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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GANEXT
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, IOP, IEEE, AIP

Press releases
Specialized Press
semiconductorTODAY, LEDinside, Micronews

Patents
Patent Database

Segmentation by KnowMade analysts
OPTOELECTRONICS
LED / µ-LED
Laser
Optics
Photonics

ELECTRONICS
Power electronics
RF electronics
Advanced electronics

Exhaustive III-N publications database

Refinement of the selection by KnowMade analysts
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)

PDF
Calculation of optical gain in AlGaN quantum wells for ultraviolet emission
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AIP Advances
https://doi.org/10.1063/5.0021890

Stimulated emission from AlGaN based quantum wells (QWs) emitting at ultraviolet wavelengths is investigated theoretically. Maxwell–Bloch equations in the second Born approximation are solved self-consistently with the Poisson equation. The valence band dispersion is obtained from a 6-band kp-model.
For a QW emitting at around 270 nm with a thickness of 2.2 nm, an estimated FWHM of 10 meV for homogeneous broadening and an excitonic red shift of 100 meV are extracted under typical laser conditions. From a comparison to experimental data of stimulated emission, an inhomogeneous broadening energy of 39 meV FWHM is evaluated. Calculations show that high TE gain can be achieved for thin QWs around 2 nm thickness in a multiple QW arrangement or for single QWs thicker than 6 nm.

Correlation between excitons recombination dynamics and internal quantum efficiency of AlGaN-based UV-A multiple quantum wells
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Journal of Applied Physics
https://doi.org/10.1063/5.0015554

The correlation between the recombination dynamics of excitons and the internal quantum efficiency (IQE) of AlGaN-based UV-A multiple quantum wells (MQWs) was studied via photoluminescence (PL) and time-resolved PL (TRPL) spectroscopy. The probability ratio of the capture of excitons by nonradiative recombination centers (NRCs) and the radiative recombination of excitons was evaluated individually via two different experimental analyses. The IQE was evaluated via temperature- and excitation power density-dependent PL measurements and its dependence on excitation density was analyzed using a rate equation model based on the radiative and nonradiative recombination of excitons. Moreover, the radiative and nonradiative recombination lifetimes were evaluated via temperature-dependent TRPL measurements; furthermore, they were analyzed as functions of temperature and excitation energy density. The probability ratios obtained from the two individual analyses were in agreement. This quantitative agreement indicated that the analysis based on the radiative and nonradiative recombination processes of excitons, which included the process of filling NRCs, was valid for AlGaN-based UV-A MQWs.

GaN-based high response frequency and high optical power matrix micro-LED for visible light communication
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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2020.3021282

Light-emitting diodes (LEDs) with high response frequency and high power can be applied in visible light communication (VLC). This paper studies the response frequency and optical output power of the gallium nitride (GaN) based matrix micro-LED (μLED) for visible light communication. The blue-emitting GaN μLEDs with the format from 1×1 to 6×6 are
fabricated and used to analyze the relationship between the matrix format and the response frequency, as well as the output optical power and the data transmission performance of the matrix μLED. The experimental and analysis results show that the GaN-based matrix μLED response frequency can be improved by an increase in the injection current density and a decrease in device capacitance. The experimental comparison result indicates that the −3 dB response frequency changed from 85 MHz to 401 MHz at a 60 mA injection current progressively increased as the matrix array size from 1×1 to 6×6, the 6×6 matrix μLED optical output power reaches a value of 356.7 mW.

Ultraviolet Electrostatic Field Effect Light-Emitting Diode

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IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2020.3020384

The potential of ultraviolet (UV) AlGaN quantum well (QW) light-emitting diodes (LEDs) is stunted due to the lack of efficient p-type doping for this ultra wide bandgap material. In this work, a novel device - UV electrostatic field effect LED (EFELED) is demonstrated to address this issue by significantly improving hole injection into the QW active region which leads to a relative increase of external quantum efficiency (EQE) up to 42%. The UV EFELED is realized by integrating a capacitor layer on top of a conventional 267 nm AlGaN QW LED, which introduces band bending to assist hole injection under a forward bias. A 10x increase in injection current is achieved through the application of a positive bias to the integrated capacitor layer. With 20 V applied to the capacitor, a 42% increase of EQE is achieved. Photon intensity modulation is demonstrated with the application of varying capacitor biases, which presents a novel brightness control at UV wavelength. Thus, the proposed UV EFELED provides significantly improved hole injection through a capacitor integration, which leads to high-efficiency UV LEDs for important applications such as sterilization and purification.

Fabrication of gallium nitride and nitrogen doped single layer graphene hybrid heterostructures for high performance photodetectors

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Scientific Reports
https://doi.org/10.1038/s41598-020-71514-9

Gallium nitride (GaN) was epitaxially grown on nitrogen doped single layer graphene (N-SLG) substrates using chemical vapour deposition (CVD) technique. The results obtained using x-ray diffractometer (XRD) revealed the hexagonal crystal structure of GaN. Photoluminescence (PL) spectroscopy, energy dispersive x-ray (EDX) spectroscopy and x-ray photoelectron (XPS) spectroscopy revealed traces of oxygen, carbon and nitrogen occurring either as contamination or as an effect of doping during the GaN growth process. In addition, PL revealed a weak yellow luminescence peak in all the samples due to the presence of N-SLG. From the obtained results it was evident that, presence of N-SLG underneath GaN helped in improving the material properties. It was seen from the current–voltage (I–V) response that the barrier height estimated is in good agreement with the Schottky–Mott model, while the ideality factor is close to unity, emphasizing that there are no surface and interface related inhomogeneity in the samples. The photodetector fabricated with this material exhibit high device performances in terms of carrier mobility, sensitivity, responsivity and detectivity. The hall measurement values clearly portray that, the GaN thus grown possess high electron contents which was beneficial in attaining extraordinary device performance.
Milliwatt power 233 nm AlGaN-based deep UV-LEDs on sapphire substrates
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Applied Physics Letters
https://doi.org/10.1063/5.0015263

Deep UV-LEDs (DUV-LEDs) emitting at 233 nm with an emission power of \((1.9 \pm 0.3)\) mW and an external quantum efficiency of \((0.36 \pm 0.07)\%\) at 100 mA are presented. The entire DUV-LED process chain was optimized including the reduction of the dislocation density using epitaxially laterally overgrown AlN/sapphire substrates, development of vanadium-based low resistance n-metal contacts, and employment of high thermally conductive AlN packages. Estimated device lifetimes above 1500 h are achieved after a burn-in of 100 h. With the integration of a UV-transparent lens, a strong narrowing of the far-field pattern was achieved with a radiant intensity of \(3\) mW/sr measured at 20 mA.

GaN-Based LEDs Grown on Graphene-Covered SiO2/Si (100) Substrate
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Crystals
https://doi.org/10.3390/cryst10090787

The growth of nitride on large-scale and low-cost amorphous substrates has attracted considerable attention for applications in large-scale optoelectronic devices. In this paper, we reported the growth of GaN-based light-emitting diodes (LEDs) on amorphous SiO2 substrate with the use of nanorods and graphene buffer layers by metal organic chemical vapor deposition (MOCVD). The effect of different growth parameters on the morphology and vertical-to-lateral aspect ratio of nanorods was discussed by analyzing growth kinetics. Furthermore, we tuned nanorod coalescence to obtain continuous GaN films with a blue-LED structure by adjusting growth conditions. The GaN films exhibited a hexagonal wurtzite structure and aligned c-axis orientation demonstrated by X-ray diffractometer (XRD), Raman, and transmission electron microscopy (TEM) results. Finally, five-pair InGaN/GaN multi-quantum-wells (MQWs) were grown. The photoluminescence (PL) showed an intense emission peak at 475 nm, and the current–voltage (I–V) curve shows a rectifying behavior with a turn-on voltage of 5.7 V. This work provides a promising fabrication method for the large-area and low-cost GaN-based devices on amorphous substrates and opens up the further possibility of nitride integration with Si (100) complementary metal oxide semiconductor (CMOS) electronics.

Origin of carrier localization in AlGaN-based quantum well structures and implications for efficiency droop
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Applied Physics Letters
https://doi.org/10.1063/5.0018885

We investigate carrier localization in Al-rich AlGaN/AIN quantum well (QW) structures. Low temperature time-resolved photoluminescence (PL) experiments reveal a strong variation of the carrier decay times with detection photon energy, suggesting a strong impact of carrier localization, which is found to depend primarily on the QW width. In combination with time-integrated PL measurements and numerical band structure calculations, we are able to provide conclusive evidence that the localization strength in AlGaN-based QW structures is directly coupled to the oscillator strength, providing an explanation for its strong dependence on the QW width. This is further supported by the observation of a strong polarization field dependency of the carrier localization, which excludes excitons and may be explained by the accumulation of electrons close to the QW interface,
while holes are independently localized across the QW. We complete our discussion by proposing a model to explain the well-known phenomenon of efficiency droop in accordance with our findings, suggesting delocalization-induced Auger recombination as the responsible loss channel.

**UV-emission from GaN wires with m-plane core-shell GaN/AlGaN multiple quantum wells**

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ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.0c08765

The present work reports high quality non-polar GaN/Al0.6Ga0.4N multiple quantum wells (MQWs) grown in core-shell geometry by metalorganic vapor phase epitaxy on the m-plane sidewalls of c̄-oriented hexagonal GaN wires. Optical and structural studies reveal UV emission originating from the core-shell GaN/AlGaN MQWs. Tuning the m-plane GaN QW thickness from 4.3 to 0.7 nm leads to a shift of the emission from 347 to 292 nm, consistent with Schrödinger-Poisson calculations. The evolution of the luminescence with temperature displays signs of strong localization, especially for samples with thinner GaN QWs and no evidence of quantum confined Stark effect, as expected for non-polar m-plane surfaces. The internal quantum efficiency derived from the photoluminescence intensity ratio at low and room temperature is maximum (~7.3 %) for 2.6 nm-thick quantum wells, emitting at 325 nm and shows a large drop for thicker QWs. An extensive study of the PL quenching with temperature is presented. Two non-radiative recombination paths are activated at different temperatures. The low temperature path is found to be intrinsic to the heterostructure, whereas the process that dominates at high temperature depends on the QW thickness and is strongly enhanced for QWs larger than 2.6 nm, causing a drop of the internal quantum efficiency.


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ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.0c03259

There has been a relentless pursuit of transverse electric (TE)-dominant deep ultraviolet (UV) optoelectronic devices for efficient surface emitters to replace the environmentally unfriendly mercury lamps. To date, the use of the ternary AlGaN alloy inevitably has led to transverse magnetic (TM)-dominant emission, an approach that is facing a roadblock. Here, we take an entirely different approach of utilizing a binary GaN compound semiconductor in conjunction with ultrathin quantum disks (QDisks) embedded in AlN nanowires (NWs). The growth of GaN QDisks is realized on a scalable and low-cost Si substrate using plasma-assisted molecular beam epitaxy as a highly controllable monolayer growth platform. We estimated an internal quantum efficiency of ~81% in a wavelength regime of ~260 nm for these nanostructures. Additionally, strain mapping obtained by high-angle annular dark-field scanning transmission electron microscopy is studied in conjunction with the TE and TM modes of the carrier recombination. Moreover, for the first time, we quantify the TE and TM modes of the PL emitted by GaN QDisks for deep-UV emitters. We observed nearly pure TE-polarized photoluminescence emission at a polarization angle of ~5°. This work proposes highly quantum-confined ultrathin GaN QDisks as a promising candidate for deep-UV vertical emitters.
Monolithic InGaN/GaN photonic chips for heart pulse monitoring
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Optics Letters
https://doi.org/10.1364/OL.400733

Photo-plethysmography (PPG) making use of a monochromatic light source and a photoelectric sensor is a non-invasive detection method to record blood volume changes in vessels and can be used to extract cardiac-related heart pulse information. Here, we demonstrated the fabrication of a monolithic photonic chip by integrating light-emitting diodes (LEDs) with photodetectors (PDs) on the same GaN-on-sapphire wafer containing InGaN/GaN multi-quantum wells (MQWs). The MQWs simultaneously act as light emitters in the LEDs and detectors in the PDs, and their mechanism has been studied. The fabricated chip operating in reflection mode is flip-chip bonded on a flexible polydimethylsiloxane (PDMS) strip, enabling the sapphire surface in close contact with the skin. The optical and electrical properties of the LED and PD have been thoroughly characterized, confirming that the PDs using identical MQWs can detect the reflected light from the LEDs. By attaching the chip to the wrist, PPG heart pulse signals from the arterial blood flow can be obtained, thereby verifying the feasibility of the proposed monolithic chip.

Enhancement in the photonic response of ZnO nanorod (NR) gated AlGaN/GaN high electron mobility transistor (HEMT) structure. The PDs fabricated with ZnO NRs plasma-treated for 6 min show superior performance in terms of responsivity (~1.54×10^5 A/W), specific detectivity (~ 4.7×10^13 cm·Hz−1/2/W), and on/off current ratio (~40). These improved performance parameters are the best among those from HEMT-based PDs reported to date. Photoluminescence analysis shows a significant enhancement in near band edge emission due to the effective suppression of native defects near the surface of ZnO NRs after plasma treatment. As our X-ray photoelectron spectroscopy reveals a very high O/Zn ratio of ~0.96 from the NR samples plasma-treated for 6 min, the N2O plasma radicals also show a clear impact on ZnO stoichiometry. From our X-ray diffraction analysis, the plasma-treated ZnO NRs show much greater improvement in (002) peak intensity and degree of (002) orientation (~0.996) than those of as-grown NRs. This significant enhancement in (002) degree of orientation and stoichiometry in ZnO nanocrystals contribute to the enhancement in photoresponse characteristics of the PDs.

Temperature dependence of the Auger recombination coefficient in InGaN/GaN multiple-quantum-well light-emitting diodes
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Optics Express
https://doi.org/10.1364/OE.402831

This study investigated the temperature dependence of the Auger recombination coefficient (C) in an InGaN/GaN blue multiple-quantum-well (MQW) light-emitting diode structure at temperatures between 20 and 100°C. The temperature dependence of C was determined by fitting the measured external quantum efficiency (EQE) data using an analytical model or numerical simulation. In the analytical model, the carrier density in InGaN MQWs was assumed to be constant and independent of temperature. In contrast, the inhomogeneous carrier distribution in MQWs and its temperature-dependent redistribution...
were included in the numerical simulation. When the analytical model was employed to fit the EQE curve, C decreased with increasing temperature. On the other hand, when the numerical simulation was employed, C increased steadily by ∼31% as the temperature was increased from 20 to 100°C. We found that the temperature-dependent carrier distribution is important to consider when determining the temperature dependence of the Auger recombination coefficient in InGaN MQW structures.

**Current-induced degradation process in (In)AlGaN-based deep-UV light-emitting diode fabricated on AlN/sapphire template**

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Optical Materials
https://doi.org/10.1016/j.optmat.2020.110352

A comprehensive analysis of the degradation behavior of (In)AlGaN-based deep-ultraviolet light-emitting diode (DUV LED) stressed at a constant dc current of 60 mA has been presented. This work is based on combined X-ray diffraction (XRD), atomic force microscopy (AFM), electroluminescence (EL), cathodoluminescence (CL), current-voltage (I–V) and capacitance-voltage (C–V) characteristics. We used XRD and AFM data to investigate the structural properties of the epilayer. The EL spectrum shows two clear emission peaks at around 4.71 and 3.77 eV and a plateau region within 4.24 to 3.82 eV. To know the origin of the plateau region and the peak at 3.77 eV, we performed CL measurement. As a consequence of constant current stress, we obtained the following results: (1) a gradual degradation in EL power due to increase of Shockley–Read–Hall (SRH) recombination and the generation of new point defects in the active region; (2) a significant improvement in the leakage current, that is attributed to the enhance in trap assisted tunneling; and (3) a strong increment in the device capacitance in both reverse and forward bias regions, that is ascribed to the improvement in the net charge concentration and their redistribution in the active region of the LED.

**Semi-polar (20–21) InGaN/GaN multiple quantum wells grown on patterned sapphire substrate with internal quantum efficiency up to 52 per cent**

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Applied Physics Express
https://doi.org/10.35848/1882-0786/abac91

This letter reports three semi-polar (20–21) InGaN/GaN multiple quantum wells (MQWs) on patterned sapphire substrates. The well and barrier thicknesses are 3.5 nm and 9.5 nm, respectively, and the indium contents are estimated to be from 9% to 26%. As a consequence of its high crystal quality, the semi-polar sample, with an emission wavelength of 460 nm, exhibits an internal quantum efficiency (IQE) of up to 52%, based on photoluminescence (PL) measurements. Furthermore, we find that carriers are confined in deep localization centers, which enable the major carriers to recombine radiatively, even at room temperature.

