suppresses the field distribution of the higher order modes. Laser emission with high unidirectionality with a far-field divergence angle of about 40° has been achieved, meanwhile the Q factor of the whispering gallery modes is remains high as 6388. Finite-difference time-domain numerical simulation is carried out to prove that the far-field profile of the eccentric microring structure can be controlled by the position and the size of the hole. The properties of the whispering gallery mode microcavities are improved greatly through a simple structure and process, which has an important guiding significance to the research and development of the microcavity lasers.

Highly responsive, self-powered a-GaN based UV-A photodetectors driven by unintentional asymmetrical electrodes
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Optoelectronic properties of nonpolar a-plane GaN are superior along [0002] azimuth direction compared to other azimuth directions. We have grown a-GaN on r-sapphire and IDE patterns of Au were fabricated to restrict the carrier transport only along [0002] azimuth. Surprisingly, the Schottky barriers of Au/GaN were found to be asymmetric in nature as the current on the positive side was different than negative for the same bias. Polarization on the boundaries of the basal plane defects has been already investigated for the possible reason of the Schottky barrier inhomogeneity. Thus, it can be expected that the overall effect of these polarization centers would change the Schottky barrier height of one of the electrodes. Electronic band-alignment based on asymmetrical contacts reveals that difference in Schottky barrier height would create a net electrical field towards the higher Schottky barrier, which is exploited here for self-powered photodetection and also enhanced photodetection and higher applied bias. The spectral response of all the devices was studied within 300-700 nm and it was found that spectral response enhances with applied voltage. The maximum responsivity and detectivity for 364 nm light source observed at 5 V was around 400 AW−1 and 6.6×1012 Jones while at 0 V it was 4.67 m AW−1 and 3.0×1013 Jones, respectively, which is the highest known responsivity for a-plane GaN to the best of our knowledge. The spectral response shows that the devices work for a very narrow band of radiation and hence can be used for selective UV-A photodetection. Overall, these results demonstrate much-improved UV photodetection properties compared to existing GaN-based photodetectors.

Effects of Different InGaN/GaN Electron Emission Layers/Interlayers on Performance of a UV-A LED
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Appl. Sci.
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In this study, we investigated the effects of InGaN/GaN-based interlayer (IL) and electron emitting layer (EEL) consisting of a GaN barrier layer grown with different metal-organic (MO) precursors of gallium (Ga), which were grown underneath the active layer. The growth behavior of GaN with triethyl Ga (TEGa)
showed an increasing growth time due to a lower growth rate compared with GaN grown with trimethyl Ga (TMGa), resulting in the formation of columnar domains and grain boundary with reduced defect. UV-A light emitting diode (LED) chips with three types of ILs and EELs, grown with different MO sources, were fabricated and evaluated by light output power (LOP) measurements. The LOP intensity of UVLED-III with the GaN barrier layer-based IL and EEL grown by TEGa was enhanced by 1.5 times compared to that of the IL and EEL grown with TMGa at 300 mA current injection. Use of the GaN barrier layer in ILs and EELs grown by TEGa improved the crystal quality of the post grown InGaN/GaN multiple quantum well, which reduces leakage current. Therefore, for the UV-A LED with ILs and EELs grown with TEGa MO precursors, electrical and optical properties were improved significantly.

Ultra-High and Fast Ultraviolet Response Photodetectors Based on Lateral Porous GaN/Ag Nanowires Composite Nanostructure

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Composite nanostructures with plasmonic metals can introduce optical resonances and enhance optoelectronic performance significantly. In this work, novel lateral porous GaN/Ag nanowires (NWs) composite nanostructure-based UV photodetectors were designed and fabricated, and the detectivity is up to 1015 Jones at V = 1 V with a fast response speed of ≈180 µs under UV illumination, which is more than ≈105 times faster than that of the photodetectors without Ag NWs. Combined with finite-difference time-domain simulations, the results show that such superior performance is mainly attributed to the surface plasmon resonance effect, which leads to a strong light trapping and efficient carriers' transport process at the lateral porous GaN/Ag NWs interfaces. This approach paves a way to realize ultra-sensitive UV photodetectors with fast response through plasmonic metal/semiconductor nanocomposites, which are desirable for applications in optical switches, optical logical operations, and lightweight communications.

A broadband ultraviolet light source using GaN quantum dots formed on hexagonal truncated pyramid structures

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Nanoscale Advances
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Group III-nitride semiconductor-based ultraviolet (UV) light emitting diodes have been suggested as a substitute for conventional arc-lamps such as mercury, xenon and deuterium arc-lamps, since they are compact, efficient and have a long lifetime. However, in previously reported studies, group III-nitride UV light emitting diodes did not show a broad UV spectrum range as conventional arc-lamps, which restricts their application in fields such as medical therapy and UV spectrophotometry. Here, we propose GaN quantum dots (QDs) grown on different facets of hexagonal truncated pyramid structures formed on a conventional (0001) sapphire substrate. A hexagonal truncated GaN pyramid structure includes {101} semipolar facets as well as a (0001) polar facet, which have intrinsically different piezoelectric fields and growth rates of GaN QDs. Consequently, we successfully demonstrated a plateau-like broadband UV spectrum ranging from ~400 nm (UV-A) to ~270 nm (UV-C) from the GaN QDs. In addition, at the top-edge of the truncated pyramid structure, a strain was locally suppressed compared to the center of the truncated pyramid structure. As a result, various emission wavelengths in the UV range were achieved from the GaN QDs grown on the sidewall, top-edge and top-center of hexagonal truncated pyramid structures, which ultimately
provide a broadband UV spectrum with high efficiency.

**High-speed Nonpolar InGaN/GaN Superluminescent Diode with 2.5 GHz Modulation Bandwidth**

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IEEE Photonics Technology Letters
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We demonstrate a superluminescent diode fabricated on a nonpolar m-plane GaN substrate by employing a linearly tapered waveguide design. A high electrical 3dB modulation bandwidth (f3dB) of 2.5 GHz at a current density of 30 kA/cm² is achieved. The high modulation bandwidth is attributed to the shorter carrier recombination lifetime, the linear gain curve in the nonpolar m-plane quantum wells, and the ability to operate at high current densities while effectively suppressing lasing. We derive a general expression for the -3dB bandwidth as a function of current density for SLDs using a similar approach to that for laser diodes. The -3dB bandwidth of a nonpolar superluminescent diode increases exponentially with current density. The experimental results are consistent with the derived expression for f3dB vs. current density.

**High-efficiency AlGaN/GaN/AlGaN tunnel junction ultraviolet light-emitting diodes**

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Photonics Research
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AlGaN is the material of choice for high-efficiency deep UV light sources, which is the only alternative technology to replace mercury lamps for water purification and disinfection. At present, however, AlGaN-based mid- and deep UV LEDs exhibit very low efficiency. Here, we report a detailed investigation of the epitaxy and characterization of LEDs utilizing an AlGaN/GaN/AlGaN tunnel junction structure, operating at \(~265\) nm, which have the potential to break the efficiency bottleneck of deep UV photonics. A thin GaN layer was incorporated between p+ and n+-AlGaN to reduce the tunneling barrier. By optimizing the thickness of the GaN layer and thickness of the top n-AlGaN contact layer, we demonstrate AlGaN deep UV LEDs with a maximum external quantum efficiency of 11% and wall-plug efficiency of 7.6% for direct on-wafer measurement. It is also observed that the devices exhibit severe efficiency droop under low current densities, which is explained by the low hole mobility, due to the hole hopping conduction in the Mg impurity band and the resulting electron overflow.
An improved method of average channel temperature and channel temperature profile determination is introduced in this paper applied to AlGaN/GaN HEMT using quasi-static I–V characterization and external heater. Particular HEMT resistances and threshold voltage were experimentally determined at different ambient temperatures from TLM measurements, HEMT output and transfer I–V characteristics. Negligible pinch-off area and leakage current dependence on drain voltage allows to obtain average temperature ~77 °C for dissipated power 1.5 W using simple recurrent differential calculations. The HEMT channel temperature profile exhibiting maximum peripheral temperature ~130 °C for dissipated power 1.5 W was simulated and verified utilizing the device electrical parameters variation.

Self-termination of contactless photo-electrochemical (PEC) etching on aluminum gallium nitride/gallium nitride heterostructures
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Applied Physics Express
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Contactless photo-electrochemical (PEC) etching was successfully demonstrated on AlGaN/GaN heterostructures using a K2S2O8 aqueous solution. The etching was conducted by a simple method such as just dipping the sample with Ti-cathode pads into the solution under UVC illumination. The etching morphology of the AlGaN surface was very smooth with a root mean square roughness of 0.24 nm. The etching was self-terminated in the AlGaN layer, whose residual thickness was 5 nm uniformly throughout the etched region. These contactless PEC etching features are promising for the fabrication of recessed-gate AlGaN/GaN high-electron-mobility transistors with high recessed-gate thickness reproducibility.

Analysis of threshold voltage instabilities in semi-vertical GaN-on-Si FETs
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Applied Physics Express
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We present a firststudy of threshold voltage instabilities of semi-vertical GaN-on-Si trench-MOSFETs, based on double pulsed, threshold voltage transient, and UV-assisted C–V analysis. Under positive gate stress, small negative V_th shifts (low stress) and a positive V th shifts (high stress) are observed, ascribed to trapping within the insulator and at the metal/insulator interface. Trapping effects are eliminated through exposure to UV light; wavelength-dependent analysis extracts the threshold de-trapping energy ≈2.95 eV. UV-assisted CV measurements describe the distribution of states at the GaN/Al2O3 interface. The described methodology provides an understanding and assessment of trapping mechanisms in vertical GaN transistors.

Highly reliable AlSiO gate oxides formed through post-deposition annealing for GaN-based MOS devices
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The electrical stabilities of AlSiO gate oxides formed through post-deposition annealing (PDA) and
intended for GaN-based power devices were assessed. No degradation of the interface properties of AlSiO/n-type GaN or the oxide breakdown voltage was observed, even after PDA up to 1050 °C. Furthermore, higher temperature PDA drastically reduced the trap density in the oxide, as indicated by current–voltage and positive bias temperature instability data. Time-to-breakdown characteristics showed sufficient lifetimes above 20 years at 150 °C in an equivalent field of 5 MV cm−1. Therefore, AlSiO films fabricated by high-temperature PDA are reliable gate oxide films for GaN-based devices.

Optical Investigation of Proton Irradiated MOCVD AlGaN/GaN HEMT Structures
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2 MeV proton numerical calculation damage indicates that a quasi-flat profile is introduced into the GaN-buffer layer of high electron mobility transistor (HEMT) templates. Previous transport study of such HEMT structures showed increased breakdown voltage and reduced GaN-buffer layer leakage after proton irradiation. Hyperspectral electroluminescence measurements detected emission band in the spectral region between 700-800 nm. This emission is assumed to be associated with the generation of trap levels responsible for the device failure. To obtain insights on the nature of radiation generated traps detailed low-temperature photoluminescence and cathodoluminescence experiments were carried out in a set of virgin and proton-irradiated device structure templates. Both the photoluminescence and cathodoluminescence spectra show large intensity variation of all emission bands, in the spectral range between 330-890 nm, with increasing proton dosage. This is consistent with the introduction of compensating and/or non-radiative recombination centers in the GaN buffer layer. Luminescence measurements carried out under various excitation conditions have shown different recombination rates for emission bands observed near 420 nm and 550 nm, indicating different free carrier capture rates. Spectral analysis suggests that this two emission bands have different dependence on proton irradiation dosage, consistent with different chemical nature.

Modeling of gate capacitance of GaN-based trench-gate vertical metal-oxide-semiconductor devices
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We propose a model for the gate capacitance of GaN-based trench-gate metal-oxide-semiconductor transistors, based on combined measurements, analytical calculations and TCAD simulations. The trench capacitance is found to be equivalent to four different capacitors, used to model the various regions with different doping and orientation of the semiconductor/dielectric interface. In addition, we demonstrate and explain the characteristic double-hump behavior of the G-D and G-DS capacitance of trench-MOSFETs. Lastly, a TCAD simulation results accurately reproduce the experimental data, thus confirming the interpretation on the double hump behavior, and providing insight on the electron density at the gate interface.

A broadband RLC matched GaN power amplifier using interposer-MMIC technology
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Microwave and Optical Technology Letters
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In this article, we report a compact and low-profile GaN-based broadband power amplifier using silicon interposer-MMIC (iMMIC) technology. The iMMIC technology enables a GaN HEMT to be embedded in the silicon substrate, and passive circuit elements such as metal-insulator-metal (MIM) capacitors, spiral inductors, and thin film resistors to be implemented.
on the high-resistivity silicon (HRS) substrate using standard integrated passive device (IPD) process, so that the final power amplifier is almost indistinguishable from a single GaN MMIC power amplifier. The RLC matched all-pass network and LC ladder type low-pass network are employed as the input matching network and output matching network, respectively. The proposed power amplifier has a Psat of 39.1 to 39.2 dBm with a power-added efficiency (PAE) of 40% to 50.5% in the frequency range of 2.1 to 3.5 GHz under continuous wave (CW) input signal. The proposed iMMIC power amplifier occupies only 9.9 mm².

The Influence of AlN Nucleation Layer on RF Transmission Loss of AlN-on-Si Hetero-Structure
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physica status solidi a
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Reducing radio frequency (RF) transmission loss is one of the key requirements when fabricating GaN-on-Si RF devices. To get a better insight of the RF loss mechanism in the GaN-on-Si structure, the RF loss of AlN/Si template was investigated by varying the growth temperature of AlN during metalorganic chemical vapor deposition process. Our results show that the RF loss of AlN/Si template is dominated by the interface loss due to the p-type conductive channel at AlN/Si interface which is induced by the thermal diffusion of Al during the high temperature growth. Although a low growth temperature of AlN nucleation layer can suppress the RF loss in AlN/Si template, it results in a low crystalline quality of AlN for practical use. It is essential to optimize the growth temperature of the AlN nucleation layer in order to obtain a good balance between the crystalline quality, morphological quality and RF loss, such that the AlN/Si template can be suitable for epitaxial growth of the complete GaN-on-Si RF device structure.

Simple and Accurate Prediction of AlGaN Metal-Organic Vapor Phase Epitaxy Growth
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physica status solidi b
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Modeling of metal-organic vapor phase epitaxy (MOVPE) is very complex, with many effects of temperature, hydrodynamics, thermodynamics, and kinetics needing to be taken into account. However, in this study, the growth behavior of AlGaN growth for high electron mobility transistors (HEMTs) is predicted using a simple model of parasitic gas phase reactions between tri-methyl aluminium (TMAI) and NH₃, while taking into consideration desorption of AlGaN during growth with Arrhenius behavior. This leads to an average difference between predicted and measured values of around 1% for both thickness and composition calculations, which is very accurate considering the wide range of conditions used. This opens the way for simple predictions for AlGaN growth using a close-coupled showerhead reactor within a defined process window.

An X-band high-efficiency GaN load modulated balanced amplifier MMIC
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Microwave and Optical Technology Letters
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An X-band high-efficiency GaN load modulated balanced amplifier monolithic microwave integrated circuit (MMIC) composed of 90° Lange Couplers at radio frequency (RF) input and output, a pair of balanced power amplifier (BPA) and a control signal (CS) PA is presented in this article. The impedance of the BPA is modulated by varying the amplitude and phase of the injected CS at same frequency. The prototype has a peak continuous wave output power of 42.5 dBm, with efficiency of 45% to 55% at peak power and 40% to 45% at 6 dB output back-off over 8 to 11 GHz. The average efficiency for the 37.2 dBm output power is 40%, with adjacent channel leakage ratio of −32 dBc without digital predistortion at 10 GHz center frequency.
624 V 5 A All-GaN Integrated Cascode for Power Switching Applications
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https://doi.org/10.1002/pssa.201900783

An all-GaN integrated cascode device with an output current of 5 A, threshold voltage of +0.65 V and breakdown voltage of 624 V is demonstrated. Compared to the commercial 600 V hybrid GaN plus Si cascode device (TPH3202), the integrated cascode exhibits a significantly reduced delay time when switched at 200 V and 2.7 A. This is attributed to the absence of a Si MOSFET driver, leading to a much smaller input capacitance as indicated by the high voltage capacitance measurements. In addition, the integrated cascode device shows a reduced ringing effect due to monolithic integration. When compared to commercial 600 V standalone GaN devices (GS66502B and GS-065-004), a reduced Miller effect is observed for the integrated cascode when switched under low gate driving current conditions. The results demonstrate the advantages of the cascode device to switch with low gate driving current using cheaper, faster and more efficient gate drivers.