**Impact of the effective refractive index in AlGaN-based mid-UV laser structures on waveguiding**

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Japanese Journal of Applied Physics
https://doi.org/10.35848/1347-4065/abab44

The effective refractive index in optically-pumped 265 nm AlGaN-based lasers is assessed from the spacing of the longitudinal cavity modes in short laser cavities. It is found that the effective refractive index is significantly higher than the value estimated from the Sellmeier equation (n = 2.5) and reaches values of 2.9 and 3.2 for structures with 3 and 15 quantum wells,
respectively. These results indicate that the Sellmeier equation underestimates the effective refractive index in AlGaN-based laser structures and that a different approach is needed for successful mid-UV laser modeling and design.

**A thin transferable blue light-emitting diode by electrochemical lift-off**

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Nano Express

https://doi.org/10.1088/2632-959X/abb07d

We demonstrate a transferable blue light-emitting diode (LED) fabricated using a cost-effective approach. By means of solution-based electrochemical etching, an ultrathin free-standing membrane can be obtained from a commercial III-nitride LED wafer. The membrane, containing a full LED structure (including p-/n-type layers and multiple quantum wells) epitaxially grown on a sapphire substrate, is transferable to foreign substrates with a simple lift-off process facilitated by electrochemical etching. After fabrication, optical properties of the thin film are massively improved, accompanied by a 17-fold enhanced photoluminescence normal to the film surface. Prototype transferable blue LEDs are realized on both a copper-coated glass substrate and a polypropylene substrate. The devices exhibit a high performance with bright emission at 447 nm under electrical injection at room temperature.

**Theoretical Analysis of Tunnel-Injected Sub300 nm AlGaN Laser Diodes**

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IEEE Journal of Quantum Electronics

https://doi.org/10.1109/JQE.2020.3021404

Electrically-pumped AlGaN-based edge-emitting laser diodes with a buried tunnel junction (TJ) for sub-300 nm emission are designed in this paper. Hole injection is one of the major concerns for the design of ultraviolet (UV) lasers based on this material system. The use of a low-resistive TJ as an intracavity contact within the devices will offer an opportunity to replace highly resistive p-type AlGaN-based cladding and contact layers by their n-doped counterparts. This advanced polarization-engineered interband TJs will lead to improved hole injection and a significantly reduced threshold voltage. The thermal properties of the tunnel-injected devices are thoroughly studied theoretically. For the demonstration of continuous-wave operating lasers, possible improvements in terms of better thermal management of the device are also discussed. Our improved design allows CW-operating AlGaN lasers with a threshold current density of <8 kA/cm² and maximum optical output power of >220 mW, yielding a wall-plug efficiency of >2.8%.

**Design and characterization of a low-optical-loss UV-C laser diode**

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Japanese Journal of Applied Physics

https://doi.org/10.35848/1347-4065/abaac6

We present an optical modeling and characterization study of prototype ultraviolet laser diode (LD) structures grown on single-crystal AlN substrates, with focus on the reduction of modal loss caused by optical mode coupling to the absorptive layers on the p-side (i.e. p-contact and p-metal layers). The transparent AlN substrates enabled optical pumping for measuring modal loss without requiring functioning LDs. The modal loss measured in this way was in good agreement with electrically evaluated results of processed LDs, and both results were consistent with optical modeling predictions. By using 0.32 μm thick p-
side cladding, we were able to suppress the modal loss of the designed LD structure to 8.4 cm\(^{-1}\), where the contribution from the absorptive p-contact layers was less than 3 cm\(^{-1}\).

Low resistance n-contact for UVC LEDs by a two-step plasma etching process
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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab9ea7

The impact of plasma etching on the formation of low-resistance n-contacts on the AlGaN:Si current spreading layer during the chip fabrication of ultraviolet light-emitting diodes (UV LEDs) emitting at 265 nm is investigated. A two-step plasma etching process with a first rapid etching using BCl3/Cl2 gas mixture and a second slow etching step using pure Cl2 gas has been developed. The etching sequence provides smooth mesa side-walls and an n-AlGaN surface with reduced surface damage. Ohmic n-contacts with a contact resistivity of 3.5 \(\times 10^{-4}\) \(\Omega cm^2\) are obtained on Si-doped Al0.65Ga0.35N layers and the operating voltages of the UVC LEDs were reduced by 2 V for a current of 20 mA.

Fabrication of a thermostable Ga-face GaN template on a molybdenum substrate via layer transfer
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Optical Materials Express
https://doi.org/10.1364/OME.400388

Gallium nitride (GaN) films on high-thermal-conductivity substrates have attracted considerable attention for their applications in high-power light-emitting diodes and electronic devices. Herein, a 2-inch 8-µm-thick thermostable GaN/Mo template with Ga-face was fabricated via two consecutive layer transfer technique. The full-widths at half-maximum for the x-ray rocking curves of GaN (002) and (102) plane were 314 and 325 arcsec, respectively. Atomic force microscopy revealed that the surface had step-and-terrace structures with a root-mean-square value of 0.397 nm. Five periods of In0.15Ga0.85N/GaN multiple-quantum-wells and Mg-doped p-type GaN layers were regrown on the GaN-doped p-type GaN/Mo template, which exhibited blue light emission without distinct degradation.

High-performance electron-blocking-layer-free deep ultraviolet light-emitting diodes implementing a strip-in-a-barrier structure
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Optics Letters
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In this Letter, the electron-blocking-layer (EBL)-free AlGaN ultraviolet (UV) light-emitting diodes (LEDs) using a strip-in-a-barrier structure have been proposed. The quantum barrier (QB) structures are systematically engineered by integrating a 1 nm intrinsic Al\(_x\)Ga(1–\(x\))N strip into the middle of QBs. The resulted structures exhibit significantly reduced electron leakage and improved hole injection into the active region, thus generating higher carrier radiative recombination. Our study shows that the proposed structure improves radiative recombination by \(\sim 220\%\), reduces electron leakage by \(\sim 11\) times, and enhances optical power by \(\sim 225\%\) at 60 mA current injection compared to a conventional AlGaN EBL LED structure. Moreover, the EBL-free strip-in-a-barrier UV LED records the maximum internal quantum efficiency (IQE) of \(\sim 61.5\%\) which is \(\sim 72\%\) higher, and IQE droop is \(\sim 12.4\%\), which is \(\sim 333\%\) less compared to the conventional AlGaN EBL LED structure at \(\sim 284.5\) nm wavelength. Hence, the proposed EBL-free AlGaN LED is the potential solution to enhance the optical power and produce highly efficient UV emitters.
In this letter, a beveled-mesa edge termination technology was developed to improve the performance of GaN p-i-n ultraviolet avalanche photodiodes (APDs). Simulation results showed that the beveled-mesa is effective in reduction of the electric field at the mesa sidewall. With a photoresist thermal-reflow process, 12°-angle beveled-mesa APDs were fabricated from homoepitaxial p-i-n structures on GaN substrate. The most beneficial property of the beveled-mesa termination is the uniform breakdown-characteristic of the beveled-mesa APDs compared to the vertical-mesa APDs. Record-high VBR uniformity of 95.4 V ± 0.2 V and average avalanche gain up to 3 × 106 were observed for the beveled-mesa APDs within a linear array across 4 mm side-length. These results indicate the potential of the beveled-mesa GaN APD array for ultraviolet light imaging applications.

Deterioration of near-UV GaN-based LEDs in seawater vapour
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Reliability investigations were conducted after GaN-based LEDs were stressed in seawater vapour. Multiple electrical, optical, and material analyses on the fine nanostructures of the LED were examined. Results indicate that dark spots on the surface and etching trenches observed on the cross section might damage the quantum well and degrade LED performance. Dissolved sodium ions might diffuse and punch through the quantum well and be responsible for these spots and trenches.

Comparison between GaN and InN quantum-dot semiconductor optical amplifiers
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GaN/A10.5Ga0.5N and InN/A10.5Ga0.5N as a III-nitride quantum dot semiconductor optical amplifiers (QD-SOAs) are studied in detail in this paper. The optical gain, spontaneous emission rate, and lineshape function are calculated using non-Markovian relaxation compared with Markovian one. Gain is then connected with the rate equations model to obtain a dB gain, output power, and shot noise in these SOAs. GaN peaked at 351 nm which is preferred in optical coherence tomography applications. InN is peaked at 1028 nm which can be used in gas detection and environmental pollution monitoring. Both structures studied have high gain and low noise and nearly equivalent TE and TM gain which makes them adequate for the use in both these two modes. These calculations show the importance of InN and GaN QD nanostructure in the applications.

Nitride light-emitting diodes for cryogenic temperatures
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A novel approach to fabricate efficient nitride light-emitting diodes (LEDs) grown on gallium polar surface operating at cryogenic temperatures is presented. We investigate and compare LEDs with standard construction with structures where p-n junction field is inverted through the use of bottom tunnel junction (BTJ). BTJ LEDs show improved turn on voltage, reduced parasitic recombination and increased quantum efficiency at cryogenic temperatures. This is achieved by moving to low resistivity n-type contacts and nitrogen polar-like built-in field with respect to current flow. It inhibits the electron overflow past quantum wells and improves hole injection even at
T=12K. Therefore, as cryogenic light sources, BTJ LEDs offer significantly enhanced performance over standard LEDs.

Violet semipolar (20-2-1) InGaN microcavity light-emitting diode with a 200 nm ultra-short cavity length
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Optics Express
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Violet semipolar (20-2-1) InGaN microcavity light-emitting diodes (MC-LED) with a 200 nm ultra-short cavity length were demonstrated. The emission wavelength was 419 nm with a spectrum width of 20 nm. The external quantum efficiency (EQE) of MC-LED was constant at 0.8% for a forward current from 0.5 to 2 mA with the emitting area of 30×30 µm². With increasing forward current, the peak wavelength and spectrum width of the emission showed almost no changes. For epitaxial growth, metal-organic chemical vapor deposition (MOCVD) was used. Substrate removal and tunnel-junction with an Ag-based electrode made possible the fabrication of the ultra-short 200 nm thick cavity MC-LED. This is more than a factor of 2 improvement compared to previous MC-LEDs of 450 nm cavity thickness sustaining 5 modes.

Strong and robust polarization anisotropy of site- and size-controlled single InGaN/GaN quantum wires
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Scientific Reports
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Optical polarization is an indispensable component in photonic applications, the orthogonality of which extends the degree of freedom of information, and strongly polarized and highly efficient small-size emitters are essential for compact polarization-based devices. We propose a group III-nitride quantum wire for a highly-efficient, strongly-polarized emitter, the polarization anisotropy of which stems solely from its one-dimensionality. We fabricated a site-selective and size-controlled single quantum wire using the geometrical shape of a three-dimensional structure under a self-limited growth mechanism. We present a strong and robust optical polarization anisotropy at room temperature emerging from a group III-nitride single quantum wire. Based on polarization-resolved spectroscopy and strain-included 6-band k·p calculations, the strong anisotropy is mainly attributed to the anisotropic strain distribution caused by the one-dimensionality, and its robustness to temperature is associated with an asymmetric quantum confinement effect.

Joint evaluation of internal quantum efficiency and light extraction efficiency for AlGaN-based deep ultraviolet LEDs considering optical polarization properties
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In this work, a joint evaluation method for the internal quantum efficiency (IQE) and light extraction efficiency (LEE) for AlGaN-based deep ultraviolet (DUV) light emitting diodes (LEDs) is proposed by fully considering the optical polarization properties. In this method, the IQE curve varying with the forward current can be reconstructed from a few measurement data at a small injection level. The corresponding LEE can be determined using the composition of spontaneous emission light with transverse electric and transverse magnetic components at different forward currents. The proposed method is applied for the efficiency evaluation of the AlGaN-based LED sample and verified by comparing with the EQE result deduced from the measured light output power–current (L–I) characteristic. It is demonstrated that the very low EQE and significant efficiency droop is from not only IQE but also LEE for AlGaN-based DUV LEDs.
The 2020 UV emitter roadmap

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Solid state UV emitters have many advantages over conventional UV sources. The (Al,Ga)N material system is best suited to produce LEDs and laser diodes from 400 nm down to 210 nm—due to its large and tuneable direct band gap, n- and p-doping capability up to the largest bandgap material AlN and a growth and fabrication technology compatible with the current visible InGaN-based LED production. However AlGaN based UV-emitters still suffer from numerous challenges compared to their visible counterparts that become most obvious by consideration of their light output power, operation voltage and long term stability. Most of these challenges are related to the large bandgap of the materials. However, the development since the first realization of UV electroluminescence in the 1970s shows that an improvement in understanding and technology allows the performance of UV emitters to be pushed far beyond the current state. One example is the very recent realization of edge emitting laser diodes emitting in the UVC at 271.8 nm and in the UVB spectral range at 298 nm. This roadmap summarizes the current state of the art for the most important aspects of UV emitters, their challenges and provides an outlook for future developments.

Analysis of low-threshold optically pumped III-nitride microdisk lasers

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Low-threshold lasing under pulsed optical pumping is demonstrated at room temperature for III-nitride
microdisks with InGaN/GaN quantum wells on Si in the blue spectral range. Thresholds in the range of 18 kW/cm² have been achieved along with narrow linewidths of 0.07 nm and a large peak-to-background dynamic of 300. We compare this threshold range with the one that can be calculated using a rate equation model. We show that thresholds in the few kW/cm² range constitute the best that can be achieved with III-nitride quantum wells at room temperature. The sensitivity of lasing on the fabrication process is also discussed.

**InGaN-based lasers with an inverted ridge waveguide heterogeneously integrated on Si(100)**

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ACS Photonics

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Highly efficient electrically injected light source on exact Si(100) has been the bottleneck of Si photonics for decades. InGaN-based laser with a direct bandgap may serve as an efficient on-chip light source. But InGaN-based laser with a p-side ridge waveguide usually has a large electrical resistance and operation voltage, converting electricity into excessive Joule heat. The low wall plug efficiency, together with a large thermal resistance, leads to a high junction temperature, severely degrading device performance. Here, we proposed and fabricated a new laser structure with the ridge waveguide inverted from p-side to n-side. The differential electrical resistance and threshold voltage were slashed by 48% and 1.4 V, respectively. The thermal resistance and junction temperature were also reduced by 8 K/W and 25 oC, respectively. As a result, room-temperature continuous-wave electrically injected InGaN-based laser on exact Si(100) has been demonstrated, which is fully compatible with Si-based microelectronics and photonics platform.

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**Bright high-purity quantum emitters in aluminum nitride integrated photonics**

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ACS Photonics

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Solid-state quantum emitters (QEs) are fundamental in photonic-based quantum information processing. There is strong interest to develop high-quality QEs in III-nitride semiconductors because of their sophisticated manufacturing driven by large and growing applications in optoelectronics, high voltage power transistors, and microwave amplifiers. Here, we report the generation and direct integration of QEs in an aluminum nitride-based photonic integrated circuit platform. For individual waveguide-integrated QEs, we measure an off-chip count rate exceeding 6 × 10⁴ counts per second (cps) (saturation rate > 8.6 × 10⁴ cps) at room temperature under continuous-wave (CW) excitation. In an unpatterned thin-film sample, we measure antibunching with g(2)(0) ~ 0.08 and photon count rates exceeding 8 × 10⁵ cps (saturation rate > 1 × 10⁶ cps) at room temperature under CW excitation. Although spin and detailed optical linewidth measurements are left for future work, these results already show the potential for high-quality QEs monolithically integrated in a wide range of III-nitride device technologies that would enable new quantum device opportunities and industrial scalability.

**Full and gradient structural colouration by lattice amplified gallium nitride Mie-resonators**

Nanoscale

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The hybridised resonances between Mie-scatterers and lattice resonances, i.e. quasi-guided mode resonances, are investigated. The scattering of the Mie-resonators is boosted by the first order of transmitted diffracted light which is coupled into the lattice formed by the Mie-resonators. The conditions
of coupling are bounded by the refractive index of the substrate and the effective refractive index of the unit cell of the resonators. Based on momentum matching conditions, the cut-off wavelength of coupling and the amount of the amplification can be controlled at will. As a proof-of-concept application of this framework, gallium nitride metasurfaces are designed to produce metasurfaces that display structural colour. Palettes of full spectral colour and gradients are successfully demonstrated. The hue of the colour can be controlled by changing the periodicity of the unit cell at a fixed filling ratio of Mie-scatterer radius to unit cell periodicity, since the increase in periodicity red shifts the cut-off wavelength of the lattice resonance condition, identified as the Rayleigh anomaly. The brightness of the colour can be tuned by adjusting the filling ratio of the unit cell. Consequently, the proposed framework may provide a fundamental guideline to design spectral filters made up of low-index Mie-scatterers for various applications.

Graphene quantum dots sensitized ZnO-Nanorods/GaN-Nanotowers heterostructure based high performance UV Photodetector
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The fabrication of superior performance ultraviolet photodetector utilizing graphene quantum dots (GQDs) as sensitization agent on ZnO-Nanorods/GaN-Nanotowers heterostructure has been realized. GQD sensitization displays substantial impact on the electrical as well as the optical performance of heterojunction UV photodetector. The GQDs sensitization stimulates charge carriers in both ZnO & GaN and allows energy band alignment which is realised by spontaneous time-correlated transient response. The fabricated device demonstrates an excellent responsivity of 3.2x103 A/W at -6V and displays an enhancement of ~ 265% compare to its bare counterpart. In addition, the fabricated heterostructure UV photodetector exhibits very high external quantum efficiency of 1.2x106 %, better switching speed and signal detection capability as low as ~50fW

Design and Integration of Layered MoS2/GaN van der Waals Heterostructure for Wide Spectral Detection and Enhanced Photoresponse
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Molybdenum disulfide (MoS2) as a typical two-dimensional (2D) transition metal dichalcogenides exhibits great potential applications for next generation nanoelectronics such as photodetectors. However, most MoS2-based photodetectors hold obvious disadvantages including a narrow spectral response in visible region, the poor photoresponsivity and slow response speed. Here, for the first time, we report the design of a two-dimensional MoS2/GaN van der Waals (vdWs) heterostructure photodetector consisting of few-layer p-type MoS2 and very thin n-type GaN flakes. Thanks to the good crystal quality of 2D-GaN flake and the built-in electric field in the interface depletion region of MoS2/GaN p-n junction, photogenerated carriers can be rapidly separated and more excitons are collected by electrodes towards the high photoresponsivity of 328 A/W and a fast response time of 400 ms under the illumination of 532 nm light, which is 7 times faster than pristine MoS2 flake. Additionally, the response spectrum of the photodetector is also broadened to UV region with a high photoresponsivity of 27.1 A/W and fast response time of 300 ms after integrating with 2D-GaN flake, exhibiting advantageous synergetic effect. These excellent performances render MoS2/GaN vdWs heterostructure photodetectors as promising and competitive candidates for next-generation optoelectronic devices.
265 nm AlGaN-based deep-ultraviolet light-emitting diodes grown on AlN substrates studied by photoluminescence spectroscopy under ideal pulsed selective and non-selective excitation conditions

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Applied Physics Express
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Photoluminescence (PL) spectroscopy under ideal pulsed selective and non-selective excitation conditions is used to study 265 nm AlGaN-based light-emitting diodes grown on AlN substrates. Excitation-power-density-dependent PL measurements under selective excitation conditions show that the internal quantum efficiency of the quantum-well layers is unity at cryogenic temperatures under weak excitation regime. Temperature-dependent and time-resolved PL measurements demonstrate the high internal quantum efficiency at room temperature. The PL thermal quenching behaviors differ under the two excitation conditions, indicating a nonradiative recombination process at the quantum-barrier layers. We propose that the nonradiative recombination process is a limiting factor of the external quantum efficiency.

*UV Emission from GaN Wires with m-Plane Core–Shell GaN/AlGaN Multiple Quantum Wells

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The present work reports high-quality nonpolar GaN/Al0.6Ga0.4N multiple quantum wells (MQWs) grown in core–shell geometry by metal–organic vapor-phase epitaxy on the m-plane sidewalls of c-oriented hexagonal GaN wires. Optical and structural studies reveal ultraviolet (UV) emission originating from the core–shell GaN/AlGaN MQWs. Tuning the m-plane GaN QW thickness from 4.3 to 0.7 nm leads to a shift of the emission from 347 to 292 nm, consistent with Schrödinger–Poisson calculations. The evolution of the luminescence with temperature displays signs of strong localization, especially for samples with thinner GaN QWs and no evidence of quantum-confined Stark effect, as expected for nonpolar m-plane surfaces. The internal quantum efficiency derived from the photoluminescence (PL) intensity ratio at low and room temperatures is maximum (≈7.3% measured at low power excitation) for 2.6 nm thick quantum wells, emitting at 325 nm, and shows a large drop for thicker QWs. An extensive study of the PL quenching with temperature is presented. Two nonradiative recombination paths are activated at different temperatures. The low-temperature path is found to be intrinsic to the heterostructure, whereas the process that dominates at high temperature depends on the QW thickness and is strongly enhanced for QWs larger than 2.6 nm, causing a rapid decrease in the internal quantum efficiency.

Characterization of semi-polar (20-21) InGaN microLEDs

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Scientific Reports
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In this paper, semi-polar (20°-1) InGaN blue light-emitting diodes (LEDs) were fabricated and compared the performance with those of LEDs grown on c-plane sapphire substrate. LEDs with different chip sizes of 100 μm × 100 μm, 75 μm × 75 μm, 25 μm × 25 μm, and 10 μm × 10 μm were used to study the influence of chip size on the device performance. It was found that the contact behavior between the n electrode and the n-GaN layer for the semi-polar (20°-1) LEDs was...
different from that for the LEDs grown on the c-plane device. Concerning the device performance, the smaller LEDs provided a larger current density under the same voltage and presented a smaller forward voltage. However, the sidewall’s larger surface to volume ratio could affect the IQE. Therefore, the output power density reached the maximum with the 25 μm × 25 μm chip case. In addition, the low blue-shift phenomenon of semi-polar (2 0 2~1) LEDs was obtained. The larger devices exhibited the maximum IQE at a lower current density than the smaller devices, and the IQE had a larger droop as the current density increased for the LEDs grown on c-plane sapphire substrate.

Carrier recombination dynamics in green InGaN-LEDs with quantum-dot-like structures
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Exciton localization phenomena are considered here to comprehend the high internal quantum efficiency in InGaN/GaN multiple-quantum-well structures having discrete quantum dots (QDs) prepared by metal–organic-chemical-vapor deposition method on c-sapphire substrates. Spectroscopic results from the variable-temperature steady-state photoluminescence and time-resolved photoluminescence (TRPL) are investigated. While the exciton localization is enhanced by strong localized states within the InGaN/GaN QDs—the impact of free carrier recombination cannot be ignored. The observed non-exponential decay in TRPL measurements is explained using a model by meticulously including localized exciton, non-radiative and free carrier recombination rates. A new method is proposed to calculate the internal quantum efficiency, which is supplementary to the traditional approach based on temperature-dependent photoluminescence measurement.

Impact of carbon nanotube pattern layers on gallium nitride-based light emitting diodes
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Semiconductor Science and Technology
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Patterned sapphire substrate has been used extensively in the growth of gallium nitride (GaN) material and related light emitting devices (LEDs). Recently, carbon nanotube patterned sapphire (CNTPS) was utilized to improve the GaN material and LED devices. In this article, intrinsic analysis of LEDs on CNTPS were studied. LEDs grown on three layers of CNTs showed highest radiative quantum efficiency and internal quantum efficiency, while LEDs on double layers of CNTs exhibited the best light output power and external quantum efficiency. The physics of carriers' injection, radiative, non-radiative, Auger recombination and light extraction in CNT patterned LEDs were unraveled by the 'ABC' modelsimulation.
**Ultrathin barrier AlGaN/GaN hybrid-anode-diode with MOCVD in-situ Si3N4-cap and LPCVD-Si3N4 bilayer passivation stack for dynamic characteristic improvement**

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Electronics Letters
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A novel ultrathin barrier AlGaN/GaN hybrid-anode-diode (UTB-HAD) with in-situ Si 3 N 4 -cap passivation is experimentally demonstrated. The forward turn-on voltage (V on) of the UTB-HAD is determined by the intrinsic threshold voltage of the two-dimension electron gas (2DEG) channel, which can be precisely controlled by tailoring the as-grown AlGaN-barrier thickness. The typical V on as low as 0.48 V is obtained by using the UTB AlGaN/GaN with a barrier thickness of 4.9 nm. The MOCVD has grown in-situ Si 3 N 4 -cap and the LPCVD-Si 3 N 4 bilayer passivation stack is developed to effectively restore the 2DEG in the UTB AlGaN/GaN heterostructure and simultaneously improve the dynamic characteristics of the diode. The UTB-HAD and the novel passivation scheme are of great potential for power applications.

**Scaling Effect in Gate-Recessed AlGaN/GaN Fin-Nanochannel Array MOSHEMTs**

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In this study, to compare the performance of planar, fin-submicron, and fin-nanochannel array-structured AlGaN/GaN metal-oxide-semiconductor high-electron-mobility transistors (MOSHEMTs), the scaling effect of fin-channels was investigated by decreasing the nanochannel width to 50 nm using an electron-beam lithography system. The photoelectrochemical oxide method was used to directly oxidize the AlGaN layer into a gate oxide layer and to passivate the fin-nanochannel array. Consequently, the low-noise performance and Hooge’s coefficient were improved in AlGaN/GaN fin-nanochannel MOSHEMTs with narrower fin-channels. The improvement was attributed to the effective passivation and the screening effect of trapping probability. Moreover, owing to the improvement in gate control capability caused by the fin structure and the improvement in heat dissipation caused by the lateral heat flow, the direct current and high-frequency performances were improved by using a narrower fin-channel in AlGaN/GaN fin-nanochannel array MOSHEMTs.

**Quasi-Normally-Off AlGaN/GaN HEMTs with SiNx Stress Liner and Comb Gate for Power Electronics Applications**

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Recess processes for the fabrication of normally-off GaN HEMTs generally compromise devices’ on-state performance. In this work, recess-free quasi-normally-off GaN HEMTs with a threshold voltage of 0.24 V is realized by local control of two-dimensional electron gas (2DEG) density. The devices feature a 0.1 μm gate length, SiNx stress liner, and comb gate. SiNx liner can
provide significant stress to AlGaN/GaN heterostructure in the scaled gate region. The additional stress translates to the additional electric field and depletes the 2DEG in the gate region. As a result, the quasi-normally-off operation is achieved. Furthermore, the comb gate structure is introduced to suppress the short channel effects, supported by TCAD simulation. The quasi-normally-off devices’ excellent on-state performances are benchmarked against the normally-off devices reported recently and a p-GaN HEMT purchased from a commercial foundry. The results support strain engineering as a promising technique to pursue the normally-off operation of GaN HEMTs.

Impact of Surface Treatments and Post-Deposition Annealing upon Interfacial Property of ALD-Al2O3 on a-plane GaN

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Optimization of interface characteristics between dielectric and non-polar GaN surface is very important and urgent for vertical GaN MOS device whose channel is perpendicular to the conventional c-plane. In this work, the effects of piranha cleaning and N2 post deposition annealing (PDA) to the interface between atomic-layer-deposited (ALD)-Al2O3 and a-plane GaN samples were comprehensively investigated by X-ray photoelectron spectroscopy (XPS), atomic force microscopy (AFM) and photo-assisted capacitance-voltage (C-V) measurements. The piranha cleaning and N2 annealing can improve interface characteristics through the reduction in surface roughness and Ga-O bonds, respectively. Therefore, the frequency dispersion and hysteresis are nearly suppressed with a low interface trap quantity (Qit) of 4.11011 cm-2 and a low average interface state density (Dit) of 2.04×1011 cm-2·e-V-1 from photo-assisted C-V measurements, showing the great promise of utilizing piranha pretreatment, buffered oxide etch (BOE) dip, and N2 annealing as an effective route to improve the vertical GaN MOS interface properties.

Very-low Resistance Contact to 2D Electron Gas by Annealing Induced Penetration Without Spikes Using TaAl/Au on Non-recessed i-AlGaN/GaN

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IEEE Electron Device Letters
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A novel ohmic contact formation mechanism is revealed for the annealed Ta0.83Al0.17/Au stacks on non-recessed i-AlGaN/GaN. It is demonstrated that the contact metal alloy mainly composed by Au penetrates the AlGaN layer without apparent Ta-related solid phase reactions, establishing a spike-free contact to the 2D electron gas. A low contact resistivity of 0.14 Ω-mm (4.24E-7 Ω·cm²) is then obtained after 900 °C/60s annealing.

Mechanisms of a Rectifying TiN Gate Contact for AlGaN/GaN HEMTs on Silicon Substrate

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Rectifying Titanium Nitride (TiN) gate contact technology is developed for AlGaN/GaN based micro and nanometer HEMTs. A high compressive strain occurring in thinner TiN films (ranging from 5 nm to 60 nm), deposited by sputtering, leads to a reduction in tensile strain at the surface of AlGaN barrier. The diminution in tensile strain forms a pseudo-p-type layer (diode-like). This strain reduction has no effect
Progress on and challenges of p-type formation for GaN power devices

The fabrication processes of p-type regions for vertical GaN power devices are investigated. A p-type body layer in a trench gate metal-oxide-semiconductor field-effect transistor requires precise control of the effective acceptor concentration, which is equal to the difference between the Mg acceptor concentration (Na) and the compensating donor concentration (Nd). The carbon atoms incorporated during growth via metalorganic vapor phase epitaxy substitute nitrogen sites (CN) and function as donor sources in a p-type GaN layer. Since interstitial H atoms (Hi) also compensate holes, their removal from an Mg-doped layer is crucial. Extended anneals to release H atoms cause the formation of extra hole traps. The p+ capping layer allows effective and rapid removal of H atoms from a p-type body layer owing to the electric field across the p+/p– junction. On the other hand, selective area p-type doping via Mg ion implantation is needed to control the electrical field distribution at the device edge. Ultrahigh-pressure annealing (UHPA) under a nitrogen pressure of 1 GPa enables post-implantation annealing up to 1753 K without thermal decomposition. Cathodoluminescence spectra and Hall-effect measurements suggest that the acceptor activation ratio improves dramatically by annealing above 1673 K as compared to annealing at up to 1573 K. High-temperature UHPA also induces Mg atom diffusion. We demonstrate that vacancy diffusion and the introduction of H atoms from the UHPA ambient play a key role in the redistribution of Mg atoms.

AIN MEMS filters with extremely high bandwidth widening capability

This paper presents radio frequency (RF) microelectromechanical system (MEMS) filters with extremely high bandwidth widening capability. The proposed filtering topologies include hybrid configurations consisting of piezoelectric MEMS resonators and surface-mounted lumped elements. The MEMS resonators set the center frequency and provide electromechanical coupling to construct the filters, while the lumped-element-based matching networks help widen the bandwidth (BW) and enhance the out-of-band rejection. Aluminum nitride (AlN) S0 Lamb wave resonators are then applied to the proposed filtering topologies. AlN S0 first- and second-order wideband filters are studied and have shown prominent performance. Finally, the AlN S0 first-order wideband filter is experimentally implemented and characterized. The demonstrated first-order filter shows a large fractional bandwidth (FBW) of 5.6% (achieved with a resonator coupling of 0.94%) and a low insertion loss (IL) of 1.84 dB. The extracted bandwidth widening factor (BWF) is 6, which is approximately 12 times higher than those of the current ladder or lattice filtering topologies. This impressive bandwidth widening capability holds great potential for satisfying the stringent BW requirements.
of bands n77, n78, and n79 of 5G new radio (NR) and will overcome an outstanding technology hurdle in placing 5G NR into the marketplace.

Low interface state densities at Al2O3/GaN interfaces formed on vicinal polar and non-polar surfaces

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Ni/Al2O3/GaN structures with vicinal GaN surfaces from the c- or m-plane were formed. Then, electrical interface properties of the structures were systematically investigated. It was found that interface state density (Dit) at the Al2O3/GaN interface for the c-plane is higher than that for the m-plane, and post-metalization annealing is quite effective to reduce Dit for both c- and m-planes. As a result, the low Dit value of \(3 \times 10^{10}\) eV\(^{-1}\) cm\(^{-2}\) was demonstrated for both planes.

Effects of thermal annealing on the electrical and structural properties of Mo/Au schottky contacts on n-GaN

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Journal of Alloys and Compounds
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The current conduction mechanisms of the Mo/Au Schottky contacts on n-GaN with post metal annealing at 300, 500 and 700 °C have been investigated. The barrier height and ideality factor directly extracted from the measured current-voltage characteristics based on the thermionic emission (TE) theory show variations with the temperature, suggesting that inhomogeneous barrier heights were formed. A modified TE model considering the barrier height inhomogeneity with a Gaussian distribution was found to be able to explain the measurement data well. From the modified Richardson plot, the mean barrier heights \(0.598, 0.566, 0.789, 0.567\) and the standard deviations \(125.70, 113.14, 89.77, 121.24\) were obtained for the sample with as-deposited Mo/Au, the one with post metal annealing at 300 °C, the one annealed 500 °C and the one annealed at 700 °C, respectively. The specific on-resistance does not show any obvious change after post thermal annealing. The best values of reverse leakage current and the breakdown voltage were achieved after post metal annealing at 500 °C. Transmission Electron Microscopy (TEM) images and energy dispersive X-ray (EDX) spectroscopy mapping results reveal that the interaction between Mo and GaN during the annealing contributes to the observed Schottky barrier height difference under different annealing conditions.