Low Static and Dynamic On-Resistance with High Figure-of-Merit in AlGaN/GaN HEMTs on CVD Diamond
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AlGaN/GaN HEMTs-on-CVD Diamond with different gate-drain spacing (Lgd) was fabricated, and OFF-state breakdown voltage (BVgd) along with dynamic specific on-resistance (Dyn.-Ron, sp) were measured. Ron, sp was obtained in the range of 0.32 to 0.98 mΩ-cm² for HEMTs with Lgd of 2 to 8 µm. This is the lowest value of Ron, sp reported so far for GaN-on-CVD diamond. The HEMTs exhibited a BVgd of 415 V (Lgd= 8 µm) with maximum lateral breakdown strength of 0.72 MV/cm (Lgd= 4 µm). The power device figure-of-merit (FOM) of ~0.18 GW/cm² was obtained from the HEMTs with Lgd of 8 µm. Our HEMTs exhibited about 60% of higher FOM when compared with the reported HEMTs on CVD Diamond (~0.11 GW/cm²). This is mainly due to the improvement of Ron, sp through the reduction of contact resistance (Rc) and sheet resistance (Rsh). The Dyn.-Ron, sp of ~0.52 mΩ-cm² was estimated from pulsed (pulse width/period =200ns/1ms) ID-VD characteristics for the HEMTs with Lgd=3 µm using the gate- and drain-quescient biases of [(Vgs0, Vds0)= (-5,50) V], which is comparable to the static Ron, sp. These improved results of the fabricated AlGaN/GaN HEMTs on CVD-diamond make it a promising candidate for high-voltage power switching device applications.

Comparative Study of Characteristics and Interface States with and without Post-Gate-Annealing Treatment for AlGaN/GaN-Recessed Metal–Insulator–Semiconductor High Electron Mobility Transistors Using HfO2 Gate Insulator on Si Substrates
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Three types of enhancement-mode (E-mode) AlGaN/GaN metal–insulator–semiconductor high electron mobility transistors (MIS-HEMTs) with different barrier depths are fabricated on Si substrates. A HfO2 gate insulator with a thickness of 30 nm is grown by plasma-enhanced atomic layer deposition (PEALD) at 300 °C. The drain current density and transconductance increase greatly after post-gate-annealing (PGA, 400 °C, 5 min) treatment. The Vth of the MIS-HEMT decreases after PGA treatment and the C–V characteristics are a good match to the Vth change of the transfer characteristics. The interface states are in the form of trap states and fixed charges. The trap states at the HfO2/AlGaN interface are measured by the frequency- and voltage-dependent conductivity method. The trap state density and time constant decrease after the PGA treatment. The fixed charge density can be...
calculated by the Vth shift. According to the calculation results, the fixed charge density also decreases. The PGA treatment can reduce the interface state density effectively and is a significant process for the gate-recessed MIS-HEMT.

**Strain Recovery and Defect Characterization in Mg Implanted Homoepitaxial GaN on High Quality GaN Substrates**

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physica status solidi b

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The evolution of defects due to high-pressure annealing of magnesium ion implanted epitaxial GaN grown on high quality GaN substrates is investigated. Changes in the implant-induced strain is quantified as a function of annealing temperature and annealing time. After annealing at 1300 °C for 10 min, the implant-induced strain was fully relieved and accompanied by the presence of extended defects such as basal plane stacking faults and prismatic loops. The basal plane stacking faults corespond to the formation of zinc blende GaN in the wurtzite GaN lattice. Annealing at lower temperatures, even for times as long as 100 min, leads to only partial recovery of the implant-induced strain. Approximately one third of the original implant-induced strain remains after annealing at 700 °C and 5% of the original strain remains at 1000 °C for 100 min. In all cases, nearly all of the recovered strain occurs within the first few minutes of annealing. A prominent increase in the asymmetric (101—4) triple axis X-ray rocking curve full width 0.01 maximum (FW0.01M) is observed after annealing at 1300 °C for 10 min. After annealing at 1300 °C for 100 min, a subsequent decrease in the FW0.01M is correlated with a reduction of the extended defect density from 4·108 cm−2 to 3·107 cm−2, which is determined through TEM measurements. Further reduction in the density of the extended defects by optimizing annealing temperature and annealing time is expected to have a significant impact on improving the performance of GaN-based vertical power devices.

**Current Transport Mechanism in Palladium Schottky Contact on Si-Based Freestanding GaN**

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Nanomaterials

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In this study, the charge transport mechanism of Pd/Si-based FS-GaN Schottky diodes was investigated. A temperature-dependent current–voltage analysis revealed that the I-V characteristics of the diodes show a good rectifying behavior with a large ratio of 103–105 at the forward to reverse current at ±1 V. The interface states and non-interacting point defect complex between the Pd metal and FS-GaN crystals induced the inhomogeneity of the barrier height and large ideality factors. Furthermore, we revealed that the electronic conduction of the devices prefers the thermionic field emission (TFE) transport, not the thermionic emission (TE) model, over the entire measurement conditions. The investigation on deep level transient spectroscopy (DLTS) suggests that non-interacting point-defect-driven tunneling influences the charge transport. This investigation about charge transport paves the way to achieving next-generation optoelectronic applications using Si-based FS-GaN Schottky diodes.
The Influence of Anode Trench Geometries on Electrical Properties of AlGaN/GaN Schottky Barrier Diodes
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Electronics
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AlGaN/GaN lateral Schottky barrier diodes (SBDs) with three different anode geometries (stripe, circular, and the conventional plane one) and different rows of anode trenches are fabricated and electrically characterized to study the influence of anode trench geometries. The SBDs with anode trenches exhibit the lower on-state resistance (RON) than that with the conventional plane one. It can be explained that the anode trenches made the Schottky metal directly contact to the 2DEG at the sidewall of the AlGaN/GaN interface, removing the AlGaN barrier layer in the conventional plane anode. In addition, the RON of the SBDs with circular trenches is smaller than that of the SBDs with stripe ones. Furthermore, the RON decreases with the increasing rows of anode trenches, which can be attributed to the increased contact area between the Schottky metal and the 2DEG. For the reverse characteristics, the anode trenches do not lead to performance degradation. The fabricated devices exhibit the low reverse current (IR, IR < 1 μA/mm), and the breakdown voltage (VBK) remains unchanged with different anode geometries.

Investigation of Recessed Gate AlGaN/GaN MIS-HEMTs with Double AlGaN Barrier Designs toward an Enhancement-Mode Characteristic
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Micromachines
https://doi.org/10.3390/mi11020163

In this work, recessed gate AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) with double AlGaN barrier designs are fabricated and investigated. Two different recessed depths are designed, leading to a 5 nm and a 3 nm remaining bottom AlGaN barrier under the gate region, and two different Al% (15% and 20%) in the bottom AlGaN barriers are designed. First of all, a double hump trans-conductance (gm)–gate voltage (VG) characteristic is observed in a recessed gate AlGaN/GaN MIS-HEMT with a 5 nm remaining bottom Al0.2Ga0.8N barrier under the gate region. Secondly, a physical model is proposed to explain this double channel characteristic by means of a formation of a top channel below the gate dielectric under a positive VG. Finally, the impacts of Al% content (15% and 20%) in the bottom AlGaN barrier and 5 nm/3 nm remaining bottom AlGaN barriers under the gate region are studied in detail, indicating that lowering Al% content in the bottom can increase the threshold voltage (VTH) toward an enhancement-mode characteristic.

Fabrication and Evaluation of N-Channel GaN Metal–Oxide–Semiconductor Field-Effect Transistors Based on Regrown and Implantation Methods
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Materials
https://doi.org/10.3390/ma13040899

We have demonstrated the enhancement-mode n-channel gallium nitride (GaN) metal-oxide field-effect transistors (MOSFETs) on homoepitaxial GaN substrates using the selective area regrowth and ion implantation techniques. Both types of MOSFETs perform normally off operations. The GaN-MOSFETs fabricated using the regrowth method perform superior characteristics over the other relative devices fabricated using the ion implantation technique. The electron mobility of 100 cm²/V·s, subthreshold of 500 mV/dec, and transconductance of 14 μs/mm are measured in GaN-MOSFETs based on the implantation technique. Meanwhile, the GaN-MOSFETs fabricated using the regrowth method perform superior characteristics over the other relative devices fabricated using the ion implantation technique. The electron mobility of 100 cm²/V·s, subthreshold of 500 mV/dec, and transconductance of 14 μs/mm are measured in GaN-MOSFETs based on the implantation technique. Additionally, the MOSFETs with the regrown p-GaN gate body show the Ion/Ioff ratio of approximately 4 × 107, which is, to our knowledge, among the best results of GaN-MOSFETs to date. This research
contributes a valuable information for the design and fabrication of power switching devices based on GaN.

**Gallium nitride tunneling field-effect transistors exploiting polarization fields**

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Applied Physics Letters
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This report showcases a vertical tunnel field effect transistor (TFET) fabricated from a GaN/InGaN heterostructure and compares it to a gated vertical GaN p-n diode. By including a thin InGaN layer, the interband tunneling in the TFET is increased compared to the gated homojunction diode. This leads to an increased drain current of 57 μA/μm and a reduced subthreshold swing of 102 mV/dec, from 240 mV/dec. However, trap assisted tunneling prevents devices from realizing subthreshold slopes below the Boltzmann limit of 60 mV/dec. Nevertheless, this work shows the capability of tunnel field effect transistors to be realized in GaN by taking advantage of the spontaneous and piezoelectric polarization in the III-N material system.

**Electrical characterization of GaN Schottky barrier diode at cryogenic temperatures**

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In this report, electrical characteristics of the Ni/GaN Schottky barrier diode grown on sapphire have been investigated in the range of 20 K–300 K, using current–voltage, capacitance–voltage, and deep level transient spectroscopy (DLTS). A unified forward current model, namely a modified thermionic emission diffusion model, has been developed to explain the forward characteristics, especially in the regime with a large ideality factor. Three leakage current mechanisms and their applicability boundaries have been identified for various bias conditions and temperature ranges: Frenkel–Poole emission for temperatures above 110 K; variable range hopping (VRH) for 20 K–110 K, but with a reverse bias less than 20 V; high-field VRH, in a similar form of Fowler–Nordheim tunneling, for cryogenic temperatures below 110 K, and relatively large bias (>25 V). Four trap levels with their energy separations from the conduction band edge of 0.100 ± 0.030 eV, 0.300 eV, 0.311 eV, and 0.362 eV have been tagged together with their capture cross sections and trap concentrations. The significantly reduced DLTS signal at 100 K suggested that traps practically became inactive at cryogenic temperatures, thus greatly suppressing the trap-assisted carrier hopping effects.

**Lateral p-GaN/2DEG junction diodes by selective-area p-GaN trench-filling-regrowth in AlGaN/GaN**

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Applied Physics Letters
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This work demonstrates a lateral p-n junction diode formed between the two-dimensional electron gas (2DEG) and the selective-area regrown p-GaN in AlGaN/GaN. Benefiting from the in-plane 2DEG channel, this p-GaN/2DEG diode can directly characterize the current conduction and voltage blocking characteristics of the regrown sidewall p-n junction, which has been regarded as the key building block of future high-voltage GaN power devices. Control samples with planar regrown p-n junctions are first used to optimize the regrowth conditions. The
planar junction characteristics show considerable improvement by adding the Mg pre-flow (Cp2Mg) before the p-GaN regrowth, which is attributed to the Mg out-diffusion beyond the regrowth interface. A record high ratio between the Mg concentration and the maximum impurity (C, Si, O) spike at the regrowth interface is demonstrated. Using the optimal regrowth conditions, the fabricated p-GaN/2DEG junction diodes show excellent rectifying behavior with an on/off ratio of over 5 × 10^7 in both large-area devices and the multi-finger devices with 1 µm-wide finger trenches. A breakdown voltage over 100 V is demonstrated, where the peak electric field is estimated to be at least 2.5 MV/cm at the sidewall junction. These results not only suggest that p-GaN trench-filling regrowth is a viable approach for selective-area p-type doping in GaN power devices but also open a door for the development of unconventional GaN devices based on p-GaN/2DEG junctions.

On the performance of GaN-on-Silicon, Silicon-Carbide, and Diamond substrates
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International Journal of RF and Microwave Computer-Aided Engineering
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In this article, threading dislocations and its impact on the electrical and thermal performance of GaN-on-Diamond (Dia), -SiC, and -Si high electron mobility transistor (HEMT) has been investigated. TCAD simulation of GaN-HEMT is performed with various buffer traps to mimic the lattice mismatch/dislocation density at GaN/Si, GaN/SiC, and GaN/Dia interface. It has been found that, the dislocations not only induce traps, but also degrade the thermal conductivity of the GaN-buffer. This accordingly could deteriorate the thermal characteristic of GaN-on-Dia, which has higher lattice mismatch with respect to GaN-on-SiC. This investigation showed that the growth process of GaN-on-Dia should be optimized in order to reduce the threading dislocations. This accordingly could dramatically further improve its outstanding thermal characteristics with respect to GaN-on-SiC and GaN-on-Si devices.

Growth and Characterization of N-polar AlGaN/AlN Heterostructure for High Electron Mobility Transistor
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A nitrogen-polar (N-polar) AlGaN/AlN high electron mobility transistor (HEMT) is proposed, and the generation of a two-dimensional electron gas (2DEG) is simulated. The band diagram of N-polar (Al)GaN/AlN shows the generation of the 2DEG, whereas that of the conventional metal-polar (Al)GaN/AlN structure shows the generation of a 2D hole gas. Furthermore, the concentration of the 2DEG is considerably high even when the (Al)GaN layer is as thin as a few nanometers. N-polar AlGaN/AlN is grown on sapphire substrates with a misorientation angle of 2°; further, atomic force microscope measurements in a range of 5 × 5 µm^2 demonstrate that the root mean square value obtained from atomic force microscopy of N-polar AlGaN is approximately 0.7 nm. N-polar AlGaN layers with a thickness of approximately 40–60 nm with more than 50% Al content are almost coherently grown on the N-polar AlN layer with a thickness of approximately 400 nm.

Experimental investigation of buffer traps physical mechanisms on the gate charge of GaN-on-Si devices under various substrate biases
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Applied Physics Letters
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The gate charge change (ΔQg) of GaN-on-Si power devices subjected to different substrate biases has been investigated. On-wafer pulse-mode voltage stress measurement is examined to probe the physical insight of different trap mechanisms into Qg characteristics. Distinct injected electrons interacting with the buffer traps lead to a significant decrease
(increase) in $Q_g$ under negative (positive) substrate bias. Different levels of degradation on $\Delta Q_{gd}$ to $\Delta Q_{gs}$ after stress under negative and positive substrate biases indicate uneven distribution of acceptor-like traps and uniform distribution of donor-like traps in the GaN buffer level. Using Arrhenius plots associated with the $\Delta Q_g$ shift, three dominant buffer traps with activation energies of $E_V + 0.542\, \text{eV}$, $E_C - 0.604\, \text{eV}$, and $E_C - 0.608\, \text{eV}$ are extracted.