High-Performance Ultrathin-Barrier AlGaN/GaN Hybrid Anode Diode With Al2O3 Gate Dielectric and In Situ Si3N4-Cap Passivation

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In this article, an ultrathin-barrier (UTB) AlGaN/GaN diode featuring metal-insulator-semiconductor (MIS)-gated hybrid anode (MG-HAD) and in situ Si3N4 cap passivation is demonstrated. The intrinsic turn-on voltage (Von) as low as 0.31 V determined by the as-grown AlGaN-barrier thickness (4.9 nm) is obtained and the Von exhibits excellent uniformity. More importantly, benefit from the MIS-gated hybrid anode structure, the UTB MG-HAD features good thermal stability in reverse blocking capability. The device delivers a substantially low leakage less than 1 μA/mm at -300 V at high temperature (HT) up to 200 °C, which is more than 100x lower than that in the reference
device w/o gate dielectric. Besides, the device exhibits respectively improved dynamic characteristics due to the incorporation of in situ Si₃N₄-cap passivation layer and remote plasma pretreatment (RPP) prior to Al₂O₃ gate dielectric deposition. The UTB MG-HAD featuring precisely Von modulation and low reverse leakage is of great interest for power electronic applications.

**Analysis of Gate-Metal Resistance in CMOS-Compatible RF GaN HEMTs**

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IEEE Transactions on Electron Devices  
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To enable CMOS-compatible GaN HEMTs for the next generation of communication systems (5G and beyond), a low gate resistance is of great importance since it directly affects the RF power gain and fMAX of the transistor. In this article, the impact of various gate-metal stacks on the gate resistance and RF performance of the devices is studied. The optimized Ti-free gate-metal process leads to fMAX enhancement up to ~50% for devices scaled down to 0.32-µm gate lengths. The gate resistance for the T-shaped gate is modeled from the S-parameters and validated on various gate field plate geometries. The tradeoff between the gate resistance and the parasitic capacitance in GaN HEMTs is highlighted in this case.

**Analysis of DC, Channel Temperature, and RF Performance of In Situ SiN/AlGaN-Sandwich-Barrier/ GaN/Al0.05GaN HEMTs**

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IEEE Transactions on Electron Devices  
https://doi.org/10.1109/TED.2020.3017136

In order to further improve the electrical characteristics of AlGaN-buffer devices, we propose a new in situ SiN/AlGaN-sandwich-barrier (SWB)/GaN/Al0.05GaN high-electron mobility transistors (HEMTs). The dc, channel temperature, and RF temperature of the proposed AlGaN-buffer devices have been systematically studied and analyzed. The SWB structure can effectively reduce the peak value of the electric field, thus effectively reducing the self-heating effect and improving the breakdown characteristics. Through the channel temperature extraction method of pulsed IV and TCAD thermal simulation, the channel temperature of devices with different barrier structures is compared and analyzed, which proves that SWB structure can effectively reduce the channel temperature of devices. Due to the more obvious potential modulation effect between gate and drain, the fmax of device can improve more effectively with the increase of drain voltage. In addition, load-pull measurement at 10 GHz revealed that a saturated power density increased from 7.3 to 8.4 W/mm and an associated PAE increased from 24.9% to 29.4%.

**Impact of Relative Gate Position on DC and RF Characteristics of High Performance AlGaN/GaN HEMTs**

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We have investigated the impact of relative gate position between source and drain on the DC and RF characteristics for AlGaN/GaN high electron mobility transistors. Devices with fixed source drain separation (LSD) of 5 µm, width (W) of 2x 50 µm and gate length (LG) of 200 nm are fabricated and characterized. The relative position of the gate is varied with constant LSD. The value of saturation drain current (IDS,sat) and maximum transconductance (gm,max) change from 740 mA/mm and 168 mS/mm for gate to source separation (LGS) of 3.8 µm to 1071 mA/mm and 245 mS/mm for LGS = 0.25 µm, respectively. The corresponding breakdown voltage (Vbr) significantly improves from 65 V (for LGS = 3.8 µm) to 189 V (for LGS = 0.25 µm). The unity current gain frequency (fT) is observed to remain constant at 55 GHz for all positions of the gate. However, output power density is found to increase from 3.8 to 5.1 W/mm for the same relative change in the gate position.
Low-Noise Amplifiers Using 100-nm Gate Length GaN-on-Silicon Process in W-Band
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IEEE Microwave and Wireless Components Letters
https://doi.org/10.1109/LMWC.2020.3019816

Two low-noise amplifiers fabricated with 100-nm gate length gallium nitride (GaN)-on-silicon process in W-band are presented in this work. One has a gain of 17.5-20.5 dB in 77.5-84 GHz with 3.8-4.7-dB noise figure (NF), the other has wider bandwidth of 78.5-90 GHz with 4.5-5.2-dB NF. The chip sizes of these two low-noise amplifiers (LNAs) are 3x1.6 mm² and 3x1.4 mm² separately. The power dissipation of these two LNAs is about 190 mW. These LNAs can be integrated with high-power GaN power amplifier on the same chip, which avoids the peripheral packaging loss and achieves smaller module size. The universal gate length in commercial process with low-cost silicon substrate brings these LNAs great potential for mass production in future millimeter-wave communications.

N-polar GaN-on-Sapphire Deep Recess HEMTs with High W-Band Power Density
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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2020.3022401

This work presents recent progress in the W-band (94 GHz) power performance of N-polar GaN deep recess HEMTs grown on sapphire substrates. While SiC has been the substrate of choice to achieve the highest level of performance, sapphire substrates are a lower cost alternative. In this work we show that N-polar GaN deep recess HEMTs grown on sapphire match the power performance of a device on SiC up to 14 V with 5.1 W/mm of output power density. At 16 V the device on sapphire starts to suffer from thermal effects but still demonstrated 5.5 W/mm with an associated 20.6% power-added efficiency. This work also examines the impact of encapsulating the device in a low dielectric constant film often used for the implementation of a RF wiring environment.

AllnN/GaN diodes for power electronic devices
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Applied Physics Express
https://doi.org/10.35848/1882-0786/abb180

AllInN/GaN power diodes consisting of a p-type GaN and a 300-nm-thick n-type AlInN drift layer are demonstrated. The p–n junction is grown using metalorganic chemical vapor deposition, and the AlxIn1−x N drift layer is lattice-matched to GaN (x ~ 0.82) with an electron concentration of ~8 × 1016 cm−3 after correcting for the 2-dimensional electron gas. The diodes exhibit ~60 V blocking capability. Under forward bias, the diode has a turn-on voltage of ~4 V. If experimental challenges are overcome, the ultrawide bandgap and high mobility of an AlInN drift layer could increase the performance of GaN-based power devices.

Ultra-high silicon doped N-polar GaN contact layers grown by metal-organic chemical vapor deposition
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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab9727

We report thin, high quality n+ type doped N-polar GaN contact layers grown using metal-organic chemical vapor deposition with carrier concentration as high as 3.5 × 1020 cm−3 and an electron mobility of 80 cm2 V−1 s−1 at room temperature resulting in a low sheet resistance of 57.3 Ω/sq and specific contact resistance of 1.7 × 10−7 Ω.cm2. These results were obtained via silicon doping of ($000\overline{1}$ N-polar GaN grown on 4° miscut sapphire substrates using a flow modulation growth scheme at a deposition temperature of 850 °C.
Lateral and vertical growth of Mg-doped GaN on trench-patterned GaN films
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Applied Physics Letters
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Growth of Mg-doped GaN on trench-patterned GaN films consists of competing lateral and vertical growth fronts that result in regions with different electronic properties. Under typical growth conditions, lateral growth from the trench sidewall occurs at a faster rate than vertical growth from the trench base. When the trench width is sufficiently narrow, the growth fronts from opposite sidewalls coalesce and lead to eventual planarization of the top surface. Secondary electron imaging and cathodoluminescence mapping are used to correlate the morphology and the optical properties of regions resulting from lateral and vertical growth. For our growth conditions, the lateral-to-vertical growth rate ratio is found to be about 2.

Influence of Fe in the buffer layer on the laser lift-off of AlGaN/GaN HEMT film: phenomena and mechanism
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Semiconductor Science and Technology
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In this paper, a study is presented of the effect of Fe in the buffer layer on the laser lift-off (LLO) of GaN high electron mobility transistors (HEMTs). AlGaN/GaN HEMTs grown on Fe-doped and unintentionally doped buffer layers were separated from sapphire substrates using a 248 nm KrF excimer laser lift-off system. We analyzed the variations of the crystal characteristics, two-dimensional electron gas (2DEG) characteristics and the strain state of AlGaN/GaN HEMT films before and after LLO by the x-ray diffraction, Hall and Raman methods. The measurement of the distribution of elemental Fe in the GaN buffer layer was performed by secondary ion mass spectroscopy. The results show that a peak Fe concentration of 9.56 × 1018 cm−3 appears at the interface. Moreover, the crystal quality and 2DEG characteristics of the Fe-doped GaN film obviously degenerated, with the formation of micro-cracks under the threshold laser separation energy density (Es). In this case, the threshold laser damage energy density (ED) was used to measure the laser damage tolerance of GaN in LLO. The analysis considers that additional laser absorption centers, induced by the Fe impurity energy level, coupled with a large residual stress of up to 1.0763 GPa in Fe-doped GaN, reduced the threshold laser damage energy density (ED).

Analysis of simultaneous occurrence of shallow surface Fermi level pinning and deep depletion in MOS diode with Mg-ion-implanted GaN before activation annealing
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Japanese Journal of Applied Physics
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The characteristics of a MOS diode with Mg-ion-implanted GaN before activation annealing were investigated. Mg ion implantation onto n-GaN with slightly high Si doping concentration (5 × 1017 cm−3) was performed with a moderate dosage (1.5 × 1012 cm−2). The completed MOS diode showed n-type features. The capacitance–voltage (C–V) and capacitance–frequency (C–f) characteristics of the MOS diode indicated that shallow surface Fermi level pinning and deep depletion occurred simultaneously. By applying the conductance method to the measured C–f characteristics, a discrete level at 0.2–0.3 eV below the conduction band edge was detected. On the basis of the simulation of the high-frequency-limit C–V curve, the detected discrete level distributed in the bulk of n-GaN rather than at the insulator/semiconductor interface, so that it caused surface Fermi level pinning at a relatively shallow energy level and deep depletion owing to its acceptorlike nature simultaneously.
Ultrawide bandgap Al$_{0.4}$Ga$_{0.6}$N channel heterostructure field transistors with drain currents exceeding 1.3 A mm$^{-1}$

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Applied Physics Express

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We report an Ultrawide Bandgap Al$_{0.4}$Ga$_{0.6}$N channel metal-oxide-semiconductor heterostructure field effect transistor with drain currents exceeding 1.33 A mm$^{-1}$ (pulse) and 1.17 A mm$^{-1}$ (DC), around a 2-fold increase over past reports. This increase was achieved by incorporating a hybrid barrier layer consisting of an AlN spacer, n-doped Al$_{0.6}$Ga$_{0.4}$N barrier and a thin reverse graded Al$_x$Ga$_{1-x}$N ($x$ from 0.60 to 0.30) cap layer. To enhance current spreading, a "perforated" channel layout comprising of narrow channel sections separated by current blocking islands was used. A composite ALD deposited ZrO$_2$/Al$_2$O$_3$ film was used as gate dielectric. A breakdown field above 2 MV cm$^{-1}$ was measured.

Characterization of AlSiO dielectrics with varying silicon composition for N-polar GaN-based devices

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Semiconductor Science and Technology

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The properties of aluminum-silicon-oxide (AlSiO) dielectric with varying silicon composition, grown on (000–1) N-polar GaN, were investigated in this paper. The refractive index, dielectric constant, and film density of AlSiO decreased with the increase of the silicon composition as indicated by ellipsometry, low-frequency capacitance-voltage (CV), and x-ray reflectivity (XRR) measurements, respectively. Negligible frequency dispersion in CV measurements and high-intensity XRR oscillations peaks were measured for all AlSiO samples with different silicon compositions, suggesting a high-quality N-polar GaN-AlSiO interface. The leakage current characteristics and flat-band voltage stability improved with the increase of the silicon composition from 20% to 46% and degraded for the sample that had a silicon composition of 73%. This study contributes to understanding the AlSiO dielectric performance for future use in the gate stack of N-polar GaN-based transistors.

Monolithic Integrated AlGaN/GaN Power Converter Topologies on High-Voltage AlN/GaN Superlattice Buffer

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A high-voltage AlN/GaN superlattice buffer for monolithic AlGaN/GaN power circuits is experimentally compared to a step-graded AlGaN/GaN buffer. The AlN/GaN superlattice as part of a 5.1μm epitaxial stack withstands over 1.3 kV. While the step-graded buffer is sufficient for low-side high-voltage circuits, the operation voltage of monolithic topologies such as a half-bridge is limited: Static negative back-gating at -200 V already depletes the lateral channel completely. Excessive asymmetrical buffer leakage at a positive substrate voltage of +250 V limits the operation voltage further. The superlattice buffer mitigates both effects: a negative substrate voltage of -200 V reduced the lateral channel current only by 25%. However, this condition is not necessarily required for half-bridge operation on the superlattice, because low-symmetrical vertical buffer leakage at substrate voltages of ±500 V allows operation of power topologies with positive substrate bias. Measured transfer characteristics of HEMTs on the graded buffer show excessive threshold voltage shift at negative substrate bias, preventing reliable circuit operation. On the superlattice buffer, the threshold voltage is shifted only +1 V from negative substrate biases, which allows monolithic high-voltage power topology operation. 98.8% efficient operation of a 6×4mm$^2$ GaN-on-Si power IC with a monolithic half-bridge, freewheeling diodes and drivers is demonstrated on the superlattice epitaxy.
Multi-aperture anode based AlGaN/GaN Schottky barrier diodes with low turn-on voltage and high uniformity
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In this letter, an anode configuration with multi-aperture structure and fully recessed AlGaN barrier layer is proposed in the AlGaN/GaN Schottky barrier diode. With the Schottky junction formed between the Ni anode metal and the channel of two-dimensional electron gas, as well as the evidently enlarged contact profile by the introduction of multiple apertures, the device’s forward turning-on performances are dominated by the sidewall Schottky contact, achieving a low turn on voltage of 0.35 V with high uniformity. Accompanied with the high breakdown voltage of 2770 V, the diode achieved a power figure-of-merit as high as 1.1 GW cm\(^{-2}\).

Three Subband Occupation of the Two-Dimensional Electron Gas in Ultrathin Barrier AlN/GaN Heterostructures
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Advanced Functional Materials
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Ultrathin barrier AlN/GaN heterostructure with record low sheet resistance of 82 Ω sq\(^{-1}\) is achieved by molecular beam epitaxy, where Shubnikov-de Haas oscillations (SdHOs) and quantum Hall effect (QHE) of two-dimensional electron gas (2DEG) are observed. The fast Fourier transform analysis of the SdHOs demonstrates a three-subband occupation in the triangle quantum well for the first time, with the electron density of \(n_1 = 2.2 \times 1013\) cm\(^{-2}\), \(n_2 = 2.3 \times 1012\) cm\(^{-2}\), and \(n_3 = 8.8 \times 1011\) cm\(^{-2}\), respectively, and the corresponding energy of 265, 28, and 11 meV below Fermi level. The three-subband QHE with a superposed feature is also demonstrated for the first time in AlN/GaN heterostructure, with large filling factors at high electron densities. By analyzing the first subband as the dominant part of the superposed QHE, the transport physics of a special magneto-intersubband scattering is revealed. These results contribute to a better understanding of the quantum physics for 2DEG, leading to a versatile functionality for AlN/GaN devices.

Thermal Modeling of GaN HEMT Devices with Diamond Heat-spreader
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Harvesting the potential performance of GaN-based devices in terms of the areal power density and reliability, relies on the efficiency of their thermal management. Integration of extremely high thermal conductivity Single-crystalline CVD-diamond serves as an efficient solution to their strict thermal requirements. However, the major challenge lies in the Thermal Boundary Resistance (TBR) at the interface of GaN/Diamond or SiC/Diamond. Junction temperature of the device shows a sensitivity of 1.28°C for every unit of TBR for GaN-on-Diamond compared to 0.43°C for every 10 units of TBR for GaN/SiC-on-Diamond. Finite Volume Thermal Analysis has shown a limit of around 22 m2K/GW beyond which the merit of proximity to the heat-source for GaN-on-Diamond can no more outperform GaN/SiC-on-
Diamond. Besides, due to the temperature dependency of the thermal conductivity K, an increase in the temperature causes an increase in the thermal resistivity of the device which is more significant in high power operations. Simplified assumption of constant K overestimates the device performance by resulting in 17°C lower junction temperature for the areal power density of 10W/mm. Other part of the project regarding the in-house growth of CVD-diamond to be bonded to the GaN device has been simultaneously in progress.

An ambient temperature dependent small signal model of GaN HEMT using method of curve fitting
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International Journal of RF and Microwave Computer-Aided Engineering
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In this article, ambient temperature effect on small signal model of AlGaN/GaN HEMT has been explored. Based on the study, an analytical method to understand the ambient temperature dependence on device behavior has been developed. Effectiveness of the proposed method has been illustrated through comparison with measured data. Moreover, comparison with other analytical methods has also been carried out illustrating its acceptability threshold.

A Monolithic GaN-IC With Integrated Control Loop for 400-V Offline Buck Operation Achieving 95.6% Peak Efficiency
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IEEE Journal of Solid-State Circuits
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Gallium nitride (GaN) transistors enable efficient and compact high-voltage power converters. In the state-of-the-art enhancement mode GaN-on-Si technology, a 650-V power transistor is formed as a lateral structure enabling monolithic integration with a driver and analog control circuits on one die. Offline power converters show a trend toward a higher level of integration, shifting from monolithic silicon (CMOS) to various integration levels in GaN technology. In this article, a monolithic, self-biased GaN buck converter for offline operation is presented, supporting both 110- and 230-V ac line voltage and providing up to 29-W output power. The converter shows a superior efficiency of 95.6% and a very high level of integration in a 650-V p-GaN gate e-mode GaN-on-Si technology. Analog design techniques for GaN integration, such as an auto-zero comparator and a high-voltage supply regulator, are discussed. Experimental results of stand-alone circuit blocks and the full buck converter confirm the viability of monolithic GaN integration as a path toward compact and efficient offline power converters.

Improved the C-V Curve Shift, Trap State Responsiveness, and Dynamic RON of SBDs by the Composite 2-D-3-D Channel Heterostructure Under the off-State Stress
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IEEE Transactions on Electron Devices
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In this article, the C-V curve shift, trap densities responsiveness, and dynamic Ron of AlGaN/GaN/GaN:C (SH:C) and AlGaN/GaN/graded-AlGaN:Si/GaN:C (DH:Si/C) heterostructure Schottky barrier diodes (SBDs) have been systematically analyzed. Due to additional 3-D electrons in graded-AlGaN:Si layer, the composite 2-D-3-D channel of DH:Si/C has a higher carrier concentration. Reducing the off-state electric field strength through AlGaN:Si insert layer, the composite 2-D-3-D channel of DH:Si/C has a higher carrier concentration. Reducing the off-state electric field strength through AlGaN:Si insert layer, a smaller positive shift of C-V curve is achieved under off-state stress. Due to the charge shielding effect of AlGaN:Si insert layer, trapping/detrapping effects in GaN:C buffer under the off-state stress are well suppressed. Compared with SH:C heterostructure, the trap density responsiveness of DH:Si/C heterostructure under off-state stress is significantly reduced. At the same time, trap density responsiveness of the upper channel is immune to off-
state electric stress time. In addition, the proposed SBDs show lower on-resistance with on reverse bias stress and better dynamic performance with on reverse stress time.

**A Review of High Frequency Power Converters and Related Technologies**

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Development of power electronic converters tend to achieve high efficiency and at the same time high power density in many industrial applications. In recent years, with emerging third-generation semiconductor materials i.e. Silicon Carbide (SiC) and Gallium Nitride (GaN), the switching frequency of several MHz has become a widely studied frequency band, therefore traditional technology can no longer meet the demand, and many new challenges appear. This paper presents a comprehensive review of high frequency (HF) converters, the essential challenges are analyzed such as topology selection, soft-switching technologies, resonant gate drivers, magnetic components design and optimization.

Quasi-vertical GaN heterojunction diodes with p-NiO anodes deposited by sputtering and post-annealing

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Vacuum
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Quasi-vertical GaN heterojunction diodes were fabricated with p-NiO anodes deposited by radio frequency magnetron sputtering. The influence of sputtering gas ratio on the quality of the NiO films was investigated and the crystalline quality of the NiO film is better at a lower oxygen ratio. The crystal structure, electrical and optical properties of the NiO thin films after post-deposition annealing (PDA) at various temperatures in oxygen ambient were evaluated. X-ray diffraction and optical results showed that the crystallinity of the NiO films was improved after annealing. With increasing PDA temperature, the carrier concentrations of the NiO films decreased and the bandgap became larger, which is ascribed to the out-diffusion of oxygen interstitial atoms. Moreover, high-performance NiO/GaN heterojunction PN diodes (HJPNDs) were obtained. The ideality factor and reverse voltage characteristics of the HJPNDs were enhanced with increasing PDA temperature. The hard breakdown voltage of the HJPND with PDA at 500 °C was 698 V without optimized termination techniques.

Impact of dislocation pits on device performances and interface quality degradation for E-mode recessed-gate Al2O3/GaN MOSFETs

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The device electrical characterizations and MOS interfacial quality degradation caused by dislocation pits on recessed-gate GaN surface are directly observed and investigated for e-mode Al2O3/GaN MOSFETs on Si substrate. The pits have resulted in negative shift of threshold voltage (Vth), leaky gate current and deteriorated channel conduction. Moreover, the serious gate trapping effects reflected in Vth instability are confirmed to be correlated with these pits. It has been mainly attributed to the formation of poor-quality MOS interface with high interface traps density more than 1013 cm−2eV−1. Further experimental measurements reveal that the pits tend to induce detrimental Ga–O on the recessed GaN surface, generally known as a common origin of interface traps, and thus cause the undesirable effects. A lower pit density helps to suppress the Ga–O, and improve the interface stability and device performances of e-mode MOS-gate GaN transistors.
Designing and optimizing high switching frequency, ultra-efficient converters requires detailed knowledge of the behavior and parasitic parameters for both active and passive components. Recently, wide bandgap transistors have enabled simultaneous increases in both switching frequency and efficiency due to higher maximum operating junction temperature limits, lower dc on-state resistances, and reduced parasitic inductances and capacitances. Yet, the early acceptance of gallium-nitride (GaN) switches was plagued by detrimental dynamic on-state resistance effects. This complex phenomenon for GaN devices is characterized by deviations in on-state resistance from dc operating characteristics based on design choices such as the magnitude and duration of both voltage and current stress, switching mode, and junction temperature. While device manufacturers have made improvements compared to early generation devices, experimental evidence from a survey of commercial GaN transistors highlight measurable change in on-state resistance still exists due to variations in voltage stress during hard-switching operation. After sharing insights for obtaining low noise measurements, an analysis method along with two metrics are proposed to characterize dynamic on-state resistance measurements for power electronics designers. Quantifying the performance of GaN devices with standardized metrics facilitates a fair comparison between different GaN device technologies during converter development, enables manufacturing qualification for GaN switches, and provides a benchmark to catalyze improvement for the next generation of GaN device development.

A new and versatile mechanism for electrical tuning of intersubband transitions (ISBT) in GaN High Electron Mobility Transistor (HEMT) device at room temperature is presented. In present study, experimental demonstration is provided which clearly discriminate ISBT from any other transitions induced by deep level traps, defects, etc. in 100 nm GaN HEMT device at room temperature. The strong interaction of light with two-dimensional electron gas (2DEG) inside asymmetrical triangular quantum well of GaN HEMT is investigated. The resultant ISBT of the carriers can be explained through pinning of the fermi level inside the quantum well by applying an electrical field along growth direction through gate. Presently intersubband (ISB) based devices are operated at cryogenic temperature to minimize the thermal lattice vibration. The inherent advantage of conduction band tuning through external bias in HEMT structure as demonstrated in this works can leads to room temperature device operation feasibility.

The aim of this work is to demonstrate high breakdown voltage and low buffer trapping in superlattice GaN-on-Silicon heterostructures for high voltage applications.
voltage applications. To this aim, we compared two structures, one based on a step-graded (SG) buffer (reference structure), and another based on a superlattice (SL). In particular, we show that: (i) the use of an SL allows us to push the vertical breakdown voltage above 1500 V on a 5 µm stack, with a simultaneous decrease in vertical leakage current, as compared to the reference GaN-based epi-structure using a thicker buffer thickness. This is ascribed to the better strain relaxation, as confirmed by X-Ray Diffraction data, and to a lower clustering of dislocations, as confirmed by Defect Selective Etching and Cathodoluminescence mappings. (ii) SL-based samples have significantly lower buffer trapping, as confirmed by substrate ramp measurements. (iii) Backgating transient analysis indicated that traps are located below the two-dimensional electron gas, and are related to CN defects. (iv) The signature of these traps is significantly reduced on devices with SL. This can be explained by the lower vertical leakage (filling of acceptors via electron injection) or by the slightly lower incorporation of C in the SL buffer, due to the slower growth process. SL-based buffers therefore represent a viable solution for the fabrication of high voltage GaN transistors on silicon substrate, and for the simultaneous reduction of trapping processes.

**Effects of GaN Buffer Resistance on the Device Performances of AlGaN/GaN HEMTs**

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Crystals

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We investigated the effects of GaN buffer resistance of AlGaN/GaN high-electron-mobility transistors (HEMTs) on direct current (DC), low-frequency noise (LFN), and pulsed I-V characterization performances. The devices with the highest GaN buffer resistance were grown on sapphire substrate using two-step growth temperature method without additional compensation doping. The proposed device exhibited the degraded off-state leakage current due to the improved GaN buffer quality compared to the reference devices with relative low buffer resistance, which is confirmed by high resolution X-ray diffraction (HRXRD). However, the proposed device with deep-level defects in GaN buffer layer showed the reduced hysteresis (ΔVth), increased breakdown voltage (BV), and enhanced pulse I-V characteristics. Regardless of GaN buffer resistance, all devices clearly showed 1/f behavior with carrier number fluctuations (CNF) at on-state but followed 1/f2 characteristic at off-state. From the 1/f noise characteristics, the extracted trap time constant (τi) of the proposed device can be obtained to be 10 ms, which is shorter than those of the reference devices because of the full compensation of deep-level defects in the GaN buffer layer.

**Monolithic Integrated High Frequency GaN DC-DC Buck Converters with High Power Density Controlled by Current Mode Logic Level Signal**

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Electronics

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Integration is a key way to improve the switching frequency and power density for a DC-DC converter. A monolithic integrated GaN based DC-DC buck converter is realized by using a gate driver and a half-bridge power stage. The gate driver is composed of three stages (amplitude amplifier stage, level shifting stage and resistive-load amplifier stage) to amplify and modulate the driver control signal, i.e., CML (current mode logic) level of which the swing is from 1.1 to 1.8 V meaning that there is no need for an additional buffer or preamplifier for the control signal. The gate driver can provide sufficient driving capability for the power stage and improve the power density efficiently. The proposed GaN based DC-DC buck converter is implemented in the 0.25 µm depletion mode GaN-on-SiC process with a chip area of 1.7 mm × 1.3 mm, which is capable of operating at high switching frequency up to 200 MHz and possesses high power density up to 1 W/mm² at 15 V output voltage. To the authors’ knowledge, this is the highest power
density for GaN based DC-DC converter at the hundreds of megahertz range.

**Development of Catalytic-CVD SiNx Passivation Process for AlGaN/GaN-on-Si HEMTs**

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Crystals
https://doi.org/10.3390/cryst10090842

We optimized a silicon nitride (SiNx) passivation process using a catalytic-chemical vapor deposition (Cat-CVD) system to suppress the current collapse phenomenon of AlGaN/GaN-on-Si high electron mobility transistors (HEMTs). The optimized Cat-CVD SiNx film exhibited a high film density of 2.7 g/cm³ with a low wet etch rate (buffered oxide etchant (BOE) 10:1) of 2 nm/min and a breakdown field of 8.2 MV/cm. The AlGaN/GaN-on-Si HEMT fabricated by the optimized Cat-CVD SiNx passivation process, which had a gate length of 1.5 μm and a source-to-drain distance of 6 μm, exhibited the maximum drain current density of 670 mA/mm and the maximum transconductance of 162 mS/mm with negligible hysteresis. We found that the optimized SiNx film had positive charges, which were responsible for suppressing the current collapse phenomenon.

**Low-Frequency Noise Behavior of AlGaN/GaN HEMTs with Different Al Compositions**

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Crystals
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AlxGa1–xN/GaN heterostructures with two kinds of Al composition were grown by metal organic chemical vapor deposition (MOCVD) on sapphire substrates. The Al compositions in the AlGaN barrier layer were confirmed to be 13% and 28% using high resolution X-ray diffraction (HRXRD). AlxGa1–xN/GaN high-electron mobility transistors (HEMTs) with different Al compositions were fabricated, characterized, and compared using the Hall effect, direct current (DC), and low-frequency noise (LFN). The device with high Al composition (28%) showed improved sheet resistance (Rsh) due to enhanced carrier confinement and reduced gate leakage currents caused by increased Schottky barrier height (SBH). On the other hand, the reduced noise level and the low trap density (Nt) for the device of 13% of Al composition were obtained, which is attributed to the mitigated carrier density and decreased dislocation density in the AlxGa1–xN barrier layer according to the declined Al composition. In spite of the Al composition, the fabricated devices exhibited 1/f noise behavior with the carrier number fluctuation (CNF) model, which is proved by the curves of both (Sld/Id2) versus (gm/Id)² and (Sld/Id2) versus (Vgs–Vth). Although low Al composition is favorable to the reduced noise, it causes some problems like low Rsh and high gate leakage current. Therefore, the optimized Al composition in AlGaN/GaN HEMT is required to improve both noise and DC properties.

**Graphene as a Schottky Barrier Contact to AlGaN/GaN Heterostructures**

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Materials
https://doi.org/10.3390/ma13184140

Electrical and noise properties of graphene contacts to AlGaN/GaN heterostructures were studied experimentally. It was found that graphene on AlGaN forms a high-quality Schottky barrier with the barrier height dependent on the bias. The apparent barrier
heights for this kind of Schottky diode were found to be relatively high, varying within the range of \( \phi_b = (1.0–1.26) \) eV. AlGaN/GaN fin-shaped field-effect transistors (finFETs) with a graphene gate were fabricated and studied. These devices demonstrated \textasciitilde8\ order of magnitude on/off ratio, subthreshold slope of \textasciitilde1.3,\ and low subthreshold current in the sub-picocamperes range. The effective trap density responsible for the 1/f low-frequency noise was found within the range of \( (1–5) \cdot 10^{19} \) eV\(^{-1}\) cm\(^{-3}\). These values are of the same order of magnitude as reported earlier and in AlGaN/GaN transistors with Ni/Au Schottky gate studied as a reference in the current study. A good quality of graphene/AlGaN Schottky barrier diodes and AlGaN/GaN transistors opens the way for transparent GaN-based electronics and GaN-based devices exploring vertical electron transport in graphene.

**Formation of quantum dots in GaN/AlGaN FETs**
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Scientific Reports
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GaN and the heterostructures are attractive in condensed matter science and applications for electronic devices. We measure the electron transport in GaN/AlGaN field-effect transistors (FETs) at cryogenic temperature. We observe formation of quantum dots in the conduction channel near the depletion of the 2-dimensional electron gas (2DEG). Multiple quantum dots are formed in the disordered potential induced by impurities in the FET conduction channel. We also measure the gate insulator dependence of the transport properties. These results can be utilized for the development of quantum dot devices utilizing GaN/AlGaN heterostructures and evaluation of the impurities in GaN/AlGaIn FET channels.

**A 2 kW S-band RF source for multipactor research utilizing GaN HEMTs**
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A high power, pulsed RF source designated for use in multipactor research is described. Four gallium nitride high electron mobility transistors from Cree/Wolfspeed, capable of 700 W in long pulse mode (500 W rated output), are combined to achieve a maximum rated output of 2.8 kW with a pulse length of \textasciitilde100\ µs. Custom splitters/combines are used due to the power levels considered in addition to a custom power and sequencing control system to ensure the proper biasing and sequencing of the relatively delicate depletion mode GaN devices. With high efficiency and small size, gallium nitride devices present a good solution for lab based sources, and this paper aims to provide information helpful in the construction of such a source. The multipactor phenomenon itself is studied within a high impedance waveguide section—achieved with a tapered impedance transformer—placed in a WR284 traveling wave ring resonator, which increases the effective power up to a factor of 20, or \textasciitilde40\ kW.