Explore an approach towards the intrinsic limits of GaN electronics
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To fully exploit the advantages of GaN for electronic devices, a critical electric field which approaches its theoretical value (3 MV/cm) is desirable but has not yet been achieved. It is necessary to explore a new approach towards the intrinsic limits of GaN electronics from the perspective of epitaxial growth. By using a novel two-dimensional growth mode benefiting from our high temperature AlN buffer technology which is different from the classic two-step growth approach, our high electron mobility transistors (HEMTs) demonstrate an extremely high breakdown field of 2.5 MV/cm approaching the theoretical limit of GaN and an extremely low off-state buffer leakage of 1 nA/mm at a bias of up to 1000 V. Furthermore, our HEMTs also exhibit an excellent figure-of-merit ($V_{br2}/R_{on,sp}$) of $5.13 \times 10^8\, \text{V}^2/\Omega\cdot\text{cm}^2$.

Forward Current Transport Properties of AlGaN/GaN Schottky Diodes Prepared by Atomic Layer Deposition
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Coatings
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Atomic layer deposited AlGaN on GaN substrate with different thicknesses was prepared and the electron transport mechanism of AlGaN/GaN Schottky diodes was investigated. Above 348 K, both 5 and 10 nm thick AlGaN showed that the thermionic emission model with inhomogeneous Schottky barrier could explain the forward current transport. Analysis using a dislocation-related tunneling model showed that the current values for 10 nm thick AlGaN was matched well to the experimental data while those were not matched for 5 nm thick AlGaN. The higher density of surface (and interface) states was found for 5 nm thick AlGaN. In other words, a higher density of surface donors, as well as a thinner AlGaN layer for 5 nm thick AlGaN, enhanced the tunneling current.

Effect of InGaN/GaN superlattice as underlayer on characteristics of AlGaN/GaN HEMT
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The impact of an InGaN/GaN superlattice (SL) on AlGaN/GaN high electron mobility transistor characteristics was investigated, and two effects were discovered: one is a substantial improvement in the conduction characteristics as a result of the InGaN/GaN channel layer, while the other is the effect of diffusion suppression relating to impurities or point defects from the carbon-doped layer. The InGaN/GaN SL was used as a channel layer to improve the mobility and concentration of the two-dimensional channel electron gas. It was found that by inserting the InGaN/GaN SL just above a C-doped semi-insulating GaN layer as the InGaN underlayer, the conduction current of the SL with five periods (5SL) was observed to be much higher than that of the conventional material with a GaN channel layer of over 2 μm in thickness. The results demonstrated that this SL layer is effective in suppressing the diffusion of impurities or point defects originating from the carbon-doped layer, resulting in the device performance improvement.
Gallium Nitride (GaN) High-Electron-Mobility Transistors with Thick Copper Metallization Featuring a Power Density of 8.2 W/mm for Ka-Band Applications

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Micromachines
https://doi.org/10.3390/mi11020222

Copper-metallized gallium nitride (GaN) high-electron-mobility transistors (HEMTs) using a Ti/Pt/Ti diffusion barrier layer are fabricated and characterized for Ka-band applications. With a thick copper metallization layer of 6.8 μm adopted, the device exhibited a high output power density of 8.2 W/mm and a power-added efficiency (PAE) of 26% at 38 GHz. Such superior performance is mainly attributed to the substantial reduction of the source and drain resistance of the device. In addition to improvement in the Radio Frequency (RF) performance, the successful integration of the thick copper metallization in the device technology further reduces the manufacturing cost, making it extremely promising for future fifth-generation mobile communication system applications at millimeter-wave frequencies.

P-GaN Gated Hybrid Anode Lateral Diode with a Thicker AlGaN Barrier Layer

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A p-GaN gated Hybrid Anode Lateral Diode with a 45 nm-thick AlGaN barrier was successfully fabricated through p-GaN regrowth over recessed structure. This diode features a recessed p-GaN-gated ohmic hybrid anode, and the current flow from the anode to the cathode can be well controlled by the p-GaN structure. With this architecture of regrown p-GaN structure and thick AlGaN barrier, the forward turn-on voltage (Von) and on-resistance (Ron) of the diode can be reduced simultaneously. Both Von and Ron exhibit an excellent uniformity with an average value of 0.71 ± 0.02 V, 10.6 ± 0.27 Ω·mm, respectively. And a high breakdown voltage (~ 488 V) has been achieved even in the absence of field plate structure. The fabrication process of the diode seems to be fully compatible with that of normally-off HEMTs with p-GaN gate, which has been successfully commercialized, enabling more convenient monolithic integration.

Multiband Dual-Mode Doherty Power Amplifier Employing Phase Periodic Matching Network and Reciprocal Gate Bias for 5G Applications

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This article presents a novel method to design the multiband Doherty power amplifier (DPA). It is illustrated that phase periodic matching networks (PPMNs) can be used as multiband impedance inverters, off-set elements, and phase compensators to realize multiband DPAs. Moreover, the number of Doherty operation bands can be further increased by employing the reciprocal gate biases. A six-band dual-mode DPA with 1.8-2.2-/3.9-4.3-GHz operation bands in Mode I and 1.52-1.72/-2.38-2.53/-3.67-3.82-/4.53-4.68-GHz operation bands in Mode II using commercial GaN transistors is designed and implemented to validate the proposed method. The fabricated DPA achieves 8.7-13.5-dB gain and 39.6-41.5-dBm peak output power at all the designed bands. Drain efficiency of 49.2%-54.5% and 42.2%-56.7% is measured at a 6-dB output back-off in Mode I and Mode II, respectively. When stimulated by a five-carrier 100-MHz OFDM signal with a 7.7-dB peak-to-average power ratio (PAPR), adjacent channel power ratio (ACPR) of better than -48.9 dBc can be obtained by the proposed DPA after digital predistortion with
35.5%-50.1% average drain efficiency at 1.65/1.95/2.45/3.75/4.1/4.6 GHz, respectively.

**Normally-off p-GaN Gated AlGaN/GaN HEMTs Using Plasma Oxidation Technique in Access Region**

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Normally-off p-GaN gated AlGaN/GaN high electron mobility transistors (HEMTs) were developed. Oxygen plasma treatment converted a low-resistive p-GaN layer in the access region to a high-resistive GaN (HR-GaN); that oxygen plasma treatment used an AlN layer as an oxygen diffusion barrier layer to prevent further oxidizing of the underlying AlGaN barrier layer, and to ensure that the low-resistive p-GaN layer in the access region was fully oxidized. Relative to conventional p-GaN gated AlGaN/GaN HEMTs, these AlGaN/GaN HEMTs with HR-GaN layers achieved a lower drain leakage current of 4.4×10^7 mA/mm, a higher drain current on/off ratio of 3.9×10^9, a lower on-state resistance of 17.1 Ω-mm, and less current collapse.

**Engineering a Unified Dielectric Solution for AlGaN/GaN MOS-HFET Gate and Access Regions**

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IEEE Transactions on Electron Devices
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Typically GaN metal-oxide-semiconductor heterojunction-field-effect transistors (MOS-HFETs) have used two separate dielectrics for the gate and access regions. However, as this article shows, with proper gate-stack engineering, a unified dielectric solution can be achieved for the transistor. HfO2 dielectrics were deposited by atomic layer deposition (ALD). Two types of oxidants were investigated, namely, water (H2O) and ozone (O3). It was found that MOS-HFETs with O3 oxidant yielded lower threshold voltage (VTH) shifts, higher maximum drain current (IDS,max) of 340 mA/mm, 20% lower on-resistance (RON), higher peak transconductance at 112.66 mS/mm, lower hysteresis, and lower gate leakage (5.4×10^-6 A/cm^2) compared to water oxidant based MOS-HFETs with IDS,max of 240 mA/mm, 81.38 mS/mm peak transconductance, and 1.7×10^-4 A/cm^2 gate leakage. DC/RF dispersion tests showed MOS-HFETs with O3 oxidant had ~200x better current collapse recovery. Temperature characterization and reliability test results, such as high-temperature reverse bias (HTRB), are published for the first time on ALD-HfO2/AlGaN/GaN MOS-HFETs using tetrakis(dimethylamino)hafnium (TDMAH) and O3 precursor. Using an ozone oxidant provided more stability (i.e., less variability in RON and VTH) as a function of temperature. Finally, when devices were electrically stressed in the OFF-state, the HTRB test showed minimal VTH drift (<0.5 V) in the case of O3 oxidant versus much larger VTH drift (2.5 V) in the case of H2O oxidant.

**A High-Performance GaN-Modified Nonuniform Distributed Power Amplifier**

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IEEE Transactions on Microwave Theory and Techniques
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This article proposes a modified nonuniform distributed power amplifier (NDPA) design to increase the output power and power-added efficiency (PAE) in wideband. In the proposed NDPA, drain-line impedances are recalculated, including the drain-source capacitances, which cannot be ignored as the transistor size becomes larger at high frequencies. In addition, instead of using a large-sized transistor in the first section of the NDPA, the design proposes a method of halving the characteristic impedance by doubling the phase of the drain line. When compared with the conventional NDPA, the modified NDPA shows the power gain and output power characteristics close to those of the ideal NDPA. To obtain high efficiency in the NDPA, a programmable gate-line termination resistance switching technique (PGT) is proposed. The power gain is increased by using the standing wave generated from the
mismatched termination, enhancing the PAE. For design verification, two modified NDPA monolithic microwave integrated circuits (MMICs) were fabricated using a commercial 0.25-μm gallium nitride (GaN) high-electron-mobility transistor (HEMT) process. The two-way power-combined NDPA shows an average output power of 20 W or more and a power density of 1.9 W/mm² from 6 to 18 GHz. The NDPA using the proposed PGT accomplishes an average output power of 10 W and an average PAE of 20% or more from 6 to 18 GHz.

**Temperature-dependent dynamic RDS,ON under different operating conditions in enhancement-mode GaN HEMTs**

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IET Power Electronics


High-voltage enhancement-mode (E-mode) gallium nitride (GaN) high electron mobility transistor (HEMT) is a superior candidate to enable higher efficiency and higher power density when compared with silicon power devices in power converter applications. However, the dynamic RDS,ON of E-mode GaN HEMT device during operation. This finding is important since in converter applications the devices are typically operating at elevated temperatures. The proposed comprehensive experimental method can be used to estimate and analyse the dynamic RDS,ON characteristics of other GaN devices.

**High-temperature electrical performances and physics-based analysis of p-GaN HEMT device**

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IET Power Electronics

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High-temperature electrical performances of enhancement-mode (E-mode) high electron mobility transistor with p-type Gallium Nitride (GaN) gate cap are evaluated here. The physics-based mechanisms behind the behaviours are also analysed by the simulations and analytical models. For static electrical performances, the changes of GaN bandgap and the interface states or traps are considered to be influential factors for the little variations of threshold voltage (VT). Meanwhile, the on-state resistance increases and trans-conductance decreases at high temperatures due to the reduction in electron mobility (μ_eff). As for blocking characteristic, high temperature-induced increase of leakage current may result from multi-reasons, such as the increase of intrinsic carrier concentration and lowering of trap barrier. In addition, a segmental method is presented to understand the gate leakage current at high temperatures. For capacitance characteristics, the increase of channel resistance makes the measured gate capacitance lower than the intrinsic value. For dynamic electrical performances, the high temperature-induced decrease of μ_eff leads to the increase of plateau voltage, bringing the decreases of total switching time and total switching energy loss, which are quite different from those of the devices with traditional metal-oxide-semiconductor structures.
Tri-Gated Hybrid Anode AlGaN/GaN Power Diode With Intrinsic Low Turn-on Voltage and Ultralow Reverse Leakage Current
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IEEE Transactions on Electron Devices
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In this article, a novel tri-gated hybrid anode AlGaN/GaN power diode (TG-HAD) with intrinsic low turn-on voltage (Von) is demonstrated. A novel forward Von modulation technique based on an ultrathin barrier (UTB) AlGaN/GaN heterostructure is proposed. Von of the diode is determined by the intrinsic threshold voltage of the two-dimensional electron gas (2DEG) channel of the UTB heterostructure, which can be precisely controlled and which fundamentally features excellent uniformity by tailoring the AlGaN barrier thickness. On the other hand, compared with the planar GaN diodes, the proposed TG-HAD achieves significant reverse leakage current reduction originating from the effectively suppressed buffer leakage by the tri-gate design. The detailed device characteristics and the underlying mechanisms are investigated by TCAD simulation. The TG-HAD, together with the proposed turn-on voltage modulation technique, is promising for fabricating high performance large periphery devices for power applications.

Investigation of Inverse Piezoelectric Effect and Trap Effect in AlGaN/GaN HEMTs Under Reverse-Bias Step Stress at Cryogenic Temperature
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The inverse piezoelectric effect and trap effect in GaN HEMTs under the high electric field by reverse-bias step stress at cryogenic temperature (CT, 77K) have been investigated. It is found that the inverse piezoelectric effect is suppressed while the trap effect is enhanced at CT. Due to the lower tensile stress in the as-grown AlGaN barrier at CT, the amplitude of the critical voltage related to inverse piezoelectric effect increases from 75V at 300K to 100V at CT, mitigating the irreversible degradation of the devices. The inverse piezoelectric effect dominates the degradation of reverse gate leakage, which is weakened at CT. However, the devices suffer from more degradation of I d (decreases by 94.38%) and G m, max (decreases by 95.15%) at CT in the dark, induced by the serious trap effect due to the longer emission time. UV-light-assisted stress measurements have been utilized to identify the contribution of the two mechanisms to the degradation of device characteristics at CT. The degradation of I d (G m, max ) is only 0.82% (3.31%) for the piezoelectric effect and 93.56% (91.84%) for trap effect at CT, respectively.

A Compact, Low Power Consumption, and Highly Sensitive 95 GHz Doppler Radar
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We report on the architecture and performance of a highly sensitive 95 GHz Doppler radar instrument with 0.6 Watt transmit power designed for low power consumption and small size. The radar’s sensitivity is validated using a calibration target, and its remote sensing capabilities are demonstrated through the detection of clouds, rain, insects, and distant vehicles. The radar uses a frequency-modulated continuous-wave (FMCW) waveform, a single antenna with ultra-high-isolation quasioptical transmit/receive duplexing, an InP low-noise amplifier for receiving, and a GaN power amplifier for transmitting. A DC power consumption of 22 W for the RF and digital subsystems is achieved, in part, by a combination of a power-efficient waveform generation/detection and signal processing board and a CMOS-based system-on-chip W-band oscillator. Excluding power supplies and a computer interface, the radar system mass is under 6 kg, making it attractive for future deployment from
High-fluence Proton Induced Degradation on the AlGaN/GaN High-electron-mobility Transistors
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IEEE Transactions on Nuclear Science
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The electrical characteristics and low-frequency noise (LFN) of AlGaN/GaN high-electron-mobility transistors (HEMTs) after 3-MeV proton irradiation up to a total dose of 5.0W1014 p/cm2 have been studied in this paper. The devices experienced a 14.6% decrease in saturation current, a 0.35V positive shift of the threshold voltage (Vth) and a significant decrease in reverse gate leakage current after 3-MeV proton irradiation. Extracted by the LFN method, the flat-band voltage noise power spectral density (SVfb) increases from 4.112W10-12 7Hz -1 to 5.603W10-12 7Hz -1, the trap density increases from 2.79W1017 to 3.84W1017 cm-3 7eV-1 after the radiation. The main degradation mechanism is considered to be the increase of negatively charged trap density in the channel, which depletes more electrons and reduces the carrier mobility in the channel 2-dimensional electron gas (2DEG). We also extracted the radiation-induced trapped charge density according to the theoretical calculation; the result is consistent with the LFN measurement.