**Investigation of carrier compensation traps in n−-GaN drift layer by high-temperature deep-level transient spectroscopy**
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Applied Physics Letters
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Carrier compensation traps in n−-GaN drift layers grown on Si substrates were investigated using high-temperature deep-level transient spectroscopy (DLTS). The upper limit of the temperature range
(700 K) allows for the study of deeper levels in the bandgap than those previously reported by conventional DLTS. Three trap states were revealed to be responsible for carrier compensation. Besides the residual carbon (C) acceptor, two deep electron traps detected in the DLTS high-temperature range, labeled E2 and E3 with energies EC of 0.98 and 1.38 eV, respectively, were also found to have contributions to the carrier compensation. A comprehensive investigation combining with positron annihilation spectroscopy measurements revealed that E2 and E3 are related to the (–/2–) and (0/–) acceptor levels of the VGa–ON complex, respectively. The relatively high concentrations of E2 and E3 imply that the VGa–ON complex is an essential carrier compensation source in the drift layer and plays a crucial role in developing kV-class vertical GaN power devices.

**Study on the electron mobility related with ohmic contact width in AlGaN/GaN HEMTs**

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Modern Physics Letters B  
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For the fabricated AlGaN/GaN high electron mobility transistors (HEMTs) with different Ohmic contact widths, the gate-channel electron mobility is obtained experimentally. Mobility curves show very different values and trends. This phenomenon is investigated with the scattering theory in AlGaN/GaN HEMTs. The reason for the different mobility curves is found to be attributed to the different polarization charge distributions at the AlGaN/GaN interface. The AlGaN/GaN HEMT with a smaller Ohmic contact width corresponds to positive additional polarization charge near the Ohmic contact. The AlGaN/GaN HEMT with a larger Ohmic contact width corresponds to negative additional polarization charge near the Ohmic contact. Changing the Ohmic contact width will be a new dimension to optimize the characteristics of AlGaN/GaN HEMTs effectively.

**Structural breakdown in high power GaN-on-GaN p-n diode devices stressed to failure**

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Journal of Vacuum Science & Technology A  
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The morphology of GaN-on-GaN vertical p-i-n diode devices after reverse-bias electrical stressing to breakdown has been investigated. All failed devices had irreversible structural damage, showing large surface craters that were ∼15–35 μm deep with lengthy surface cracks. Cross-sectional electron micrographs of failed devices showed substantial concentrations of threading dislocations around the cracks and near the crater surfaces. Progressive ion-milling across damaged devices revealed high densities of threading dislocations and the presence of voids beneath the surface cracks; these features were not observed in any unstressed devices. These results should serve as a useful reference for future reliability studies of vertical high-power GaN devices.

**Electron mobility influenced by optical phonons in AlGaN/GaN MISHEMTs with different gate dielectrics**

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Applied Physics A  
[https://doi.org/10.1007/s00339-020-04005-3](https://doi.org/10.1007/s00339-020-04005-3)

The electron mobility influenced by optical phonons in AlGaN/GaN metal-insulator-semiconductor high electron mobility transistors with different gate dielectrics around room temperature is investigated theoretically. The electronic states are obtained by the finite difference method in consideration of built-in electric fields and the conduction band bending. The optical phonons are analyzed using the dielectric
continuum model. Based on the theory of force balance equation, the electron mobility of two-dimensional electron gas is obtained for the structures with four different gate dielectrics of Al2O3, HfO2, SiO2 and Si3N4. Our results show that the electron mobility is the highest in HfO2 systems when Al composition in AlGaN is small, whereas the mobility is the highest in Al2O3 systems as Al composition increases to a certain value. The effects of the ternary mixed crystals, each layer’s size and the fixed charges on the sheet density and electron mobility are also discussed for different gate dielectric materials.

Impact of threading dislocations in GaN p–n diodes on forward I–V characteristics
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Japanese Journal of Applied Physics
https://doi.org/10.35848/1347-4065/abb57f

The correlation between on-resistance (Ron) and the number of dislocations under the anode electrode was evaluated using p–n junction diodes on a high-quality GaN substrate with an average threading dislocation density of ≤4 × 105 cm−2 by a newly developed maskless 3D method. A positive correlation was observed between Ron and the number of dislocations. The microdiodes with an anode electrode size of diameter 6 μm of having one dislocation and no dislocation under the anode electrode were evaluated to estimate the current reduction by one dislocation, which was derived to be about 0.37 mA at a forward voltage of 5 V. The reduction of the forward current seemed to be caused by non-radiative recombination centers around dislocation lines which weakened the photon recycling effects and conductivity modulation.

On the other hand, there was no clear correlation between the breakdown voltage and the number of dislocations.

Transient response of drain current following biasing stress in GaN HEMTs on SiC substrates with a field plate
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This paper investigates the current collapse and transient response of a drain current (Id) following the transition to an off-state in GaN high-electron-mobility transistors (HEMTs) on SiC substrates. Within a short time (~10−3 s.) after an Id transition, significant current collapse and delayed recovery are observed in GaN HEMTs with a long gate-to-drain distance (Lgd). Moreover, at least two time constants (τ1 and τ2) are found to exist in HEMTs with an Lgd of over 4.0 μm. As the Lgd becomes longer, the activation energy required for electron emission is increased from 0.46 to 0.65 eV, which causes the time constant (τ2) to rise. Furthermore, the period of the off-state affects the time constants of GaN HEMTs without a field plate (FP). An extension of the off-state leads to an increase in the activation energy of the de-trapping process, and τ1 and τ2 are increased from 13 to 21 ms and from 150 to 350 ms, respectively.
Navitas gains Lip-Bu Tan as advisor and investor

Navitas Semiconductor Inc of El Segundo, CA, USA says that Lip-Bu Tan, founder & chairman of Walden International, founding managing partner of WRVI Capital, and CEO of Cadence Design Systems Inc, has joined it as a strategic advisor and investor.

Founded in 2014, Navitas introduced what it claimed to be the first commercial gallium nitride (GaN) power ICs. The firm says that its GaNFast power ICs integrate GaN power field-effect transistors (FETs) with drive, control and protection circuits to enable 3x faster charging in half the size and weight. Tier-1 OEMs including Lenovo, Xiaomi, OPPO and NVIDIA have adopted GaNFast power ICs for their next-generation smartphone, tablet and laptop chargers.

“Lip-Bu is a pioneer in technology investment, with rich experience and an impressive track record of investing in, supporting and helping semiconductor companies navigate and create extraordinary growth and market leadership,” comments Navitas’ CEO Gene Sheridan. “His deep industry influence, insights and connections will accelerate Navitas’ market and financial success,” he believes.

“Navitas is the leader in the fast-charging GaN power semiconductor field,” comments Tan.

Tan currently serves on the boards of directors of Cadence, Hewlett Packard Enterprise, Schneider Electric and SoftBank Group. He serves on the board of trustees and the School of Engineering Dean’s council at Carnegie Mellon University, is a member of the College of Engineering advisory board at University of California Berkeley, the board of Global Semiconductor Alliance, and a member of The Business Council and Committee 100. He is the recipient of the 2016 GSA Morris Chang Exemplary Leadership Award.

Tan gained a Bachelor of Science Degree in Physics at Nanyang Technical University in Singapore in 1978, followed by a Master of Science in Nuclear Engineering at MIT in 1981, then a Master’s in Business Administration from the University of San Francisco in 1983.

SweGaN selected for second year on list of Sweden’s hottest tech startups

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 telecom, satellite, defense and power applications, has been named for the second year in a row to the Ny Teknik (New Technology) ‘33 List’ of Sweden’s most promising and innovative young companies. This year’s contenders included 270 companies.

With headquarters in the technology hub of Linköping, SweGaN manufactures QuanFINE GaN-on-SiC wafers using patented growth technology. The QuanFINE wafers are sold to manufacturers of components and devices for
satellite communication, telecom and defense applications, as well as manufacturers of power electronics used in electric vehicles, solar inverters and more.

Earlier this year, SweGaN reported 300% year-on-year revenue growth in 2019, with a doubling of commercial orders and collaboration in multiple European Union (EU) projects.

Self-Cooling Microchip Aims to Provide a Solution for Overheating

The microchip is a tiny computing marvel, powering everything from our cellphones to space satellites. But increasing demand for these chips to transform our lives can lead to some unintended consequences, namely, overheating.

This intrinsic limitation stands in the way of Moore’s Law, which anticipates that microchips and transistors will continue to get smaller and smaller as computing needs and power increase. Without being able to overcome their hot flashes, continuing to miniaturize microchips poses a problem to computing.

But a team of Swiss researchers believes they have a new solution by integrating cooling liquid directly into the chip itself. This approach could yield orders of magnitude improvements in efficiency to previously proposed cooling models, and bring computing into a new age of innovation.

In 2020, US data centers are expected to consume 73 billion kilowatt-hours of energy, according to one energy-usage report. As if that wasn't bad enough, each kilowatt-hour of energy requires two gallons of water to cool it. So, for 2020 alone, that equates to some 220,000 Olympic-size swimming pools of water.

This level of resource usage is staggering. In the new study, published in the journal Nature, the researchers say it is this extreme level of resource usage that makes it paramount to design a better, more sustainable model for advanced computation with these chips.

Previous attempts at designing self-cooling microchips have largely relied on a two-pronged approach, involving designing the cooling elements separately from the electronic elements, and then combining after the initial fabrication process.

Substantial research efforts have focused on improving the thermal path between the hotspot and the coolant. But heat extraction capability is fundamentally limited by the thermal resistance between the semiconductor hardware and packaging.

Instead, the researchers propose a "co-designed" chip, integrating cooling elements directly onto the chip itself. In this design, dubbed a "microfluidic–electronic co-design," buried coolant channels are integrated across the device, allowing for even heat dissipation and management.
According to a companion report published alongside this study, three different types of direct-to-electronic microfluidic cooling have previously been attempted, but all had drawbacks. That report’s author and mechanical engineer, Tiwei Wei, argues that issues with cost and thermo-related stress in these models limit their efficiency gains. But this new approach may offer the best of both worlds.

POWERlab Matioli (Video)
https://youtu.be/dvez_oLniA

Tiwei Wei stated that this team have made a breakthrough by developing a system in which cooling channels are integrated and co-fabricated with a chip in a single die. The buried channels are therefore embedded right below the active areas of the chip, so that the coolant passes directly beneath the heat sources.

To create the chip, the team first started by fabricating the imbedded cooling system. They did this by etching and widening coolant channels directly onto the chip’s substrate. Next, after the channels were sealed off with copper, they built the chip’s other electronic components directly on top.

To test out their design, the team used a water coolant and designed an electronic component that converted alternating current (AC) electricity into direct current (DC). Compared to a similar component without embedded cooling, the researchers saw significantly higher efficiency. The authors also report that this system has cooling power up to 50 times greater than other conventional models.

And, because the fabrication approach uses existing systems, the researchers say it’s already economically viable.

**Structural Concerns**

But this design isn’t exactly a home run, says Wei. Wei points out in his report a few structural concerns with the design; namely the material used for the substrate surface and an adhesive used to connect the coolant channels during fabrication. For both, the long-term stability and effectiveness in different environments, for example, in temperatures associated with typical microchip manufacturing processes, are cause for concern.

Likewise, water as a coolant for this system may not be a long-term solution, either — given how electronics and water typically don’t get along.

With these questions and next steps in mind, the researchers say they’re excited by the possibilities for sustainability that these initial results present.

"We anticipate that the co-design of microfluidic and electronics will be appropriate for energy-efficient thermally-aware electronics design. This may aid in solving critical challenges in electronics applications, as well as enabling future integrated power converters on a chip to support the electrification of our society in a sustainable manner."

And, despite his questions about the design, Wei also echoes this enthusiasm.

"Despite the challenges still to be addressed, this work is a big step towards low-cost, ultra-compact and energy-efficient cooling systems for power electronics," he writes.
Global GaN RF Market Expected to Reach $2 Billion by 2025

everythingRF

In the past few years, Radio Frequency (RF) applications have received a boost from the implementation of GaN technology. The main GaN RF market drivers remain to be telecom and defense applications. According to a research report from Yole Development, the total GaN RF market will increase from $740 Million to more than $2 Billion by 2025, with a CAGR of 12%. This report conveys Yole Développement’s (Yole) understanding of GaN implementation in different market segments. It also includes an extensive overview of 5G’s impact on the wireless infrastructure and RF Front Ends (FEs), along with the GaN-based military market. Furthermore, Yole shares its view of the market’s current dynamics and future evolution.

In telecom infrastructure, the aftermath of U.S. sanctions related to Huawei slowed the GaN-based Remote Radio Head (RRH) market in 2019 and pushed OEMs to restructure their supply chain for the coming years. Nevertheless, GaN deployment will remain the same for the longterm. In Active Antenna Systems (AAS), the increase in bandwidth will favor increasing GaN implementation. Also, small cells and backhaul connections will see an impressive deployment of GaN in the coming years.

In military applications, with investments from governments to improve their national security by replacing Travelling Wave Tube (TWT)-based systems, the defense will remain one of the GaN RF market’s main drivers. Radar is the main driver in military applications, mainly due to the increase of T/R modules in new GaN-based Active Electronically Scanned Array (AESA) systems and stringent requirements for lightweight devices for airborne systems. The total GaN RF military market will surpass $1.1B in 2025, at a CAGR of 22%.

For handsets, GaN’s high performance and small form factor could attract OEMs. The adoption of a GaN PA will depend on the evolution over the next five years of GaN’s technology i.e. maturity, supply chain, and cost, as well as OEM strategies.

How is the GaN RF Landscape Evolving?

GaN-based commercial products and prototypes currently exist on SiC, Si, and diamond substrates, showing different technological maturities and thus varying value chain maturity. Numerous actors are involved in the well-established GaN-on-Si technology field with different business models. However, following America’s sanctions related to Huawei in Q2/2019, a short supply situation occurred, mainly in the GaN-based telecom infrastructure market. As a result, it will be important to watch how various strategic partnerships and investments unfold during 2020 – 2021. At the RF component level, market leaders Sumitomo Electric Device Innovations (SEDI) and II-VI plan to ramp up their vertically integrated 6-inch GaN-on-SiC wafer platforms to address the increasing demand from 5G. Additionally, leading compound semiconductor foundry Win Semiconductors expects to double its GaN RF capacity during 2020 – 2021.

Regarding the military segment, each country and region is individually strengthening its GaN RF ecosystem. In the U.S., Northrop Grumman, Lockheed Martin, and Raytheon are driving GaN adoption. Meanwhile, UMS, SAAB, Airbus, Thales, and Leonardo are actively involved in Europe, while China Electronics Technology Group Corporation (CETC), a leading vertically integrated company, is boosting the Chinese GaN-based defense market. In the GaN-on-Si business, while the MACOM-ST consortium’s 6” fabrication line development is ongoing, French foundry OMMIC is offering GaN-on-Si MMIC technology for mm-wave markets. And that’s not all: in 2019, following its acquisition of EpiGaN, Soitec is considering entry into the 5G infrastructure and handset market with its own innovative GaN-on-Si technology.
This report examines the GaN RF industry playground, covering the value chain for epitaxy, device, and module design on SiC, Si, and diamond substrates. Yole also shares its understanding of the market’s current dynamics and future evolution.

Read more

**GaN Systems’ whitepaper outlines lifetime and reliability testing processes and results**

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has released a whitepaper showing that gallium nitride is reliable, with the firm’s devices surpassing the criteria of both JEDEC and AEC-Q101 test specifications.

The whitepaper ‘Qualification and Reliability of GaN Power Semiconductors: A Collaborative Approach with Partners and Customers’ provides an overview of an enhanced qualification strategy and processes developed by GaN Systems and its customers. Results based on the application of these new test methods on GaN Systems devices are also demonstrated in the paper.

Existing qualification guidelines and standards for GaN power transistors are applied with silicon transistors as the foundation, which already have several decades of use and reliability data behind them. Since GaN and other wide-bandgap transistors are different in material and construction, qualification requires a closer look at how and which testing guidelines apply, says GaN Systems. Renewed reliability testing methods are especially important as the mission profiles that model electronic system lifetimes are ever changing.

GaN Systems and its partners from the global automotive, industrial and high-reliability (HiRel) industries have taken the lifetime and reliability challenge on to create an approach that draws considerations from JEDEC and AEC-Q and an understanding of industry challenges in qualification testing. The GaN Systems’ whitepaper reviews this, and outlines:

The collaborative approach strategy which looks at device failure modes, transistor test design, and manufacturing process feedback. Enhanced product qualification processes using JEDEC and AEC-Q101 tests as a baseline and additional test methods to account for differences between silicon and GaN, and test results of GaN Systems’ devices. Definition of lifetime models by determining failure mechanisms and applying a failure mode and effects analysis (FMEA), builds parts, and test-to-failure processes. Test results of GaN Systems’ devices are also shown.

“The assumption that GaN is unproven or unreliable is no longer in question. In the last few years, we’ve seen global companies continue to use and introduce innovative products and systems using GaN Systems’ power semiconductors as the basis for design,” says CEO Jim Witham. “It is clear that the work we have done with our customers to create an enhanced reliability test set ensures that GaN Systems’ devices demonstrate industry-leading performance and lifetime in the most challenging environments.”

**EPC launches latest 100V eGaN FET family**

SemiconductorToday

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – says that it is advancing the performance capability while lowering the cost of off-the-shelf gallium nitride transistors with the introduction of the EPC2218 and EPC2204 100V eGaN FETs. Applications include synchronous rectification, class-D audio, infotainment systems, DC–DC
converters (hard-switched and resonant), and light detection & ranging (LiDAR) for autonomous cars, robotics and drones.

The EPC2218 (3.2mΩ, 231Apulsed) and the EPC2204 (6mΩ, 125Apulsed) have nearly 20% lower on-resistance (RDS(on)) as well as increased DC ratings compared with prior-generation eGaN FET products. The performance advantage over a benchmark silicon device is even higher.

The EPC2204 has 25% lower on-resistance, yet is three times smaller in area (at 1.5mm x 2.5mm versus 3.3mm x 3.3mm). Gate charge (QG) of 6.4nC (typical, at 5VGS) is less than half that of the silicon MOSFET benchmark’s 15nC (typical, at 10VGS) and, like all eGaN FETs, there is no reverse recovery charge (compared with 29nC QRR typical for the silicon MOSFET benchmark at 40V), enabling lower-distortion class-D audio amplifiers, as well as more efficient synchronous rectifiers and motor drives.

“With the clear superiority of these new 100V eGaN FETs, one might expect them to be priced at a premium. However, EPC has priced these state-of-the-art 100V transistors comparable with their aging ancestor, the silicon power MOSFET,” says co-founder & CEO Alex Lidow. “Designers can take advantage of devices that are higher performance, smaller, more thermally efficient and at a comparable cost,” he adds. “The displacement of the power MOSFET with GaN devices continues to accelerate.”

The EPC2218 is priced at $2.09 each and the EPC2204 at $0.99 each (in 2.5k reels), with half-bridge development boards EPC90123 and EPC9097, respectively, both priced at $118.75. All products and boards are available from distributor Digi-Key Corp.

### NXP Opens New GaN Foundry in Arizona for 5G PA Fabrication

NXP Semiconductors has officially opened its new 150 mm (6-inch) RF Gallium Nitride (GaN) fab in Chandler, Arizona. This highly advanced fab is dedicated to supporting 5G RF power amplifier development in the United States. The new internal factory combines NXP’s expertise as the industry leader in RF power and its high-volume manufacturing know-how, resulting in streamlined innovation that supports the expansion of 5G base stations and advanced communication infrastructure in the industrial, aerospace and defense markets.

The opening ceremony was marked by keynote addresses and remarks by NXP executives plus federal, state, and local government officials, including:

- Arizona Senators Kyrsten Sinema and Martha McSally
- U.S. Representative Greg Stanton
- Arizona Governor Doug Ducey
- City of Chandler Mayor Kevin Hartke
- U.S. Department of Commerce Deputy Under Secretary for International Trade Joseph Semsar
- Ambassador of the Kingdom of the Netherlands to the United States Andre Haspels
- In his keynote address, Kurt Sievers, NXP CEO said: “Today marks a critical milestone for NXP. By building this incredible facility and tapping key talent in Arizona, we are able to bring focus to GaN technology as part of driving the next generation of 5G base station infrastructure.”

With 5G, the density of RF solutions required per antenna has exponentially increased – yet maintaining the same box size and reducing power consumption is mandatory. GaN power transistors have emerged as the new gold
standard to address these dueling requirements, delivering significant improvements in both power density and efficiency.

Nearly 20 years of GaN development expertise and extensive wireless communication industry knowledge uniquely position NXP to lead this next wave of cellular expansion for 5G. The company has deeply optimized its GaN technology to improve the electron trapping in the semiconductor to deliver high efficiency and gain with best-in-class linearity, all of which is focused on serving NXP customers with the highest quality GaN device production.

Joakim Sorelius, Head of Development Unit Networks at Ericsson, a longstanding NXP customer, commented: “We strive to deliver industry leading products that provide maximum value to our customers, where power amplifiers play an important part of the radio technology. Similar to Ericsson’s recent US investments, we are pleased to see NXP’s investments in the U.S. semiconductor process development with the continuous focus on improving RF system performance for future high demanding radio networks.”

NXP’s strategic move to build an internal GaN fab was driven by its ability to achieve higher performance benefits through leveraging its core competency in cellular infrastructure design, proven track record for high-volume manufacturing and consistency and leadership in total quality processes.

“I am excited by the opening of our new facility in Chandler as it underscores NXP’s decades-long commitment to GaN and the communications infrastructure market,” said Paul Hart, Executive Vice President and GM of the Radio Power Group at NXP. “I would like to thank our customers for their collaboration throughout the years and the entire NXP team that has been instrumental in creating the world’s most advanced RF GaN fab, which is designed and ready to scale to 6G and beyond.”

The fab is set to ramp quickly with NXP leveraging its Chandler-based team and their long-standing expertise in compound semiconductor manufacturing. Arizona Governor Doug Ducey stated that with this new state-of-the-art manufacturing facility in Chandler, Arizona is set to expand its reputation as a high-tech manufacturing hub and a pioneer in 5G innovation. They are grateful to NXP for bringing more jobs and investment to the state.

The internal factory will serve as an innovation hub that facilitates collaboration between the fab and NXP’s onsite R&D team. NXP engineers can now more rapidly develop, validate and protect inventions for current and future generations of GaN devices, resulting in shorter cycle times for NXP GaN innovations.

NXP’s new Chandler-based GaN fab is qualified now, with initial products ramping in the market and expected to reach full capacity by the end of 2020.
ST launches first silicon-based driver and GaN transistors integrated in one package

STMicroelectronics of Geneva, Switzerland has unveiled MasterGaN, which is claimed to be the first platform embedding a half-bridge driver based on silicon technology along with a pair of gallium nitride (GaN) transistors. The combination is aimed at accelerating the creation of next-generation compact and efficient chargers and power adapters for consumer and industrial applications up to 400W.

GaN technology enables these devices to handle more power even as they become smaller, more lightweight, and more energy efficient. Such improvements can make a difference for smartphone ultra-fast chargers and wireless chargers, USB-PD compact adapters for PCs and gaming, as well as in industrial applications like solar-energy storage systems, uninterruptible power supplies (UPS), or high-end organic light-emitting diode (OLED) TVs and the server cloud.

The existing GaN market is typically served by discrete power transistors and driver ICs that require designers to learn how to make them work together for best performance. ST says that its MasterGaN approach bypasses that challenge, resulting in faster time to market and assured performance, together with a smaller footprint, simplified assembly and increased reliability with fewer components. With GaN technology and ST’s integrated products, chargers and adapters can cut 80% of the size and 70% of the weight of ordinary silicon-based solutions, it is reckoned.

“ST’s market-unique MasterGaN platform builds on our proven expertise and power-design skills to combine high-voltage smart-power BCD [bipolar-CMOS-DMOS] process with GaN technology, to accelerate the creation of space-saving and power-efficient products that are kinder to the environment,” says Matteo Lo Presti, executive VP & general manager Analog Sub-Group.

The MasterGaN platform leverages STDRIVE 600V gate drivers and GaN high-electron-mobility transistors (HEMTs). The 9mm x 9mm low-profile GQFN package ensures high power density and is designed for high-voltage applications with over 2mm creepage distance between high-voltage and low-voltage pads.

The family of devices will span different GaN transistor sizes (RDS(ON)) and will be offered as pin-compatible half-bridge products that let engineers scale designs with minimal hardware changes. Leveraging the low turn-on losses and absence of body-diode recovery that characterize GaN transistors, the products offer what is claimed to be superior efficiency and overall performance enhancement in high-end, high-efficiency topologies such as flyback or forward with active clamp, resonant, bridgeless totem pole PFC (power factor corrector) and other soft- and hard-switching topologies used in AC/DC and DC/DC converters and DC/AC inverters.

ST is launching the new platform with MasterGaN1, which contains two GaN power transistors connected as a half bridge with integrated high-side and low-side drivers. Specifically, MasterGaN1 contains two normally-off transistors that feature closely matched timing parameters, 10A maximum current rating, and 150mΩ on-resistance (RDS(ON)). The logic inputs are compatible with signals from 3.3V to 15V. Comprehensive protection features are also built in, including low-side and high-side UVLO protection, interlocking, a dedicated shutdown pin, and over-temperature protection.

MasterGaN1 is in production now, in a 9mm x 9mm GQFN package only 1mm high. Priced at $7 for orders of 1000 units, it is available from distributors. An evaluation board is also available to help jump-start customers’ power projects.
EPC Space launches 40-300V rad-hard eGaN power transistors

EPC Space LLC of Haverhill, MA, USA has launched a family of rad-hard enhancement-mode power transistors spanning a range of 40-300V and 4-30A, and demonstrating what are said to be significant performance advantages over competing silicon-based rad-hard power MOSFETs.

EPC Space was established in June as a joint venture between Efficient Power Conversion Corp of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – and VPT Inc of Blacksburg, VA, USA (part of the HEICO Corp subsidiary HEICO Electronic Technologies Group). The JV is focused on designing and manufacturing high-reliability, radiation-hardened enhancement-mode GaN-based power conversion devices for space and other harsh environments.

“We are able to offer designers a superior technology with significant space heritage, as thousands of our rad-hard GaN devices have been in orbit since January of 2019,” says CEO Bel Lazar.

EPC Space says that its technology produces devices that are smaller, have lower resistance, and have many times superior switching performance compared with silicon solutions.

Critical spaceborne applications that benefit from this newly available performance include power supplies for satellites and mission equipment, light detection & ranging (LiDAR) for robotics and autonomous navigation and rendezvous docking, motor drives for robotics and instrumentation, and ion thrusters for satellite orientation and positioning as well as interplanetary propulsion of low-mass robotic vehicles.

Beyond the performance improvement, the devices are said to offer superior radiation hardness under heavy ions (SEE) and gamma radiation (TID). SEE immunity is guaranteed at the wafer level and EPC Space devices are manufactured in an AS9100D-certified facility in the greater Boston area.

Green and orange LEDs on porous GaN

University of California Santa Barbara (UCSB) in the USA has been using a gallium nitride porosification process to increase the wavelength of indium gallium nitride (InGaN) micron-scale light-emitting diodes (μLEDs) [Shubhra S. Pasayat et al, Appl. Phys. Lett., vol117, p061105, 2020]. The porous GaN is less rigid, allowing overlying InGaN ‘pseudo-substrate’ (PS) layers to be less strained.

The relaxed InGaN in turn increases indium uptake during regrowth processes through the ‘composition pulling effect’, creating higher-indium-content layers and hence longer emission wavelengths. Composition pulling is ascribed to the reduced lattice mismatch between the InGaN growth front and the underlying InGaN pseudo-substrate, compared with InGaN grown directly on GaN. The work resulted in green (500-565nm)- and even orange (590-625nm)-emitting devices.

The researchers see the potential for applications from near-eye head-mounted to large-area self-emitting displays. Also, smaller device sizes often allow for faster switching speeds for GHz-level modulation bandwidth in visible light communications (VLC). “Owing to their small form factors, μLEDs are also being considered to possess immense potential in medical applications and mask-free lithography,” the team adds.

The UCSB group has also recently reported on use of the same concept for producing high-aluminium-content AlGaN pseudo-substrate films, which may lead to better-performing very-short-wavelength deep-ultraviolet-emitting devices [Shubhra S. Pasayat et al, Appl. Phys. Lett., vol117, p062102, 2020].

For the InGaN μLEDs, the UCSB team performed metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire. The GaN layers used trimethyl-gallium as the metal precursor, while for InGaN triethyl-gallium and trimethyl-indium were used. The nitrogen source was ammonia. Silicon doping for n-type conductivity came from disilane (Si2H6).

The first steps consisted of growing 2.8μm of unintentionally doped (UID) GaN buffer, followed by 800nm of 5x1018/cm3 Si-doped GaN (GaN:Si) and a 100nm UID GaN cap.

A 2mmx2mm die from the material was dry etched into square tiles with dimensions from 8μmx8μm up to 20μmx20μm. The target etch depth was 550nm. Electrochemical (EC) etching porosified the GaN:Si layer. Some parts of the die were protected from the electrochemical process to allow the growth of reference InGaN material. The electrochemical etch used a metal contact on the exposed GaN:Si layer as the anode, a platinum cathode, and 0.3M oxalic acid electrolyte.

The porous material was subjected to MOCVD regrowth, producing LED structures (Figure 1): 180nm of InxGa1-xN:Si, 10nm of unintentionally doped GaN, a multiple quantum well (MQW), 120nm of magnesium-doped In0.04Ga0.96N:Mg, and 16nm of heavily doped p++ n0.04Ga0.96N:Mg. The x-parameter for the 180nm InGaN layer was either 4% or 9% In.
Figure 1: Cross-sectional schematic of regrown green micro-LED structure (a) and (b) post-fabrication.

The MQW consisted of three 3nm nominal In0.2Ga0.8N wells capped with 2nm of aluminium gallium nitride (Al0.1Ga0.9N), and 10nm of UID GaN. The p-type Mg-doped layers were grown on the last well of the sequence.

The LED structure was fabricated with reactive ion etch isolation of the structure, followed by plasma-enhanced chemical vapor deposition (PECVD) of silicon dioxide insulation. Contacts were formed using wet etch and deposition of nickel/gold p-contacts and titanium/gold n-contacts. The researchers point out that the LED fabrication was “basic”, and that many enhancements could improve light output performance.

The team first looked at the mean wavelength of the electroluminescence (EL) from 4μmx4μm-area LEDs on tiles of various dimensions with a base InGaN layer of 4% indium content (Figure 2). As the tiles became smaller, the wavelength red-shifted: with 10A/cm2 injection current density the wavelength for 20μmx20μm tiles was 525nm, while 8μmx8μm-tile μLEDs produced 561nm radiation. The researchers estimated the indium content to be 0.22 and 0.245, respectively. A μLED on the non-porous region of the die emitted at an even shorter wavelength of 497nm, giving an estimated indium content of 0.2, the target value for the growth process.

The researchers explain: “The higher degree of relaxation in the n-InGaN layer on smaller tiles resulted in a higher n-InGaN in-plane lattice constant and led to an increased indium uptake during the growth of the InGaN MQW active region of the LEDs due to the composition pulling effect, resulting in the red-shift of the EL peak.”

The turn-on voltages were in the range 3-3.5V for reasons that are not yet well understood. One would hope that longer-wavelength devices would have a lower turn-on voltage, reflecting the narrower bandgap. Lower turn-on voltages are an important factor in power efficiency.

The emission wavelengths were largely independent of the size of the μ LED mesa, showing no clear trends. The researchers believe this indicates uniform indium incorporation across the tiles.

The external quantum efficiency (EQE) of the devices was less than 0.44% at 100A/cm2, with the largest values being from the largest μLEDs on the 20μm tiles. The light was only measured on the sapphire side of the device.
within an approximate 60° half-angle exit cone. “This geometry was preferred over the measurement of packaged devices in an integrating sphere as it more accurately imitated how micro-LEDs are used in displays,” the team writes.

Figure 2: Current–voltage characteristics of (a) 4μm x 4μm mesa μLEDs fabricated on various-sized tiles and on unpatterned non-porous material, and (b) for various-sized mesa /microLEDs fabricated on 20μm tiles. (c) Mean EL wavelength dependent on current density, for 4μm x 4μm mesa μLEDs fabricated on various-sized tiles and on unpatterned non-porous region. (d) Mean EL wavelength dependent on device dimensions fabricated on various-sized tiles at 10A/cm² injection. (e) EL images of 7μm x 7μm μLED on 20μm tile at varied current injection.
The better efficiency of the larger μLEDs suggests losses from the perimeter of the active area through surface recombination effects. The team comments: “Etched surfaces are known to possess crystallographic defects, impurities, nitrogen vacancies, and dangling bonds that can introduce trap states within the bandgap, which can act as non-radiative recombination centers.”