Design and Optimization of Vertical GaN PiN Diodes with Fluorine-Implanted Termination
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IEEE Journal of the Electron Devices Society
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Gallium nitride (GaN)-based power devices enable high power density and high switching frequency for power electronics systems. For the emerging vertical GaN devices, the electric field crowding around the edge of the main junction could result in premature breakdown. It is challenging to employ the commonly used junction-based terminations as in Si and SiC high-voltage devices for vertical GaN devices, due to the difficulty of selective p-type doping and activation in GaN. In this work, based on the unique feature of the negatively charged F ions in GaN which can favorably modulate the edge electric field, a fluorine-implanted termination (FIT) structure for vertical GaN PiN diodes has been designed and optimized to suppress the electric field crowding at the junction edge for a higher breakdown voltage (BV). The key parameters of the FIT, including the F ion dose, the thickness and width of the FIT and the angle of the bevel structure, have been comprehensively investigated by TCAD simulations to reveal their impacts on BV. Moreover, with a tapered dose distribution in the FIT, the device can achieve a higher BV with an enlarged FIT dose window.

High voltage GaN p-n diodes formed by selective area regrowth
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Electronics Letters
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GaN p-n diodes were formed by selective area regrowth on freestanding GaN substrates using a dry etch, followed by post-etch surface treatment to reduce etch-induced defects, and subsequent regrowth into wells. Etched-and-regrown diodes with a 150 μm diameter achieved 840 V operation at 0.5 A/cm 2 reverse current leakage and a specific on-resistance of 1.2 mΩ-cm 2. Etched-and-regrown diodes were compared with planar, regrown diodes without etching on the same wafer. Both types of diodes exhibited similar forward and reverse electrical characteristics, which indicate that etch-induced defectivity of the junction was sufficiently mitigated so as not to be the primary cause for leakage. An area dependence for forward and reverse leakage current density was observed, suggesting that the mesa sidewall provided a leakage path.
Analysis of an AlGaN/AlN Super-Lattice Buffer Concept for 650-V Low-Dispersion and High-Reliability GaN HEMTs
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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2020.2968757

In this article, an optimized carbon-doped AlGaN/AlN super-lattice (SL) buffer structure for GaN-based high electron mobility transistors, grown on 200-mm Si wafers is demonstrated. The resulting transistor structure features: 1) maximum vertical breakdown strength as high as 2.72 MV/cm, 2) vertical breakdown voltages (BVs) above 1.2 kV, 3) lateral BVs above 2.2 kV, 4) reduction in buffer traps, which is expected to result in low-dynamic RON , and 5) more than 50 years of extrapolated lifetime at 150 °C under 650-V bias. These were achieved by optimizing growth parameters by systematically varying the SL growth temperature, SL carbon-doping, ammonia flow, and SL pair count with adjusting the total buffer thickness. The detailed analysis shows fundamental improvements compared to a conventional carbon-doped (Al)GaN staircase buffer with the same thickness and comparable growth time.

Correlation Between Anode Area and Sensitivity for the TiN/GaN Schottky Barrier Diode Temperature Sensor
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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2020.2968358

TiN/GaN Schottky barrier diodes with different anode diameters are fabricated to investigate the temperature sensing mechanism. All the circular diodes present good stability over a temperature range of 25 °C–200 °C. In the fully turn-on region, the sensitivity increases with the increasing diameter. Furthermore, the highest sensitivity of 1.22 mV/K is obtained for a 300-μm-diameter device at current of 20 mA, taking into account the series resistance. In the subthreshold region, the forward current (ID) density determines the sensor sensitivity, in which a larger current density corresponds to a lower sensitivity. In addition, the strong dependence of the leakage current on the temperature indicates that the linearity of ln (Ir) versus temperature can be also used for sensor applications.

Accurate Measurement of Dynamic ON-state Resistance of GaN Devices under Reverse and Forward Conduction in High Frequency Power Converter
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IEEE Transactions on Power Electronics
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Because of trapped charges in GaN transistor structure, device dynamic ON-state resistance RDSon is increased when it is operated in high frequency switched power converters, in which device is possibly operated by zero voltage switching (ZVS) to reduce its turn-ON switching losses. When GaN transistor finishes ZVS during one switching period, device has been operated under both reverse and forward conduction. Therefore its dynamic RDSon under both conduction modes needs to be carefully measured to understand device power losses. For this reason, a measurement circuit with simple structure and fast dynamic response is proposed to characterise device reverse and forward RDSon. In order to improve measurement sensitivity when device switches at high frequency, a trapezoidal current mode is proposed to measure device RDSon under almost constant current, which resolves measurement sensitivity issues caused by unavoidable measurement circuit parasitic inductance and measurement probes deskew in
conventional device characterisation method by triangle current mode. Proposed measurement circuit and measurement method is then validated by first characterising a SiC-MOSFET with constant RDSon. Then, the comparison on GaN-HEMT dynamic RDSon measurement results demonstrates the improved accuracy of proposed trapezoidal current mode over conventional triangle current mode when device switches at 1MHz.

Optimized design of multi-MHz frequency isolated auxiliary power supply for gate drivers in medium voltage converters

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IEEE Transactions on Power Electronics
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This paper presents the design and optimisation of a suitable topology for an isolated DC-DC auxiliary power supply with high isolation voltage and low coupling capacitance. The converter consists of a GaN HEMT inverter operating at 6.78 MHz, an LCC resonance tank and a class E low dv/dt rectifier. Furthermore, the galvanic isolation is implemented using a coreless planar transformer that enables higher insulation voltage with similar or better converter efficiency compared to designs using magnetic material. An analytical design methodology is developed, however, SPICE investigations show that optimal designs might lie outside the validity of the design equations. Consequently, a virtual prototyping tool is developed based on a genetic algorithm with numerical simulations and, in turn, is used to optimise the converter. The optimisation algorithm maximises the converter efficiency while minimising the transformer size. Prototypes are constructed based on the resulting Pareto front. Experimental results show the validity of the simulated results. Prototypes transferring up to 15 W with a peak efficiency of 81% are shown. The selected topology enables insulating voltages exceeding 40 kV.

Bandwidth Enhancement of Doherty Power Amplifier Using Modified Load Modulation Network

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IEEE Transactions on Circuits and Systems I: Regular Papers
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A novel Doherty power amplifier (DPA) architecture with extended bandwidth is presented in this paper. A modified load modulation network is introduced to provide impedance condition required by the Doherty operation in a wide frequency range. Analytical parameter solutions of the proposed load modulation network and the related load modulation process are presented. A DPA with 2.80-3.55 GHz bandwidth utilizing commercial GaN transistors is implemented. The fabricated DPA attains a measured 9.3-11.1 gain and 43.0-45.0 dBm saturated power. 50.0-60.6% and 66-78% drain efficiency is obtained at 6 dB output power back-off and saturation throughout the designed band, respectively. Moreover, the back-off drain efficiencies are higher than 55% within 700 MHz bandwidth. When driven by a 6-carrier 120 MHz OFDM signal with 7.0 dB peak to average power ratio, the proposed DPA achieves adjacent channel leakage ratio of better than -50 dBc after digital pre-distortion (DPD) at 3.20 GHz with average efficiency of 53.3%.

Gate Leakage Suppression and Breakdown Voltage Enhancement in p-GaN HEMTs Using Metal/Graphene Gates

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IEEE Transactions on Electron Devices
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In this article, single-layer intrinsic and fluorinated graphene were investigated as gate insertion layers in normally-OFF p-gallium nitride (GaN) gate high electron mobility transistors (HEMTs), which wraps around the bottom of the gate forming Ti/graphene/p-GaN at the bottom and Ti/graphene/SiNx on the two sides. Compared to the Au/Ti/p-GaN HEMTs without graphene, the insertion of graphene can increase the ION/IOFF ratios by a factor of 50, increase the VTH by 0.30 V and reduce the OFF-state gate leakage by 50 times. Additionally, this novel gate structure has
better thermal stability. After thermal annealing at 350 °C, gate breakdown voltage (BV) holds at 12.1 V. This is considered to be a result of the 0.24 eV increase in Schottky barrier height and the better quality of the Ti/graphene/p-GaN and Ti/graphene/SiNx interfaces. This approach is very effective in improving the ION/IOFF ratio and gate BV of normally-OFF GaN HEMTs.

**Optimization of Ohmic Contact for AlGaN/GaN HEMT on Low-Resistivity Silicon**

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IEEE Transactions on Electron Devices

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In this article, we report the optimization of ohmic contact formation on AlGaN/GaN on low-resistivity silicon. For achieving this, a strategy of uneven AlGaN/GaN was introduced through patterned etching of the substrate under the contact. Various pattern designs (holes, horizontal lines, vertical lines, grid) and varied etch depth (above and below the 2-D electron gas) were investigated. Furthermore, a study of planar and nonplanar ohmic metallization was investigated. Compared to a traditional fabrication strategy, we observed a reduced contact resistance from 0.35 to 0.27 Ω⋅mm by employing a grid etching approach with a “below channel” etch depth and nonplanar ohmic metallization. In general, measurements of “below channel” test structures exhibited improved contact resistance compared to “above channel” in both planar and nonplanar ohmic metallization.

**Observation of Dynamic VTH of p-GaN Gate HEMTs by Fast Sweeping Characterization**

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IEEE Electron Device Letters

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In this work, fast sweeping characterization with an extremely short relaxation time was used to probe the VTH instability of p-GaN gate HEMTs. As the ID-VG sweeping time deceases from 5 ms to 5 μs, the VTH dramatically degenerates from 3.13 V to 1.76 V, meanwhile the hysteresis deteriorates from 22.6 mV to 1.37 V. Positive bias temperature instability (PBTI) measurement by fast sweeping shows the VTH features a very fast shifting process but a slower recovering process. D-mode HEMTs counterpart without Mg contamination demonstrates a negligible VTH shift and hysteresis, proving the VTH instability is probably due to the ionization of acceptor-like traps in the p-GaN depletion region. Finally, the VTH instability is verified by a GaN circuit under switching stress. The VTH instability under different sweeping speed uncovers the fact that the high VTH by conventionally slow DC measurements is probably artificial. The DC VTH should be high enough to avoid HEMT faulty turn-on.

**The Impact of Hot Electrons and Self-Heating During Hard-Switching in AlGaN/GaN HEMTs**

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IEEE Transactions on Electron Devices

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In this article, we investigate the impact of hard-switching on the dynamic ON-resistance (RON) in the AlGaN/GaN high-electron mobility transistors (HEMTs). The pulsed measurements were taken on a set of GaN-on-6H-Si wafers, showing a significant RON increase after hard-switching compared with soft-switching. The impact of hard-switching was found to be strongly dependent on the surface passivation stoichiometry. Both hot electrons and self-heating are generated during hard-switching and they were investigated separately. For the self-heating effect, we found that the heating energy dissipated during hard-switching followed a different trend to the dynamic RON, showing that self-heating was not responsible for the dynamic RON. Following hard-switching, we found that the recovery of the RON occurred on a time scale of microseconds, far too fast to be explained by buffer trapping. Consequently, we suggest that the hard-switching-induced hot electrons are trapped on the surface and result in the dynamic RON. To support these conclusions, we undertook 2-D-TCAD simulations. Self-heating was found to be incompatible with the measurements, and surface-
trapped hot electrons during hard-switching were shown to be consistent with the experimental observation. Based on the analysis, we find that modifying the field plates and stoichiometries of SiNₓ can be the possible solutions to suppress dynamic RON after hard-switching.

A Normally-Off Co-Packaged SiC-JFET/GaN-HEMT Cascode Device for High-Voltage and High-Frequency Applications

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IEEE Transactions on Power Electronics
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A 1200-V/100-mΩ SiC-JFET/GaN-HEMT hybrid power switch is demonstrated, which features a flip-chip co-packaged cascode configuration incorporating a vertical SiC junction field-effect-transistor (JFET) and a lateral GaN high-electron-mobility-transistor (HEMT). The high-voltage SiC-JFET provides the high-voltage blocking capability while the low-voltage GaN HEMT enables the normally-off gate control with superior switching characteristics. Compared to conventional SiC-JFET/Si-MOSFET cascode devices, the SiC-JFET/GaN-HEMT cascode device exhibits fast switching speed, which has been validated by systematic characterizations including static/dynamic device-level measurements and board-level hard-switching tests. Meanwhile, the device is free from several notorious issues of high-voltage GaN power transistors such as dynamic on-state resistance degradation and threshold voltage shift. Such a wide-bandgap semiconductor-based hybrid switch is suitable to be deployed in high-power and high-efficiency power conversion systems.

Combined geometrical techniques and applying nonlinear field dependent conductivity layers to address the high electric field stress issue in high voltage high-density wide bandgap power modules

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IEEE Transactions on Dielectrics and Electrical Insulation
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Wide bandgap (WBG) power modules made from materials such as SiC and GaN (and soon Ga2O3 and diamond), which can tolerate higher voltages and currents than Si-based modules, are the most promising solution for reducing the size and weight of power electronics systems. In addition to the higher blocking voltages of WBG power modules, their volume has been targeted to be several times smaller than that of Si-based modules. This translates into higher electric stress within the module and, in turn, a higher risk for unacceptable partial discharge (PD) activities, leading to aging and degradation of both the ceramic substrate and the silicone gel. Due to the small dimensions of power module geometry, in the mm or μm (for protrusions) range, and due to its extremely non-uniform electric field geometry, conventional high voltage testing electrode geometries cannot simulate real conditions. On the other hand, university-based laboratories often cannot provide testing samples under manufacturing/factory conditions and with high-quality materials. Thus, it is difficult to determine the efficacy of electric field and PD control methods. To address this issue, an electric field criterion based on precise dimensions of a power module and its PD measurement is introduced. Then, combined geometrical techniques and the application of nonlinear field-dependent conductivity (FDC) layers are proposed, for the first time, to address the high electric field issue in an envisaged 25 kV high-density WBG power module. Electric field modeling and simulations are carried in COMSOL Multiphysics where various electric field reduction methods proposed in this paper can be used as a guideline and reference to design the insulation system for next-generation WBG power modules, meeting both the one-minute insulation and PD tests based on IEC 61287-1.
Ultrathin-Barrier AlGaN/GaN Hybrid-Anode-Diode With Optimized Barrier Thickness for Zero-Bias Microwave Mixer
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IEEE Transactions on Electron Devices
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In this article, the hybrid-anode-diode (HAD) is demonstrated for a zero-bias microwave mixer. In order to achieve a strong nonlinearity of the device at zero bias (i.e., 0 V), a novel technique based on the ultrathin-barrier (UTB) AlGaN/GaN heterostructure is proposed to precisely modulate the turn-on voltage (V_T) of the HAD and yet the nonlinearity at 0 V. In order to determine the optimized AlGaN-barrier thickness and, thus, facilitate the device fabrication, the UTB-HAD is first designed by the TCAD simulation to achieve a high sensitivity at 0 V. In the fabricated UTB-HAD, the zero-bias curvature coefficient (γ) of 20.4 and 10.2 V−1 is, respectively, measured at room temperature (RT) and 200 °C, which indicates a high zero-bias sensitivity obtained in the fabricated device. The UTB-HAD for a zero-bias microwave mixer is characterized and exhibited proper functionality from RT up to 200 °C. The novel device structure together with the nonlinearity modulation technology demonstrated in this article is of great potential for high-sensitivity and high-temperature zero-bias microwave applications.

Study and implementation of 600V high voltage gate driver IC with the common mode dualinterlock technique for GaN Devices
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IEEE Transactions on Industrial Electronics
https://doi.org/10.1109/TIE.2020.2970673

Gallium Nitride (GaN) power device is well known as a favorable alternative of silicon power device for power management system. However, it is difficult to meet the demand of higher operating frequency when using the traditional high voltage gate driver IC (HVIC) to control the GaN devices. This work illustrated that the propagation delay of the high voltage level shifter structure is the primary factor in limiting the operating frequency of the HVIC, and a new high voltage level shifter structure named Common Mode Dual Interlock (CMDI) level shifter structure is proposed, which can eliminate both the common mode transient noise and differential mode transient noise effectively without adopting Resistance-Capacitance (RC) noise filter. A better tradeoff between the dVS/dt noise immunity capability and the propagation delay can be achieved. Due to the all GaN integration technology is not suitable for complicated circuits at present, a 600V HVIC for GaN device adopting the proposed CMDI level shifter structure is implemented with normal silicon based Bipolar-CMOS-DMOS (BCD) technology finally. The experimental results show that it can achieve high dVS/dt noise immunity larger than 100V/μs, low propagation delay less than 32 ns and the allowable negative VS swing to -4 V at 5 V supply voltage.

Thermal Performance of GaN/Si HEMTs Using Near-Bandgap Thermoreflectance Imaging
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IEEE Transactions on Electron Devices
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Superlattice (SL) structures have been used to reduce the stress in the GaN epilayer of high-electron-mobility transistors (HEMTs). This has led to an improvement in their properties such as the breakdown voltage. The increase in thermal resistance associated with these structures, however, causes elevated device temperatures which may outweigh the benefits of this approach. To verify this, the thermal performance of SL structures on HEMTs must, thus, be accurately characterized. Transient thermoreflectance imaging (TTI) is an optical technique that can map the temperature distribution across a surface. For materials, such as gold, TTI shows a high spatial and temporal resolution. Consequently, the technique has been primarily used to monitor the
gate metal temperature distribution in HEMTs. The origin of the localized heating in HEMTs, however, is known to be in the active GaN layer and, thus, accurate thermal characterization of the channel is necessary. Using a UV LED excitation source with a wavelength near the bandgap of GaN, TTI of GaN channels in HEMTs is presented and verified by comparing the gate metal temperature. To ensure a strong thermoreflectance signal from the GaN surface, the importance of using an excitation wavelength near the bandgap of the GaN channel is highlighted. The effect of the bandgap on the magnitude and the linearity of the thermoreflectance coefficient is presented and discussed. Overall, the improvements to TTI discussed in this article make the technique an accurate method to measure the temperature distribution in GaN HEMT SL structures.

High-performance dual-gate-charge-plasma-AlGaN/GaN MIS-HEMT
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Applied Physics A
https://doi.org/10.1007/s00339-020-3342-x

This paper presents a novel structure of dual-gate-charge-plasma (DG-CP) AlGaN/GaN metal–insulator–semiconductor high electron mobility transistor (MIS-DG-CP-HEMT) with gate oxides employing Al2O3. AlN as an interfacial layer between dielectric and semiconductor. Dual-gate technique for both CP and doped HEMT is used to improve the transport characteristics in the channel. CP-HEMT is used to enhance the conductance charge density and electron concentration at the interface of AlGaN and GaN. The DG-CP-HEMT is compared with DG-doped HEMT. The dual-gate structure helps in incorporating the two different layers of 2-dimensional electron gas (2DEG) for higher current density. Results showed a better performance of DG-CP-HEMT in term of various analog and RF parameters. HEMT gives better transconductance (29 mS), Cutoff frequency (11 GHz) and ON-state-to-OFF-state current ratio (1011), ON-resistance (6 Ω-cm) and subthreshold slope (63 mV/dec). The proposed HEMT architecture can be used for RF applications due to its exemplary characteristics.

Electrical Characteristics of AlGaN/GaN High-Electron-Mobility Transistors Fabricated with a MgF2 Passivation Layer
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Journal of the Korean Physical Society
https://doi.org/10.3938/jkps.76.278

We have demonstrated AlGaN/GaN high-electron-mobility transistors (HEMTs) fabricated with a MgF2 passivation layer. Upon MgF2 passivation using an e-beam evaporator, the HEMT showed a maximum drain saturation current of 508 mA/mm, a maximum transconductance of 136 mS/mm, a significantly reduced gate forward leakage current, a low gate reverse leakage current of 1.8 × 10−7 A/mm at gate bias voltage of −10 V, and an increased breakdown voltage of 563 V. This suggests that the MgF2 film is quite useful as a passivation layer for AlGaN/GaN HEMTs.

Highly Enhanced Inductive Current Sustaining Capability and Avalanche Ruggedness in GaN p-i-n Diodes With Shallow Bevel Termination
School of Electronic Science and Engineering, Nanjing University, Nanjing, China
IEEE Electron Device Letters
https://doi.org/10.1109/LED.2020.2970552

In this work, small-angle beveled-mesa termination technique was developed in GaN p-i-n power diodes for high avalanche performances. With effective alleviation of electric field crowding effect at the junction sidewall, near uniform distribution of avalanche breakdown was realized. Resultantly, state-of-the-art inductive avalanche current density of ~31.5 kA/cm 2 and average parallel-plane breakdown electric field of 2.86 MV/cm was achieved in the terminated diodes. Meanwhile, ruggedness of the avalanche breakdown has also been evidently promoted, under both repetitive dc reverse breakdown stresses and unclamped inductive switch conditions.
**Charge-Based Compact Model of Gate Leakage Current for AlInN/GaN and AlGaN/GaN HEMTs**
Department of Electrical Engineering, IIT Madras, Chennai, India

IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2020.2965561

The gate leakage current is analytically modeled for AlInN/GaN and AlGaN/GaN high-electron mobility transistor (HEMT) devices using a charge-based approach. Four different current mechanisms, namely Fowler–Nordheim tunneling (FNT), Poole–Frenkel emission (PFE), thermionic emission (TE), and defect-assisted tunneling (DAT) are considered. FNT and PFE are two dominant mechanisms in the reverse bias region, while TE and DAT are significant in forward and near zero gate bias regions, respectively. This model is implemented in Verilog-A and validated by comparison with experimental data for both AlInN/GaN and AlGaN/GaN HEMTs. It is shown that the model is able to capture the effects of Al molar fraction, barrier thickness, and temperature on gate leakage current over a wide range of gate and drain voltages.

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**Enhanced Sensitivity of GaN-based Temperature Sensor by using the Series Schottky Barrier Diode Structure**
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Institute of Technology and Science, Tokushima University, Tokushima, Japan

IEEE Electron Device Letters
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Temperature sensor using series GaN Schottky barrier diode (SBDs) with TiN anode was fabricated and evaluated extensively. The diode presents good characteristics in a wide temperature range from 25 °C to 200 °C. The temperature dependent forward voltage of the conventional 8-finger SBD at a fixed current shows good linearity, resulting in a sensitivity of approximately 1.14 mV/K. On the other hand, the series SBD with two 8-finger diodes enhances the sensitivity by nearly two times. The enhancement in temperature sensitivity is interpreted using a series model, with the obtained parameters are comparable with the 8-finger SBD.
PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

TMD takes stake in GaN power amplifier maker Diamond Microwave

Diamond Microwave Ltd (DML) of Shipley, UK says that it has a new shareholder in the form of TMD Technologies Ltd of Hayes, West London, which designs and manufactures transmitters, amplifiers, microwave power modules (MPMs), high-voltage power supplies, microwave tubes and transponders for radar, EW and communications applications.

Diamond Microwave is described as a pioneer in the development and manufacture of compact GaN-based microwave high-power solid-state power amplifiers (SSPA) for the radar, electronic warfare (EW), communications and aerospace sectors, with chip and wire GaN technology that is particularly suited to such demanding applications where their power-to-volume performance is said to be a capability differentiator.

The investment from TMD is “a welcome step in enhancing our existing relationship and further developing our joint interests in world-class amplifier products,” says DML’s CEO Dr Richard Lang. TMD brings “the possibility of new channels through which to develop and exploit our solid-state power amplifier technology,” he adds.

“We have been collaborating with Diamond Microwave for several years and are very pleased with this latest development, which is a logical step forward in our business relationship,” comments TMD’s group CEO Dave Brown. “Their specialized technological expertise has proved particularly successful across the aerospace and defence industries and complements our current technologies targeted at this market sector,” he adds. “We are looking forward to increased involvement with this forward-looking company.”

Transphorm showcasing market adoption of high-voltage GaN power at APEC

In booth #1514 at the Applied Power Electronics Conference (APEC 2020) in New Orleans (15-19 March), Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V and 900V gallium nitride (GaN) field-effect transistors (FETs) — is showcasing end products from more than five markets that leverage the inherent benefits offered by its GaN, including increased power density and power efficiency as well as lower overall system costs — often achieved within the same or better thermal performance range than comparative silicon-based products, it is claimed.

The customers behind the end products are using Transphorm’s GaN in a wide variety of power ranges. Information gathered from their design experiences — coupled with the company’s technological vision - has led to Transphorm’s latest innovation, the Gen IV GaN platform.

APEC attendees can get the first look at Transphorm’s new GaN devices for the power electronics market, as well as new design tools and resources for simplifying GaN power system development.

Transphorm says that its market traction to date is driven by its focus on four key areas:
• Reliability: First JEDEC- and AEC-qualified GaN power FETs that also offer less than four defective parts per million (DPPM) based on more than 5 billion field hours.
• Designability: GaN offered in standard device packages that use well-known design-in and thermal management techniques.
• Drivability: GaN FETs that require minimal external circuitry and drive like silicon.
• Reproducibility: GaN manufacturing process that offers silicon-like fab yields capable of high-volume scalability.

Transphorm’s team members will address these four key areas as they present six related topics during APEC’s educational, industry and technical sessions:

• Full Technology Validation of 600V+ GaN Power Devices — from Device Structure, Performance and Reliability, to Application Economics, User Satisfaction and ppm Field Failure Rate.
• Advances Through Innovation: Transphorm Changes the Game with Gen-IV 650V GaN Platform.
• Portable Power for the People: Inergy Realizes its Vision with Transphorm GaN.
• GaN FETs Enable High Frequency Dual Active Bridge Converters for Bi-Directional Battery Chargers.
• Best Practices Using Voltage Acceleration for Reliability Testing of High Voltage GaN.
• No Digital Control Experience Needed: Bridgeless Totem Pole PFC GaN Designs Made Simple

Navitas’ 65W GaNFast charger power ICs chosen by Xiaomi for Mi 10 Pro smartphone

Navitas Semiconductor Inc of El Segundo, CA, USA says that its GaNFast charging technology has been adopted by China’s Xiaomi for its flagship Mi 10 PRO smartphone.

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.

Since GaNFast power ICs can operate up to 100x faster than earlier silicon power chips, it takes only 45 minutes to charge the Mi 10 PRO from 0 to 100%, says Navitas.

Gallium nitride enables extremely small charger size and extremely high charging efficiency. “The 65W GaN charger is only half the size of the 65W traditional charger that comes as standard with our Xiaomi 10 PRO,” notes Xiaomi’s chairman & CEO Jun Lei.

Xiaomi’s 65W GaN charger uses Navitas’ NV6115 and NV6117 GaNFast power ICs, which are optimized for high-frequency, soft-switching topologies. Monolithic integration of FETs, drivers and logic delivers a very small, fast, easy-to-use ‘digital-in, power-out’ high-performance power conversion module. Using GaNFast, Xiaomi’s 65W GaN charger is only 56.3mm x 30.8mm x 30.8mm (53cc), which is half the size of standard adapters.

Xiaomi invested earlier in Navitas to lay the groundwork for this cooperation. Xiaomi’s strategy is to establish upstream and downstream partnerships in the industry chain through capital investment, while taking into account the dual benefits of investment and business. Navitas has hence been able to broaden its sales channels.

“I am very pleased to see Xiaomi’s open attitude towards new materials and new technologies,” comments Navitas’ CEO Gene Sheridan. “From the start, Navitas has focused on the technology application and innovation.
of GaN materials. GaNFast power ICs are monolithic integration of FET, drive and logic and achieve extremely small application size and high efficiency. For manufacturers who want to lead with technology, GaNFast enables high performance and drives product differentiation,” he adds.

“The battery capacity of smartphones, tablets and laptops is increasing, while consumers are eager to have a faster-charging experience,” says Yingjie Zha, general manager of Navitas Semiconductor China. “GaNFast technology brings the industry a small, efficient charger that can quickly charge electronic products such as mobile phones and laptops.”

**Comtech receives $8.8m contract for Ka-band in-flight connectivity solid-state amplifiers**

*SemiconductorToday*

Comtech Telecommunications Corp of Melville, NY, USA says that, during its fiscal second-quarter 2020, its subsidiary Comtech Xicom Technology Inc of Santa Clara, CA – a part of Comtech’s Commercial Solutions segment that makes tube-based and solid-state power amplifiers (SSPAs) for satellite communication (SATCOM) uplink applications – received a contract worth more than $8.8m for Ka-band solid-state amplifiers to be used in an in-flight connectivity satcom application.

“We have incorporated the latest gallium nitride (GaN) solid-state technology for use in a new cabin external application,” says Comtech Telecommunications’ chairman & CEO Fred Kornberg. “We have shipped over 2000 airborne amplifiers to date, and we continue to expand our presence in this growing market.”

Comtech Xicom’s product range spans power levels from 8W to 3kW, with frequency coverage in sub-bands within the 2-52GHz spectrum. Amplifiers are available for fixed and ground-based, shipboard and airborne mobile applications.

**Teledyne e2v HiRel and GaN Systems unveil high-reliability 100V 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 100V/90A 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 TDG100E90 GaN power HEMT is now available with a bottom-side-cooled package for all applications requiring extremely high reliability, in particular space and military. It joins the 650V, 60A TDG650E60 (launched last December) and is available to provide a lower step-down voltage in high-reliability power circuitry.

*Picture: Teledyne e2v HiRel’s new TDG100E90 100V GaN power HEMT.*
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 release of the TDG100E90 GaN HEMT delivers the efficiency, size and power-density benefits required in demanding HiRel power applications.

Teledyne e2v HiRel says that, for all product lines, it performs the most demanding qualification and testing tailored to the highest-reliability applications. This regimen includes sulfuric test, high-altitude simulation, dynamic burn-in, step stress up to 175°C ambient, testing at 9V gate voltage, and full temperature testing.

This new addition to Teledyne’s GaN power HEMT family has an extremely small form factor and leverages GaN Systems’ patented Island Technology, which 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.

Compared with silicon MOSFET devices, the GaN-based TDG100E90 HEMT significantly reduces losses and electromagnetic interference (EMI), due to no reverse recovery characteristics. To reduce drain-source on-resistance (RDS(on)) or increase the load current, the TDG100E90 can easily support parallel driving configuration. The use of high-performance GaNPX packaging allows very high-frequency switching, extremely low inductance, and excellent thermal characteristics, enabling customers to significantly reduce the size and weight of power electronics, claims GaN Systems.

“Teledyne e2v HiRel is pleased to be working with GaN Systems on solutions for the most demanding requirements in key applications for avionics, radar, satcom, space and more,” comments Mont Taylor, Teledyne e2v HiRel’s VP of business development. “In addition to the currently released TDG650E60 650V GaN HEMT, the TDG100E90 complements our portfolio with a lower-voltage, higher-current option, providing GaN flexibility and choices to the HiRel power design community.”

Qualified TDG100E90 devices with bottom-side cooling are now shipping and available for immediate purchase.

**ST and TSMC collaborate to accelerate market adoption of GaN-based products**

_**SemiconductorToday**_

STMicroelectronics of Geneva, Switzerland and Taiwan Semiconductor Manufacturing Corporation (TSMC, the world’s biggest silicon wafer foundry) are collaborating to accelerate the development of gallium nitride (GaN) process technology and the supply of both discrete and integrated GaN devices to market. Through this collaboration, ST’s GaN products will be manufactured using TSMC’s GaN process technology.

Specifically, power GaN and GaN IC technology-based products will enable ST to provide solutions for medium- and high-power applications with better efficiency compared to silicon technologies on the same topologies, including automotive converters and chargers for hybrid and electric vehicles. They will also help to accelerate the megatrend of the electrification of consumer and commercial vehicles, says ST.

“As a leader in both wide-bandgap semiconductor technology and in power semiconductors for the demanding automotive and industrial markets, ST sees significant opportunity in accelerating the development and delivery of GaN process technology and bringing power GaN and GaN IC products to the market,” says Marco Monti, president of STMicroelectronics’ Automotive and Discrete Group. “TSMC is a trusted foundry partner that can uniquely meet the challenging reliability and roadmap evolution requirements of ST’s target customers,” he comments. “This cooperation complements our existing activities on power GaN undertaken at our site in Tours, France and with CEA-Leti. GaN represents the next major innovation in power and smart power electronics, as well in process technology,” adds Monti.
“We look forward to collaborating with ST and bring the applications of GaN power-electronics to industrial and automotive power conversion,” says TSMC’s VP of business development Dr Kevin Zhang. “TSMC’s leading GaN manufacturing expertise, combined with STMicroelectronics’ product design and automotive-grade qualification capabilities, will deliver great energy-efficiency improvement for industrial and automotive power conversion applications.”

ST expects the delivery of first samples of power GaN discrete devices to its key customers later this year, followed by GaN IC products within a few months.

**TSMC’s GaN-on-Si patents supporting ST’s strategic move towards power GaN adoption in automotive applications**

*SemiconductorToday*

As announced in February, STMicroelectronics of Geneva, Switzerland is collaborating with Taiwan Semiconductor Manufacturing Corporation (TSMC, the world’s biggest silicon wafer foundry) to accelerate the development of gallium nitride (GaN) technology for power applications, and more specifically for automotive applications (converters and chargers for hybrid and electric vehicles).

With this recent manufacturing partnership, STMicroelectronics has joined the series of companies that have trusted TSMC for volume production of GaN power devices, including market leader GaN Systems, as well as VisIC and Navitas Semiconductor (focusing on GaN power IC technology). STMicroelectronics will begin by sampling discrete GaN power devices, to be followed soon by GaN IC products based on TSMC’s GaN-on-Si process technology.

TSMC’s GaN-on-Si technology was reviewed in Knowmade’s ‘GaN-on-Si Patent Landscape Analysis’ (released in January), which covers about 40 patent families (inventions) related to this technology, regrouping more than 130 patents filed worldwide, mainly in US (70+) and China (25+).

“TSMC has leading GaN-on-silicon manufacturing expertise, and we have identified at least 12 key inventions narrowly related to power applications,” says Remi Comyn PhD, Knowmade’s technology and patent analyst, Compound Semiconductors and Electronics. Indeed, TSMC was actively filing GaN-on-Si patents for power applications between 2012 and 2017 and has strongly focused on the USA (20+ granted patents).

The patent portfolio protects technological approaches providing improved GaN-on-Si buffer resistivity, using three main approaches:

- p-type conductivity dopants in graded buffer layers and ungraded buffer layers (US patent 8,791,504);
- diffusion-blocking layer between the buffer layer and the silicon substrate (US patent 9,245,991);
- multi-strained superlattice structures (SLS) to overcome the limitations due to carbon doping of the buffer layers (US patent 10,109,736).

Next, TSMC focused its patenting activity on removing the breakdown voltage limitations due to the surface gate-drain region, inserting buried dielectric portions in the AlGaN barrier (Figure 1a), in addition to the use of field-plate structures (Figure 1b) and an AlGaN barrier with Al-graded composition (US patent 10,522,532).
Interestingly, TSMC’s latest GaN-on-Si developments for power applications focused on the fabrication of GaN power integrated circuits (ICs) via US patent 9,793,389, related to the isolation of adjacent GaN-on-Si power devices, and US patent 10,522,532 related to the formation of through-GaN vias (TGVs).

In the ‘GaN-on-Si Patent Landscape Analysis’, Knowmade also analyzed the patent portfolio of STMicroelectronics, which is still strengthening its IP position in the power GaN patent landscape. In 2017-2018, ST focused on GaN device technology, especially normally-off transistor structures (Figure 2).

STMicroelectronics’ normally-off transistor structures (US patents 10,516,041, 10,566,450 and 10,522,646) are based on a tri-layer epitaxial stack NiO/AlGaN/GaN, the selective removal of NiO in the gate region and the deposition of a gate dielectric (AlN, Al2O3 or SiO2) on the AlGaN barrier (with or without recess). The buffer region may include a first carbon-doped buffer layer for increasing the breakdown voltage and a second p-type buffer layer for limiting the degradation of dynamic on-resistance due to the first buffer layer. It can be combined with the presence of a sloped field plate in order to further reduce dynamic on-resistance phenomenon, implemented with the advantageous method described in US patent 10,050,136.


CEA is also a well-established IP player in the GaN-on-Si patent landscape, with more than 40 patented inventions. Over the last three years, it has intensified its GaN-on-Si patenting activity in the field of power applications with six additional inventions. CEA first focused on enhancement-mode device technology (Figure 3a) and then focused
on the epi-structures in order to enhance the vertical breakdown voltage. Its recent GaN-on-Si patenting activity also includes an IP collaboration with automotive player Renault regarding power GaN device technology (Figure 3b).

"Following the R&D collaboration between STMicroelectronics and CEA since 2018, and the recent announcement of partnership between STMicroelectronics and TSMC, we expect an acceleration of their respective patenting activity on power GaN-on-silicon in the next months,” says Remi Comyn of Knowmade.

**STMicroelectronics To Acquire Majority Stake In Exagan**

STMicroelectronics has signed an agreement to acquire a majority stake in French GaN innovator Exagan. Exagan's expertise in epitaxy, product development and application know-how will broaden and accelerate ST's power GaN roadmap and business for automotive, industrial and consumer applications. Exagan will continue to execute its product roadmap and will be supported by ST in the deployment of its products.

Terms of the transaction were not disclosed and closing of the acquisition remains subject to customary regulatory approvals from French authorities. The signed agreement also provides for the acquisition by ST of the remaining minority stake in Exagan 24 months after the closing of the acquisition of the majority stake. The transaction is funded with available cash.

“ST has built strong momentum in SiC and is now expanding in another very promising compound material, GaN, to drive adoption of the power products based on GaN by customers across the automotive, industrial and consumer markets” said Jean-Marc Chery, president and CEO of STMicroelectronics. “The acquisition of a majority stake in Exagan is another step forward in strengthening our global technology leadership in power semiconductors and our long-term GaN roadmap, ecosystem and business. It comes in addition to ongoing developments with CEA-Leti in Tours, France, and the recently-announced collaboration with TSMC.”

Founded in 2014 and headquartered in Grenoble (France), Exagan is dedicated to accelerating the power-electronics industry's transition from silicon-based technology to GaN-on-silicon technology, enabling smaller and more efficient electrical converters. Its GaN power switches are designed for manufacturing in standard 200-mm wafer fabs.
Fairview unveils Class AB high-power amplifiers with optional heatsinks

Fairview Microwave Inc of Lewisville, TX, USA (an Infinite Electronics brand that provides on-demand RF, microwave and millimeter-wave components) has released a new series of Class AB broadband high-power amplifier modules that incorporate gallium nitride (GaN) or silicon LDMOS or VDMOS semiconductor technology.

The new line consists of 18 models spanning frequency bands from 20MHz to 18GHz. Unconditionally stable and operating in a 50Ω environment, they offer power gain up to 53dB and saturated output power levels from 10W to 200W. The line includes two new heatsink modules with DC-controlled cooling fans specifically designed for the 18 new models to ensure optimum baseplate temperature for highly reliable performance.

“This new series provides our customers with more options for applications that need a high-power, small-form-factor RF amplifier that uses cutting-edge semiconductor technology with wide dynamic range over a broad array of frequencies, high linearity and exceptional efficiency,” says Tim Galla, product line manager at Infinite Electronics brand Pasternack.

The compact coaxial packages utilize N-Type or SMA connectors and have integrated D-Sub control connectors for DC bias, enabled with TTL logic control and temperature and current sense functions. The rugged assemblies can withstand relative humidity exposure up to 95% maximum and operate over a wide temperature range from -20°C to +60°C.

Fairview’s new class AB, high-power amplifiers and heatsinks are in-stock and available for immediate shipping with no minimum order quantity required.

Nexperia partners with Ricardo to produce technology demonstrator for GaN-based EV inverter

Nexperia BV of Nijmegen, Netherlands (which manufactures discrete and MOSFET components and analog & logic ICs) has announced a partnership with global transportation technology company Ricardo to produce a technology demonstrator for an electric vehicle (EV) inverter based on gallium nitride (GaN) technology.

Nexperia says that GaN is the preferred switch for these applications as GaN FETs lead to systems with greater efficiencies at lower costs with improved thermal performance and simpler switching topologies. In automotive terms this means that the vehicle has a greater range – the major concern for EV purchasers. GaN is on the brink of replacing silicon carbide (SiC) or silicon-based insulated-gate bipolar transistors (IGBTs) as the preferred technology for the traction inverters used in plug-in hybrids or full battery electric cars, adds the firm.

Last year Nexperia launched a range of AEC-Q101-approved GaN devices, providing automotive designers with a wider portfolio of proven, reliable devices, providing the power density required for electrification of the powertrain. Ricardo designs and consults on concepts within the automotive industry, including the manufacture of prototypes and demonstrations, and has collaborations with high-profile brands such as McLaren and Bugatti.

“By designing our GaN devices into an inverter and trialling them through Ricardo, we will be able to better understand how a vehicle can be driven safely and reliably,” says Michael LeGoff, general manager GaN, Nexperia. “We are developing a real solution that I think a lot of automotive designers will be interested in having a look at,” he adds.

“Semiconductor technology is key to the efficiency of the inverter system and the role that it plays in the performance and efficiency of an electrified vehicle,” says Adrian Greaney, director - technology & products,
Ricardo. “By delivering significant benefits in terms of the switching speed and efficiency, gallium nitride is a real enabling technology. As well as leading to increased range, it allows us to reduce the package size and weight of the inverter, which provides greater powertrain design flexibility as well as contributing to vehicle mass reduction,” he adds. “There are also many associated benefits when we look at the design from a system level.”

**STAr acquires Accel-RF to expand scope of reliability test**

*SemiconductorToday*

Reliability test system and probe card supplier STAr Technologies of Hsinchu City, Taiwan has acquired Accel-RF Instruments Corp of San Diego, CA, USA (which produces turn-key reliability and performance characterization test systems for compound semiconductors).

Established in 2000, STAr provides intellectual property, software, hardware, consumables, service and expertise to the semiconductor industry, spanning parametric electrical test (E-test), wafer-level and package-level reliability (WLR & PLR), mixed-signal tests, assembly & packaging services, probe cards, load boards, test interfaces and sockets.

The acquisition enhances STAr reliability test offerings with the addition of Accel-RF’s high-temperature RF and high-voltage switching reliability test systems for compound semiconductors, such as gallium nitride (GaN) and silicon carbide (SiC).

Founded in 2003, with cumulative experience based on decades of microwave circuit design, RF component reliability testing and comprehensive reliability test methodology development, Accel-RF has helped to facilitate industry adoption of compound semiconductor transistors and MMICs into space, military and commercial wireless markets. It has supplied reliability test systems to top-tier semiconductor and aerospace defense users throughout the USA, Europe and Asia. Accel-RF claims to be the only provider of fully integrated, scalable, turnkey systems that provide dynamic, multi-dimensional, RF, DC and temperature tests on one platform through a graphical user interface, in a small footprint.

“As a member of STAr’s global connection, Accel-RF will solidify our commitment to providing a far-reaching and strong technical expertise to the compound semiconductor reliability community,” says Accel-RF’s CEO Roland Shaw. “We look forward to a collaborative future with STAr Technologies in pursuit of advanced test solutions that will reinforce our longstanding position as a leading RF and power semiconductor reliability test innovator,” he adds.

“The acquisition of Accel-RF is another step towards strengthening our presence in wireless industry markets including RF through millimetre-wave applications,” says STAr Technologies’ CEO Dr Choon-Leong Lou. “The combination of STAr Technologies expertise in DC-AC and now extending into RF with Accel-RF, creates a formidable platform for addressing rapidly growing applications such as 5G, LiDAR, photonics and advanced radar systems,” he reckons.
The JEDEC Solid State Technology Association (which develops standards for the microelectronics industry) has announced the publication of JEP180: Guideline for Switching Reliability Evaluation Procedures for Gallium Nitride Power Conversion Devices. Developed by JEDEC’s JC-70 Committee for Wide Bandgap Power Electronic Conversion Semiconductors, JEP180 is available for free download from the JEDEC website.

To enable the adoption of GaN power transistors, both reliable operation in power conversion applications and switching lifetime need to be demonstrated, says JEDEC. Existing tests for silicon power transistors do not necessarily validate operation under actual-use conditions of power conversion equipment and may not be applicable for GaN power transistors.

To address this need, JEP180 is intended for use by manufacturers of GaN power transistors and power conversion equipment. For the first time since the introduction of GaN power transistors, JEP180 will enable manufacturers to evaluate the switching reliability of GaN power transistors and to assure their robustness at the technology level and in power conversion applications. The document provides guidelines for Switching Accelerated Life and Dynamic High-Temperature Operating-Life tests that are applicable to GaN planar enhancement-mode, depletion-mode, cascode power transistors, and integrated power solutions.

JEP180 was developed over a period of more than two years by experts from leading GaN power device manufacturers.

“This new guideline provides engineers a robust evaluation of switching behavior, which will further accelerate industry-wide adoption of GaN, especially in automotive and industrial markets where efficiency, power density and reliability matter the most," says Dr Stephanie Watts Butler, GaN technology innovation architect at Texas Instruments and the chair of JC-70.

“This latest guideline covers switching reliability and helps assure successful usage of GaN devices in a wide range of applications by addressing one of the key topics identified by our committee members," says Tim McDonald, senior advisor to Infineon’s CoolGaN program and the chair of the JC-70.1 subcommittee. “We continue in our work to build a full coverage of guidelines and standards for use of both GaN and SiC devices.”

Formed in October 2017 with 23 member companies, JC-70 now has over 60 member companies, underscoring industry interest in the development of universal standards to help advance the adoption of wide-bandgap (WBG) power technologies. Global multi-national corporations and technology startups from the USA, Europe, Middle East and Asia are working together to bring to the industry a set of standards for reliability, testing and parametrics of WBG power semiconductors. Committee members include industry leaders in power GaN and SiC semiconductors, as well as prospective users of wide-bandgap power devices, and test & measurement equipment suppliers. Technical experts from universities and national labs also provide input.

JEDEC says that interested companies worldwide are welcome to join it to participate in this standardization effort. JC-70 plans to hold four committee meetings in 2020, including a meeting co-located with the IEEE Applied Power Electronics Conference and Exposition (APEC) in New Orleans, Louisiana, on 16 March.
Transphorm Inc. Raises $21 Million and Completes Reverse Merger

GOLETA, Calif.--(BUSINESS WIRE)--Transphorm, Inc. (the “Company”) a pioneer in the development and manufacturing of high reliability-high performance gallium nitride (GaN) semiconductors for power conversion, announced today it raised $21.5 million in a private placement equity financing. Prior to the financing, Transphorm Technology, Inc. (“Transphorm”) completed a reverse merger with Peninsula Acquisition Corporation (“Peninsula”), a public Delaware corporation, whereby Transphorm became a wholly owned subsidiary of Peninsula. Following the merger, Peninsula changed its name to Transphorm, Inc., and will continue the historical business of Transphorm. Previous members of Transphorm’s Board of Directors, David Kerko, Eiji Yatagawa, Brittany Bagley, Mario Rivas and Dr. Umesh Mishra will remain as directors of the Company.

With its leading technology position, Transphorm has developed, and is in the market with, multiple families of products that are the building blocks for an array of power converter and inverter systems. Transphorm’s GaN products switch much faster than traditional silicon-based solutions and provide higher efficiency with increased system power density while enabling system size reduction. Transphorm has a proven track record of high quality, high reliability (Q+R™) solutions as well as a series-of-firsts including the first JEDEC and Automotive (AEC-Q101) qualification of high voltage GaN devices. Its robust GaN platform makes GaN products easy to use and integrate in systems with standard drive electronics.

Given the clear advantages of GaN, Transphorm has begun to see meaningful customer adoption in power adapters/fast chargers, power supplies for data-centers, communication infrastructure and broad industrial applications. In addition, Transphorm continues to see heightened interest from automotive EV suppliers for chargers, converters and inverters. This is in-line with the ongoing overall adoption of GaN solutions in power conversion applications which, per the Company’s analysis, amounts to an accessible Total Available Market for GaN (GaN TAM) of approximately $3.1 billion in 2024. Factoring in GaN market adoption rates, market research firm Yole Développement (“Yole”) predicts robust growth and that GaN power device revenues may approach $400 million by 2023.1

“We are thrilled to announce this new equity financing which will support and accelerate our product development, manufacturing, and sales for our GaN power solutions,” said Mario Rivas, CEO. Mr. Rivas continued, “We believe the success of this financing demonstrates confidence and support in Transphorm’s team, technology and products by both our current partners as well as our new investors.”

“Our core capabilities in GaN epitaxy, design, process and circuit applications have positioned us well to innovate and address the power conversion systems needs of our customers,” said Dr. Primit Parikh, Co-founder and COO. “We have created an integrated device model and developed highly reliable, high performance GaN device technology, as well as amassed one of the largest intellectual property portfolios in the GaN power industry,” Dr. Parikh added.

According to external patent reports from KnowMade, a specialist in the research and development of scientific and patent information, “Transphorm today has the dream patent portfolio for all those who want to benefit from strategic advantages in the GaN power electronics market.” 2

The financing was led by existing investors including an affiliate of Kohlberg Kravis Roberts & Co. L.P. (“KKR”), a new strategic investor, Marelli, and new prominent institutional investors. B. Riley FBR, Inc. (member FINRA/SIPC) was the lead placement agent and Craig-Hallum Capital Group LLC was the co-placement agent. Montrose Capital Partners was the sponsor for this transaction.
Growing ε polytype gallium oxide with gallium nitride

SemiconductorToday

Researchers based in Germany and Italy have been exploring the growth of ε-polytype gallium oxide (ε-Ga2O3) combined with gallium nitride (GaN) on sapphire substrates with a view to deployment in high-electron-mobility transistors (HEMTs) [Stefano Leone et al, Journal of Crystal Growth, vol534, p125511, 2020].

GaN-based high-frequency and high-voltage power devices are moving to wider commercial deployment in AC-DC inverters, power supplies, 600V switches, and the generation of communications and radar radio signals. The combination of GaN with ferroelectric ε-Ga2O3 could lead to interesting further electronic opportunities.

The ε-Ga2O3 material also has a strong spontaneous charge polarization, arising from the crystal structure and stronger ionic character of the chemical bond. Such polarization could give rise to two-dimensional electron gas (2DEG) HEMT channels with very high carrier density. There are, of course, also strain-dependent piezoelectric effects to be expected.

Ferroelectricity has mainly been deployed in non-volatile memory devices up to now, but recent research has also used the property to create ‘negative capacitance’ gate stacks. Such negative capacitance enables the subthreshold swing to go lower than the standard thermal limit of 60mV/decade. Such sharply switching devices are of interest in silicon electronics for low-voltage operation and low power consumption. Of course, GaN-based electronics is not so interested in low voltage.

One factor that has to be considered is that the β polytype crystal structure is more stable and the ε form of Ga2O3 decomposes above 700°C. This restricts the thermal budget of processes involving the material.

The team from Fraunhofer Institute for Applied Solid State Physics (IAF) in Germany, University of Parma in Italy, Institute of Materials for Electronics and Magnetism (IMEM-CNR) in Italy and Albert-Ludwigs Universität Freiburg in Germany focused on growth using metal-organic chemical vapor deposition (MOCVD) since it is the technique most favored in manufacturing. The researchers claim that their work is the first investigation of GaN/ε-Ga2O3 MOCVD.

The team employed two separated MOCVD reactors for deposition of ε-Ga2O3 and GaN. The material surfaces were exposed to air on transfer between the chambers. The GaN deposition used trimethyl-gallium (TMGa) and ammonia (NH3) precursors in hydrogen carrier gas. The substrate was mainly on-axis sapphire: (001) aluminium oxide (Al2O3). The ε-Ga2O3 was deposited in a cold-wall system at 610°C. The precursors for this were TMGa and water (H2O) in hydrogen carrier gas.

The GaN growth rate at 1050°C was around 1µm/hour. The ε-Ga2O3 deposition was at about half that rate, 500nm/hour. Some samples included a 10nm silicon nitride (SiN) passivation layer for studying electronic properties towards the fabrication of HEMTs. The SiN was deposited using inductively coupled plasma CVD, using silane (SiH4) and NH3.

The ε Ga2O3 polytype has an orthorhombic (pseudo-hexagonal) crystal structure with nominal 8.8% lattice mismatch with GaN. The researchers also investigated depositing the ε-Ga2O3 before the GaN – the drawback being that ε-Ga2O3 begins a transition to β-Ga2O3 at 700°C, which completes at 900°C. Thus, with ε-Ga2O3-first deposition the researchers reduced the GaN growth temperature to 690°C. Although the GaN-on-ε-Ga2O3 (GaN/ε-Ga2O3) surface was smooth, there were several defects visible in microscopic inspection.
Depositing the GaN at high temperature (1050°C) converted the ε material to β, according to x-ray analysis. By contrast, the low-temperature GaN/ε-Ga2O3 remained in the ε phase. The crystal quality of the overlying GaN is described as “poor” in both cases, on the basis of large full-width at half-maximum (FWHM) values for various x-ray rocking curve peaks. The low-temperature sample was particularly poor.

Although the growth of ε-Ga2O3 on GaN was better, the deposition tended to begin with 3D islands that later began to coalesce. Such behavior could lead to decent quality in thick layers, but the researchers were more interested in creating thin ε-Ga2O3 on GaN heterostructures with a view to fabrication of HEMTs.

![Figure 1: SEM studies of 5-minute ε-Ga2O3 MOCVD on (left) on-axis and (right) 4° off-cut GaN on sapphire.](image)

To encourage 2D layer-by-layer growth of ε-Ga2O3 the team tried using 4° off-cut (0001) sapphire substrates, giving the GaN surface a step-and-terrace texture. “The coalescence in this sample seems to be much more effective than in the on-axis samples,” the researchers observe from scanning electron microscope (SEM) studies (Figure 1).

Capacitance-voltage (CV) analysis of the materials detected 2DEG behavior only when the sample was capped with SiN passivation. However, there was a high level of hysteresis in the curves, ~0.9V, suggesting the presence of defects or ionized states. A SiN/ε-Ga2O3/GaN structure was found to have a carrier density profile consistent with a combined SiN/ε-Ga2O3 barrier thickness of 25nm. The SiN passivation was 10nm.

The growth time of the ε-Ga2O3 was 17 minutes. Thinner layers with shorter growth times down to 3 minutes were less uniform and consequently performed less well in CV measurements. Difficulties in making Ohmic contacts has inhibited the performance of Hall measurements and hence the assessment of carrier mobility. Sheet resistance values were relatively high: 1300-2200Ω/square and 3300Ω/square for on- and off-axis samples, respectively.

The sheet carrier density was estimated to be 6.4x1012/cm2, using the CV data. This value was well short of theoretical expectations of 1.2x1014/cm2, using Schrödinger-Poisson modeling. The modeled values for AlN and Al0.25Ga0.75N barriers are 6.5x1013/cm2 and 1.1x1013/cm2, respectively. The higher expectation for ε-Ga2O3 barriers rests on a higher spontaneous charge polarization of the crystal structure and the more ionic character of the chemical bonds.
The suppression of the 2DEG sheet carrier density in the experimental samples relative to theoretical expectations could be due to factors such as non-optimized morphology and high defect densities. Despite this, the team sees their results as being “very promising”. One key component in future HEMT development would be the fabrication of low-contact-resistance Ohmic source-drain electrodes without exceeding the 700°C thermal limit imposed by the ε-to-β polytype phase transition of the Ga2O3. The team points hopefully to recent work using titanium/gold annealed for three hours at 300°C, which gave low reported contact resistance on ε-Ga2O3.

Barium titanate and aluminium gallium nitride power electronics

Ohio State University and University of South Carolina in the USA have been exploring the use of the extreme-permittivity dielectric barium titanate (BaTiO3) perovskite oxide to increase breakdown voltage and to reduce resistance in aluminium gallium nitride (AlGaN) electronics [Towhidur Razzak et al, Appl. Phys. Lett., vol116, p023507, 2020].

AlGaN is of interest in power electronics as a wide-bandgap semiconductor with a high critical breakdown electric field value of more than 9MV/cm (when the aluminium content exceeds 50%), good low-field electron transport characteristics, and high saturation velocity. Such features could enable high-power, high-frequency radio signal generation, along with allowing the handling of high power densities in electronic circuitry.

However, realizing these potential benefits in actual performance requires meeting a number of challenges for device structures with non-uniform field distributions. The researchers see BaTiO3 as having benefits for device scaling, enabling AlGaN-based transistors to access radio frequency (RF) performance.

The team explains: “Extreme-permittivity dielectrics enable improved breakdown due to two reasons. First, a high-dielectric-constant layer greatly reduces the peaking or non-uniformity in the lateral electric field between the gate to drain for lateral transistors or anode to cathode for lateral diodes and results in a higher breakdown voltage and higher average breakdown field due to a more uniform electric field distribution.”

The researchers also point to potential high-breakdown benefits from BaTiO3 use in gallium oxide (Ga2O3) structures. Due to the wider bandgap of these materials being associated with lower electron mobility compared with GaN, the team suggests that scaling would compensate for high sheet resistance. Further, the use of high-k
dielectrics in transistor gate stacks enables better electrostatic control of carrier flow in channels with lower output conductance and higher transconductance.

A potential drawback of high-k materials is extension of the drain depletion region and an increase the gate-to-channel capacitance. Such factors would tend to reduce cut-off frequencies. The researchers comment: “It is therefore important to properly optimize the thickness of the high-permittivity region to manage the trade-off between field management and gate–drain capacitance.”

The researchers used 3μm-thick AlN on sapphire templates to grow AlGaN by low-pressure metal-organic chemical vapor deposition (LP-MOCVD). The template layer was grown by the same technique at 1250°C. Further layers consisted of 500nm undoped intrinsic i-Al0.58Ga0.42N at ~1100°C, folllowed by 60nm heavily silicon-doped n-Al0.58Ga0.42N.

Selective molecular beam epitaxy (MBE) was used to construct the ohmic cathode contact (Figure 1). The patterned hard mask for the MBE was silicon dioxide. The material in the pit consisted of 50nm heavily doped n-Al0.58Ga0.42N and 50nm reverse Al-composition graded AlGaN, also heavily doped.

![Figure 1](image_url)

**Figure 1:** (a) Schematic of lateral Pt/BaTiO$_3$/Al$_{0.58}$Ga$_{0.42}$N heterojunction diode, (b) modeled band-diagram under anode, (c) schematic of fabricated lateral Pt/Al$_{0.58}$Ga$_{0.42}$N control Schottky diode, and (d) modeled band-diagram.

“The purpose of the reverse-Al-composition graded n++ AlGaN layer is to minimize abrupt conduction band offsets and facilitate low-resistance non-alloyed Ohmic contact formation,” the team explains.

The silicon dioxide hard mask was removed with a wet buffered oxide etch. The Ohmic contact metal stack was titanium/aluminium/nickel/gold. Device isolation was achieved with mesa etching through an inductively coupled plasma reaction-ion etch (ICP-RIE) process.
The high-permittivity BaTiO3 film was deposited using RF sputtering, giving a dielectric constant of about 60. The film was expected to be nanocrystalline/amorphous. Control Schottky diode samples without the BaTiO3 were created by etching the material away with a sulfur hexafluoride ICP-RIE process. The anode consisted of platinum/gold.

The control Schottky diode had a 0.9V turn-on voltage, compared with 1.5V for the heterojunction diode with BaTiO3. These values are significantly lower than is typical in AlGaN p-n or p-i-n diodes. “This suggests that the BaTiO3/AlGaN interface presents relatively small barriers to electron transport, in contrast to conventional metal-oxide-semiconductor junctions where a large voltage would be needed to achieve turn-on of the current,” the researchers comment.

The differential on-resistance was 31mΩ-cm2 for the control and 56mΩ-cm2 for the BaTiO3/AlGaN heterojunction device. The corresponding breakdown voltages were 42V and 155V for anode-cathode gaps of 0.19μm and 0.18μm, respectively, as determined by scanning electron microscope (SEM) inspection. The higher breakdown in the heterojunction device is attributed to “a reduced peak field and the suppression of anode leakage current”.

Figure 2: (a) Breakdown performance for lateral Pt/BaTiO3/Al0.58Ga0.42N heterojunction and AlGaN Schottky barrier diodes with anode–cathode distance (LAC) less than 500nm. (b) Reported experimental average breakdown fields in semiconductor devices achieved to date (pink: GaN, green: Ga2O3, red: AlGaN, and brown: diamond). Dashed orange line phenomenological fit of critical breakdown field (FBR) versus direct bandgap (EG). Solid black circles predicted critical breakdown fields.

Calculations suggest that the peak vertical field was 3.15MV/cm and the lateral field was 1.58MV/cm in the Schottky device, resulting in a total average field of 3.5MV/cm. The heterojunction had the same vertical field, but increased the lateral value to 7.94MV/cm. The average total breakdown electric field is estimated to be 8.5MV/cm.

The team comments: “The value reported in this work, 8.5MV/cm, is the highest reported experimental average breakdown field for any semiconductor material.”

The researchers hoped for even higher breakdown voltages, based on the theoretical maximum breakdown field of 9.7MV/cm with “optimization of the BaTiO3 thickness and growth conditions together with the exploration of potential integration of field plate structures”.

(GANEX Technology for Optoelectronics & Electronics Newsletter No. 02 | 51)
Compound Photonics and Plessey produce first 0.26-inch fully addressable integrated micro-LED display module for AR/MR

Compound Photonics US Corp (CP) of Vancouver, WA, USA, a provider of compact high-resolution microdisplay technologies for augmented reality (AR) and mixed reality (MR) applications, and UK-based Plessey Semiconductors Ltd, which develops embedded micro-LED technology for augmented-reality and mixed-reality (AR/MR) display applications, have produced the first fully addressable micro-LED display modules resulting from their strategic partnership (announced last October) to develop and introduce GaN-on-silicon micro-LED-based micro-display solutions for AR/MR applications.

Functional micro-LED display modules have been fabricated that combine CP’s high-speed digital low-latency display backplane with Plessey’s GaN-on-Si monolithic micro-LED array technology. Plessey produced the micro-LED array wafer bonded to CP’s backplane wafer at its facility in Plymouth, UK. CP assembled and packaged display modules from the bonded wafer pair at its facility in Phoenix, AZ, USA. Both teams are currently performing initial characterization work at CP’s headquarters in Vancouver, WA.

“This successful proof-of-concept demonstration validates both companies’ goals to produce the industry’s highest-performance micro-LED display modules that deliver improved brightness at the smallest pixel sizes, higher frame rates, with extended bit depth at the lowest power consumption to best serve next-generation emissive-display-based AR/MR smart glasses and heads-up/head-mounted displays (HUD/HMDs) applications,” says Mike Lee, Plessey’s president of corporate & business development.

“This prototype micro-LED displays provide important confirmation that Plessey’s monolithic GaN-on-silicon IP, fabrication technology and bonding processes match perfectly with CP’s industry-leading 3.015μm pixel-pitch 1080p (1920x1080 pixel) backplane design to deliver compact high-resolution micro-displays,” says Compound Photonics’ CEO Yiwan Wong. “Combined with CP’s NOVA high-performance display driver architecture, these micro-LED displays support an industry-standard MIPI interface to take advantage of CP’s unique display pipeline solution designed for the real-time needs of AR/MR applications,” he adds. “CP’s display drive technology is extensible across multiple display technologies enabled by full software configurability, allowing customers to build their systems for specific power and performance needs.”

Initial samples of a 0.26-inch diagonal, Full-HD 1080p-resolution micro-LED display module integrated with display driver IC and MIPI input are expected to be available by this summer.

Monolithic indium gallium nitride white light-emitting diode

US-based Ostendo Technologies Inc has demonstrated the color rendering index (CRI) capabilities of its monolithic color-tunable light-emitting diodes (LEDs) across a range of correlated color temperatures (CCTs) [Hussein S. El-Ghoroury et al, Optics Express, vol.28, p1206, 2020].

The devices consist of three sets of indium gallium nitride (InGaN) quantum wells (QWs) that emit at different wavelengths (460-650nm) according to the injected current. The different QW layers are separated by carrier-blocking regions of aluminium gallium nitride (AlGaN). The barriers are tailored by AlGaN composition, thickness and dopant concentration to guide carriers into targeted QWs, producing specific wavelengths at a given bias.
White light is generated using pulses of current injection at different levels to give various spectral balances. The ability to change the CCT is seen as advantageous for its effect on human circadian rhythms, mood and health. ‘Cool’ bright light in the 4000-6000K range is better at keeping people awake, while dimmer ‘warm’ light, at 3000K, is better for relaxation and preparing for sleep.

Figure 1: (a) Simplified cross-sectional view of monolithic color-tunable InGaN-based LED structure and (b) emission from 5mA to 350mA injection current.

The epitaxial structure (Figure 1) was grown using metal-organic chemical vapor deposition (MOCVD) – the topmost p-type magnesium-doped layers were activated by in-situ annealing in the reaction chamber.

The devices were tested on-wafer with contacts created through pressing an indium ball on the p-GaN surface and on a scribed region exposing the buried n-type material. The researchers comment: “For production purposes, transparent p-contacts like annealed [nickel/gold] Ni/Au or [indium tin oxide] ITO must be used for p-GaN and [titanium/aluminium] Ti/Al or Ti/Au should be used for n-GaN contacts to improve the contact resistivity.”

The drive set-up consisted of two-step pulse generators, an operational amplifier-based summing network, and a voltage-to-current converter, based again on op-amps and a bipolar transistor. The circuit targeted fast response and large current handling.

The researchers used manual fine-tuning of the pulse circuit, making it difficult to obtain spectra at the exact color coordinates. The team believes that this would be easy for a computer-controlled feedback system.

The LEDs produced CRI values above 80 across the range of CCTs from 2700K to 6500K (Figure 2). At the highest CCT the CRI was 87. The team suggests that improved CCT would result from “additional spectral emission peaks to increase the range and overlap in the spectral mixture”.

Simulations of a structure with four emission peaks and driven by a three-step pulse set-up indicate that CRIs above 90 (and up to 95.4 at 4100K CCT) would be possible. The extra peak would come from an extra red emission from low (~625nm wavelength) and medium (~585nm) current injections, enhancing spectral coverage in the long-wavelength range. The two red peaks arise from significant blue-shift effects at the higher injection current.

The team comments: “The spectral content of the blue and green QW emissions is similar to those shown in the two-step pulse design due to the minimal blue-shift of the blue and green QW emission. By optimizing the blue
and green QW growth parameters, the spectral coverage in the short-wavelength range can be enhanced and thus further improvement of CRI is possible."

Figure 2: Light spectra (top) and photographic capture (bottom) of pulsed color-tunable emission at color temperatures of (a) 2700K, (b) 3000K, (c) 3500K, (d) 4100K, (e) 5000K and (f) 6500K.

The use of such a monolithic chip would reduce material, complexity and packaging costs, compared with RGB designs based on separate chips emitting single colors or devices with filters.
Qorvo completes acquisition of Custom MMIC

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has completed its acquisition (announced at the end of January) of Custom MMIC of Westford, MA, USA, a supplier of gallium arsenide (GaAs) and gallium nitride (GaN) monolithic microwave integrated circuits (MMICs) for defense, aerospace and commercial applications.

Custom MMIC was founded in 2006 and has extensive experience developing MMICs at frequencies up to 70GHz. The firm provides Qorvo with small-signal mmWave expertise and a portfolio of more than 180 standard products including low-noise amplifiers (LNAs), mixers, attenuators, phase shifters and switches. President & chief technology officer Paul Blount joins Qorvo as a director of engineering for Infrastructure and Defense Products.

As part of Qorvo’s Infrastructure and Defense Products (IDP) business, the Custom MMIC team will continue to expand its millimetre-wave (mmWave) capabilities for products used in defense phased-array and AESA (active electronically scanned array) radars, electronic warfare, satellite communications, wireless backhaul and microwave test equipment.

“Custom MMIC’s best-in-class die and packaged components augment our power amplifiers to enable multi-chip modules for a broad range of defense, aerospace and commercial applications,” comments IDP president James Klein. “We look forward to building on Custom MMIC’s reputation as an outstanding strategic supplier to leading defense prime customers, as we expand our mmWave capabilities and product offerings for defense and commercial markets, including 5G.”

SweGaN grows revenue 300% year-on-year in 2019

SweGaN AB of Linköping, Sweden, which manufactures custom gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers (based on a unique growth technology) for RF and power electronics devices, has reported revenue growth of 300% year-on-year in 2019. “2019 was an outstanding year for SweGaN, with a doubling of commercial orders and collaboration in multiple prestigious EU projects,” says CEO Olof Kordina.

The firm’s technology was highlighted in the largest Swedish technical magazine Ny Teknik, which selected SweGaN as one of the most promising and innovative young companies. Also, a featured article ‘Transmorphic Epitaxial Growth of AlN Nucleation Layers on SiC Substrates for High-Breakdown Thin GaN Transistors’ in Applied Physics Letters, volume 115, issue 22, showed the material’s unique very high electrical breakdown voltage, making it suitable for power devices.

In addition, SweGaN has further strengthened its board of directors with the introduction of new members Agneta Franksson and Richard Weil at its annual meeting on 12 February:

- Agneta Franksson has an M.Sc. in Electrical Engineering and extensive experience from several CEO positions and over 25 years’ experience in R&D and business development and sales. Since 2006, she has run her own management consulting company and has served on several boards of directors during the last 14 years.
Richard is a co-founder and managing director of Mount Wilson Ventures, an early-stage venture fund that invests in hard-science companies rooted in biology, chemistry, materials science and data science. He is an experienced finance and operating professional with a background in start-up growth, financing and restructuring; banking; and management consulting.

“Agneta and Richard bring a wealth of specialized experience, valuable assets to the board of directors in further guiding SweGaN in its long-term strategy and growth,” comments Kordina.
More than 200+ new patent families (inventions) were published in February 2020.

Countries of patent filings
(Number of new patent applications published in February 2020)

Main patent applicants
(Number of new patent applications published in February 2020)

Other patent applicants: Aldtech, Sanan Optoelectronics, Array Photonics, Audi, Beijing Graphene Institute, Cea, Changzhou Zonghui Core Light Semiconductor Technology, Chengdu University of Information Technology, China Chippacking Technology, Chongqing University, Christian Albrechts Universitaet Zu Kiel, Dai Nippon Printing, Dalian University of Technology, Datang Semiconductor Technology, Delta Electronics, Dongguan Dongsong Electronic, Dongguan Institute of Opto Electronics Peking University, Dura Chip Nantong, East China Normal University, Electric Technology Optoelectronic Technologyco, Evana Technologies, Exagan, Facebook Technologies, Feicheng Semiconductor, Fraunhofer, Fujitsu, GaN Power Technology, Global Energy Interconnection Research Institute, Guangdong Institute of Semiconductor Industrial Technology, Guangdong Polytechnic Normal University, Guangdong Vital Materials, Guangxi University, Hangzhou Dianzi University, Hangzhou Silan Azure, Hella, Hong Kong University of Science And Technology, HRL Laboratories, IBM, Indian Institute of Technology Kanpur, Industrial Technology Research Institute, Infineon Technologies, Innoscience Technology, Intel, Kateeva, Korea Photonics Technology Institute, Korea University Industrial & Academic Collaboration Foundation, Kyushu University Institute of Technology, Lasertel, Lg Electronics, Maanshan Jiesheng Semiconductor, Macom Technology, Marubun, Micron Technology, Mitsubishi Chemical, Nanchang University, Nanjing Huneng Electronic Technology, Nanjing Jixin Optoelectronic Technology Research Institute, Nanjing Zike Photoelectric Technology, Nantong University, NASA, National Institute of Advanced Industrial Science & Technology, Navitas Semiconductor, Newport Fab
Transistor with high electron mobility
Publication Number: WO2020/035644, FR3084966
Patent Applicant: ExaGaN

The invention relates to a transistor (100) with high electron mobility, comprising: A structure (10) containing a stack (1) of III-N-type semiconductor materials defining an interface (2) and able to form a conductive layer (3) in the form of a two-dimensional gaseous layer of electrons, substantially underneath said interface (2), the stack comprising at least one channel layer (4) and one barrier layer (5) on either side of the interface (2), and the barrier layer (5) being a ternary or quaternary III-N compound comprising aluminium, • A gate electrode (40) positioned in a reinforcement (5c) of the barrier layer (5), a residual thickness (er) of the barrier layer (5) being situated underneath the gate electrode (40). The barrier layer (5) has a continuous concentration of aluminium gradient over the thickness (e) thereof: the gradient increases between a first face (5a) positioned on the interface (2) and a second face (5b) of the barrier layer (5) such that the concentration of aluminium is less than or equal to 20% in the residual thickness (er) and that the concentration of aluminium at the second face (5b) is greater than or equal to 40%.

Compound semiconductor device
Publication Number: US20200058783, JP2020027911
Patent Applicant: Fujitsu

A compound semiconductor device includes a compound semiconductor laminate structure including an electron transit layer and an electron supply layer, a gate electrode, a source electrode, and a drain electrode that are formed over the electron supply layer, a first insulating layer of diamond formed between the gate electrode and the drain electrode over the compound semiconductor laminate structure, and a second insulating layer formed between the gate electrode and the source electrode over the compound semiconductor laminate structure, wherein a positive compressive stress is applied from the first insulating layer to the electron supply layer, and a compressive stress from the second insulating layer to the electron supply layer is smaller than the compressive stress from the first insulating layer to the electron supply layer.
Field-effect transistors with semiconducting gate
Publication Number: US20200052071, CN110828564
Patent Applicant: Hong Kong University of Science and Technology

Field-effect transistors (FETs) are described that comprise a semiconducting gate (SG) layer, referred to herein as SG-FETs. In one or more embodiments, the FETs can include a channel layer and a SG layer capacitively coupled to the channel layer. The SG layer has an embedded voltage-clamping function that provides internal gate over voltage protection without an additional protection circuit. The embedded voltage-clamping function is based on the SG layer having a maximum effective gate voltage that is clamped to the depletion threshold of the SG layer.

Extrinsic field termination structures for improving reliability of high-voltage, high-power active devices
Publication Number: WO2020/033431
Patent Applicant: Macom Technology

Extrinsic structure that is formed outside the active regions of active devices can influence aging characteristics and performance of the active devices. Extrinsic structure is described that can reduce gate leakage current in transistors by over four orders of magnitude.

Gallium nitride high electron mobility transistor with ledges and field plates
Publication Number: US20200052103, WO2020/033038
Patent Applicant: Qualcomm

Certain aspects of the present disclosure provide a high electron mobility transistor (HEMT). The HEMT generally includes a gallium nitride (GaN) layer (206) and an aluminum gallium nitride (AlGaN) layer (208) disposed above the GaN layer. The HEMT also includes a source electrode (210), a gate electrode (212), and a drain electrode (214) disposed above the AlGaN layer. The HEMT further includes n-doped protuberance(s) (240A, 240B) disposed above the AlGaN layer and disposed between at least one of: the gate electrode and the drain electrode; or the source electrode and the gate electrode. Each of the n-doped protuberances is separated from the gate electrode, the drain electrode, and the source electrode.
A light emitting diode (LED) is manufactured using a process in which hydrogen diffuses out of a p-doped semiconductor layer via an exposed side wall of the p-doped semiconductor layer. The process includes forming a light generation layer on a base semiconductor layer and forming the p-doped semiconductor layer on the light generation layer. A tunnel junction layer is formed on the p-doped semiconductor layer and a contact layer is formed on the junction layer. The process also includes etching through at least the contact layer, the tunnel junction layer, and the p-doped semiconductor layer to expose the side wall of the p-doped semiconductor layer and enabling hydrogen to diffuse out of the p-doped semiconductor layer at least partially through the exposed side wall.

Embodiments disclosed herein include micro-light emitting diode (LED) displays and methods of forming such micro-LED displays. In an embodiment, a micro-light emitting diode (LED) display panel includes a display backplane substrate having a dielectric layer. In an embodiment, a plurality of electrical contacts are positioned below a first surface of the dielectric layer. In an embodiment, a plurality of micro-LED pixel elements, are affixed to corresponding ones of the plurality of contacts.

A method for fabricating conductive nitride layers results in an improved quality semiconductor device. The method involves doping an AlGaN film at a growth temperature less than 1300 °C in order to increase the conductivity of the AlGaN film. The method also comprises heating an underlying substrate to a temperature greater than 1000 C before starting the depositing and doping, while exposing the underlying substrate to an atmosphere that contains some ammonia (NH3).
**Light emitting device and projection display device**

*Publication Number: WO2020/036053*

*Patent Applicant: Sony*

A light emitting device which is provided with: a plurality of package bodies, each of which comprises a light emitting element, a reflective member that reflects light emitted from the light emitting element, and a sealed space where the light emitting element and the reflective member are contained; a base plate on which the plurality of package bodies are mounted; and lenses which face the base plate, with the plurality of package bodies being positioned therebetween, and which face the plurality of package bodies, respectively.

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**Deep ultraviolet led device and method for manufacturing same**

*Publication Number: WO2020/040304*

*Patent Applicant: Dai Nippon Printing, AIST, Toshiba, Ulvac*

Provided is a deep ultraviolet LED device comprising: a surface mount-type aluminum nitride ceramic package in which an inorganic coating film having a reflectivity of at least 91% at a deep ultraviolet LED element design wavelength $\lambda$ (200-355 nm) is coated on the inner bottom surface and inner side walls thereof, the inner side wall angle thereof is 45-60 degrees, and the outermost surface thereof is sealed with a quartz window; and a deep ultraviolet LED element mounted in the package, wherein the deep ultraviolet LED element has a reflective electrode layer (Au), a metal layer (Ni), a p-type GaN contact layer, a p-type AlGaN layer, a multi-quantum barrier layer (or electron block layer), a multi-quantum well layer, an n-type AlGaN layer, an AlN buffer layer, and a sapphire substrate in this order from the opposite side from the sapphire substrate, and has a reflective two-dimensional photonic crystal which is located within the range of the metal layer and the p-type GaN contact layer in the thickness direction and which has a plurality vacancies disposed in locations that are not beyond the boundaries of the p-type GaN contact layer and the p-type AlGaN layer. The periodic structure of the reflective two-dimensional photonic crystal has a photonic band gap that opens to a TE-polarized component, wherein the period $a$ of the reflective two-dimensional photonic crystal periodic structure satisfies the Bragg condition for light having the design wavelength $\lambda$, the order $m$ in the Bragg equation, $m\lambda/n_{eff}=2a$ ($m$: order, $\lambda$: design wavelength, $n_{eff}$: effective refractive index of two-dimensional photonic crystal, and $a$: period of two-dimensional photonic crystal) satisfies $3 \leq m \leq 4$, and the ratio of $R/a$ ($R$ is the radius of the vacancies) satisfies $0.30 \leq R/a \leq 0.40$. 