Another effect was a blue-shift with increasing current, particularly in devices on the smaller tiles. The researchers comment: “As the indium incorporation in the InGaN wells of the MQW active region increased with decreasing tile size, the barriers of the MQWs were still composed of AlGaN and GaN, giving rise to higher piezo-electric fields in the LED active region and, hence, a higher quantum-confined Stark effect (QCSE). This blue-shift can be lowered by using InGaN as barrier material in the MQWs.”

Using a 9% indium-content 180nm InGaN base layer reduced the turn-on voltage to around 2V at the cost of up to three orders of magnitude increased reverse-bias leakage. The EL wavelength was 616nm, ‘orange’, at 60A/cm2, while the EQE was around 0.001% at 100A/cm2. The estimated indium content in the wells was 0.3. A comparison device with a 4%-indium base layer had an emission wavelength of 536nm at 60A/cm2.

The team reports: “Compared to the green-emitting μLEDs, as the indium composition increased in the n-InxGa1-xN base layer as well as the quantum well for the orange-emitting μLED, enhanced v-defect formation led to the introduction of a lot of leakage pathways. This led to an enhanced leakage current in the orange μLED.”

Although the EQE of the orange-emitting device was pitifully low, the researchers believe it “demonstrates the potential of this technology for the fabrication of strain-relaxed color-tunable μLEDs.”

**UCSB Expands Patent Enforcement Campaign to Protect Its Filament LED Patents**

**LEDInside**

Nixon Peabody announced a major expansion of its groundbreaking patent enforcement campaign on behalf of the Regents of UCSB with new litigation against six leading retailers and suppliers of filament LED lighting products.

Building on a successful first phase of the campaign, which was launched in 2019, Nixon Peabody filed a new complaint with the U.S. International Trade Commission (ITC) seeking an investigation into the unauthorized importation and sale after importation of UC’s patented filament LED lighting technology by General Electric, Savant Systems, Feit Electric, Home Depot, Ikea, and Satco Products.

The goal of the campaign is to license UC’s patents covering the reinvention of the light bulb at UC Santa Barbara and to protect UC’s licensees from unlicensed competition. In the year since the campaign was launched, many retailers and suppliers including LEDVANCE, Luminance, Bed Bath & Beyond and more have licensed UC’s patented technology and are now authorized to import and sell filament LED lighting products.
ALLOS’ GaN-on-Si Wafer to Connect Semiconductor Technology and Micro LED Display Production

ALLOS, the Germany-based GaN-on-Si expert, believes that their advanced GaN-on-Si epitaxy wafer technology is the decisive contributor to overcome the yield issue which currently prohibits Micro LED volume production.

Dr. Atsushi Nishikawa, CTO of ALLOS, shared the technology of ALLOS and explained how the GaN-on-Si wafer can overturn the current Micro LED production process and pave the way for new ecosystem in the industry.

GaN-on-Si Wafer Breaks Limitations of Micro LED Production

ALLOS advocates a new approach for Micro LED display production by creating GaN-on-Si wafer, choosing a different way comparing to the mainstream sapphire-based LED wafer. Dr. Nishikawa explained how GaN-on-Si wafer can be the solution to today's problems for Micro LED display production.

“Using silicon instead of sapphire will significantly improve production yield and reduce cost,” explained Dr. Nishikawa. He pointed out three advantages of silicon-based wafer for Micro LED display production.

First of all, by adopting silicon-based wafer, involved manufacturers can easily collaborate with silicon foundry to process tiny Micro LED chips with existing semiconductor facilities which offer advanced accuracy. Also, in the case of monolithically integrated micro displays for e.g. AR application, silicon-based LED wafers with bigger diameter can bond directly with CMOS backplane without extra transferring process. Moreover, once the bonding is done, the technology for removing silicon substrate is much more mature comparing to sapphire substrate removal, so that chip makers do not have to bother with the issues of weakening structure or laser lift-off that might impact chip efficiency and yield.

In a nutshell, by utilizing silicon-based LED wafer and semiconductor equipment, most of the current challenges for Micro LED display production - covering mass transferring, mass inspection and driver IC integration - can be addressed significantly better by having chips with much higher yield available.

However, such approach of directly bonding big size wafer and driver backplane does require a much better wafer uniformity, which is the core of ALLOS’ technology.
ALLOS Realizes Reproducibility of 200 mm GaN-on-Si Wafer with High Uniformity

“ALLOS has achieved mass production requirement with 200 mm GaN-on-Si wafer,” highlighted Dr. Nishikawa. He stressed that ALLOS has proved excellent reproducibility for creating 200 mm GaN-on-Si wafer with standard deviation of wavelength uniformity below 1 nm.

Dr. Nishikawa explained the challenges to produce GaN-on-Si LED wafer with large diameter. He noted that the emission wavelength is very sensitive to the growth temperature during multi-quantum wells (MQWs). Even if the temperature changes only slightly during the process, wavelength of wafer will be affected. This is also a challenge for the uniformity of the temperature which is affecting the uniformity of wavelength. What’s more, the wafer also changes its shape during the cooling process and can easily crack. In order to compensate the shape changes during the cooling down, a properly designed amount of strain needs to be induced to the wafer during the process.

Therefore, ALLOS deploys its strain engineering technology to carefully manage the temperature over the entire wafer while designing the perfect curvature for the wafer so that it will be flat and with outstanding uniformity after cooling down.

ALLOS is already able to manufacture 200 mm wafer with a uniformity of below 0.6 nm and without a single crack and is working on further improvements. The company has demonstrated the capability of the technology for mass production with reproducibility of < 1 nm. Currently, ALLOS is working demonstrating similar results on its already existing 300 mm wafer technology.
Meanwhile, ALLOS is working with KAUST to jointly develop InGaN red Micro LED with GaN-on-Si wafer. The KAUST team announced their achievement in building InGaN red Micro LED with better efficiency earlier this year. The two parties will collaborate to apply the approach to silicon-based wafer to speed up low cost full color Micro LED display production.

**GaN-on-Si Wafer Leads to Low Cost Micro LED Display Production with Semiconductor Technology Integration**

Speaking of the outlook of Micro LED technology, Dr. Nishikawa emphasized, “Adopting larger wafer and deploying semiconductor equipment will be the key for Micro LED display technology commercialization.”

ALLOS unveiled its capability to achieve crack-free 200 mm wafer with high uniformity that meets the mass production standard and is already adopting it to 300 mm wafer production. Dr. Nishikawa concluded that bigger wafer will lead to lower cost per area and enables the usage of CMOS facilities with enhanced yield and lower cost for mass production, outpacing conventional LED production line.

In fact, utilizing semiconductor facility for Micro LED display manufacture process is a rising trend in the industry with players joining the game. The recently reported Micro LED displays developed by Sharp, for example, were manufactured by semiconductor facilities with technology provided by the Foxconn Group. TrendForce analyst Roger Chu has pointed out before that Apple could be using semiconductor facilities of TSMC to develop new Micro LED processing technology.

Silicon-based, large-diameter wafer technology – like the one of ALLOS – will facilitate the integration of Micro LED and semiconductor technology, offering alternative solutions for innovative Micro LED applications. At the moment, ALLOS is strengthening its partnership with the Micro LED supply chain, aiming to expand the deployment of silicon-based wafer in the industry to enable low cost and high yield Micro LED display manufacture.
LG Officially Launches Micro LED Display Targeting the Commercial Market

LEDinside

LG officially launched its Micro LED signage solution, named “LG MAGNIT,” on September 10, which is the first Micro LED display product debuted by the company. LG is releasing the Micro LED display to the markets of the Americas, Europe, Asia and the Middle East.

LG has already included the Micro LED category including a few product details to its Business Solution webpage earlier this year as LEDinside covered in July. With the official launch, LG further updated several features of its Micro LED display.

LG MAGNIT deploys COB technology with a pixel pitch of 0.9mm. LG also applies its new Black Coating technology to the front of the displays to improve contrast and color accuracy while helping to protect the tiny LED pixels as well as minimize reflections.

This signage is consisted of the units of Micro LED cabinet measures 600x337.5x44.9 mm. LG’s block-assembly design allows power to be sent to each cabinet via pin connectors located on the edges of the LED cabinet hub. And LG MAGNIT cuts the time needed for cable management, with only a few wires on the back of the displays to link the cabinets to system controllers and power mains.

Paik Ki-mun, senior vice president and head of the Information Display business unit of LG Electronics Business Solutions Company, commented, “With its combination of superior picture quality, expandability and convenient setup, LG MAGNIT is a great Micro LED signage solution for a wide variety of commercial and public spaces, including convention centers, corporate and hotel lobbies, luxury boutiques, broadcast studios, control rooms, exhibition halls and museums.”

UV LED sources demand calibration to precise measurements for safe operation

LEDs Magazine

Ultraviolet (UV) radiation covers a wide wavelength range between 100 and 400 nm and is divided into three main areas, according to ISO standard 21348 — UV-A, UV-B, and UV-C. Typical applications in the UV-A range between 315 and 400 nm are UV curing or UV ink printing. Light sources in the UV-B range between 280 and 315 nm are mainly used in medical skin treatment as phototherapies. The UV-C range between 100 and 280 nm can be applied in air and water disinfection, which is currently very relevant in the fight against pathogens such as the novel coronavirus SARS-CoV-2.

The lighting industry has seen increased demand for UV-C radiation sources since the COVID-19 pandemic originated. UV-C radiation between 255 and 265 nm has been studied as a highly efficient method of inactivating the DNA or RNA of microorganisms, e.g. coronavirus, and prevents their replication and ability to actively infect other cells. Investigational studies are ongoing, but some organizations have released promising data recently.

Due to their specific areas of application, all UV radiation sources should be characterized very precisely with regard to their radiant flux and spectral distribution. This requires particularly sensitive and reliable UV measuring equipment consisting of high-precision spectroradiometers with stray light correction, polytetrafluoroethylene
(PTFE)-coated integrating spheres, and calibration standards for the UV wavelength ranges A/B/C. The most important function of UV LED calibration standards is the monitoring and characterization of UV integrating spheres for radiant flux. Thus far, established standards organizations such as Physikalisch-Technische Bundesanstalt (PTB; the national metrology institute of Germany) and the National Institute of Standards and Technology (NIST) have not offered such a reference standard for the UV-B and UV-C spectral regions.

As a result, Instrument Systems has undertaken studies to develop its own UV calibration standards, namely the Advanced Calibration Standards ACS-570-UV series (Fig. 1). These are temperature-stabilized UV-LED calibration standards that have a radiant flux calibration in the UV A/B/C range traceable to the national metrology institute. The traceability of the UV-ACS to the radiant flux has been achieved by precise calibration of the spectrometer coupling optics to the irradiance and by means of integrative measurement with a goniophotometer.

Read more

### Aledia benefits from strong patent portfolio in GaN-on-Si nanowire LEDs

Aledia S.A. was spun off from Grenoble-based micro/nanotechnology R&D center CEA-Leti in 2011 to develop a disruptive 3D LED technology based on the standard 200mm silicon platform, which would shrink the cost per chip in comparison with the conventional 2D LED technology.

Now, to address a market estimated to be worth about $120m related to displays for computers, tablets, smartphones and augmented reality (AR) glasses, earlier this year the startup announced plans to build a first manufacturing facility in the Grenoble area. Aledia plans to enter mass production of micro-displays by 2022.

Jointly with Cea-Leti, Aledia has developed the fabrication of 3D LEDs based on GaN nanowires grown on large-area silicon substrates, leading to the filing of more than 100 patent families (single inventions filed in multiple countries) since 2012, grouping more than 440 patents and pending patent applications worldwide. “Interestingly, more than 180 patent applications have already been granted, putting the emphasis on Europe (90+ patents) and the USA (50+ patents), although a significant number of patents were also granted in Asia (China: 19, Japan: 10, South Korea: 4 and Taiwan: 4),” notes Remi Comyn PhD, technology & patent analyst Compound Semiconductors and Electronics at IP strategy consulting company Knowmade. “Importantly, 29 patent families have not got a granted member yet; mostly inventions filed in the last three years and related to display applications (21),” he adds.

As of September, Aledia owns 58 patent families focused on nanowire LEDs (Figure 1a). The startup first considered residential lighting and automotive lighting as the most promising markets for its technology, explaining the presence of companies such as Ikea and Valeo among its investors. However, it eventually decided to target display applications, which translated into more than 40 additional patent families related to displays in Aledia’s portfolio, with more than 30 patent applications filed in the last three years. In the nanowire LED patent landscape, several players such as Samsung and glō are following a similar trend. As a result, patenting activity related to nanowire-based micro-displays took off in 2016/2017 and is expected to accelerate in 2020/2021 as more players race towards micro-LED commercialization (Figure 1 bottom).

Another component of Aledia’s strategic move towards display applications is that Intel joined the rank of investors in 2018. At the same time, the US company was identified by Knowmade as a new entrant in the nanowire LED patent landscape, with a relatively similar approach to Aledia and a strong focus on micro-LED displays (Figure 1 top). “Intel is developing manufacturing approaches for micro-LED structures and displays based on the assembly of nanowires, including GaN nanowires, on silicon substrates,” says Comyn. Indeed, Knowmade
has identified 19 inventions from Intel in the nanowire LED patent landscape, mostly filed in the USA. As of September, 5 US patents have already been granted to Intel.

In 2020, Knowmade investigated the GaN-on-silicon patent landscape, in which Aledia owns 30 patent families. “Aledia’s inventions included in the GaN-on-silicon patent landscape are mainly related to the growth of the nanowire emitters in large quantities with a high degree of precision and control,” says Comyn. Additional inventions concern the fabrication of electrical contacts on GaN nanostructures (US9991342, US10340138), and device manufacturing issues (e.g. dry etching US20190172970), the removal of defective nanowires (US9299882), the monolithic integration of LEDs with devices such as transistors to control the nanowire LEDs (US10050080) or to detect the LED temperature (US20160197064). In addition, more and more display-related inventions have been identified in GaN-on-silicon lately (e.g. US10734442).

Furthermore, Aledia can rely on additional patents from its R&D partner Cea-Leti, which is well established in nanowire LEDs and GaN-on-Si for optoelectronics. The institute owns 50 patent families related to nanowire LEDs with more than 170 patents granted in the US (40+), Europe (30+), China (15) and Japan (15). Interestingly, at least five inventions focus on displays (e.g. US8890111). Also, 19 belong to the GaN-on-Si for optoelectronics patent landscape, where Cea is a well-established player (30+ inventions).

Figure: (top) Aledia’s main competitors in the nanowire LED patent landscape. (bottom) Timeline of publications in the Nanowire LED patent landscape.
Overall, between its own patents and IP agreements with partners, Aledia benefits from a strong patent portfolio of more than 170 patent families to protect the features of its technology in view of commercialization.

In conclusion, major endeavors in R&D over the last three years to improve the nanowire LED technology for displays, together with its global IP strategy, have put Aledia in a good position to face the tough competition in an emerging micro-LED display market, reckons Knowmade.

**Power Integrations launches GaN-powered LED driver for compact smart lighting**

Power Integrations of San Jose, CA, USA, which provides high-voltage integrated circuits for energy-efficient power conversion, has announced a new member of its LYTSwitch-6 family of safety-isolated LED driver ICs for smart-lighting applications.

The LY6078C uses the firm’s PowiGaN gallium nitride (GaN) technology to deliver efficiency and performance benefits, demonstrated by the new design’s example report (DER-920).

The PowiGaN-based LY6078C IC incorporates a 750V power switch and delivers flicker-free output up to 90W (with other members of the family providing up to 110W). Including both the power factor correction (PFC) stage and the LYTSwitch-6 LED driver, system efficiency exceeds 90%. Housed in the miniature InSOP-24 surface-mount package, LYTSwitch-6 ICs are protected by a thermal fold-back system, which reduces output power to limit device temperature during abnormal conditions, while still providing light output. LYTSwitch-6 ICs also incorporate Power Integrations’ FluxLink communication technology, which allows secondary-side control without the need for an optocoupler, and provides better than ±3% CV and CC regulation across line, load, temperature and manufacturing. All LYTSwitch-6 ICs exhibit fast transient response and support pulse-width-modulation (PWM) dimming.

The performance benefits of the LY6078C are evident in a new design report (DER-920) detailing a two-stage PFC boost plus isolated flyback on a dimmable LED ballast. It employs the LYTSwitch-6 LY6078C IC and Power Integrations’ HiperPFS-4 PFS7624C PFC controller and provides peak efficiency of greater than 91% when driving a 48V LED string at 1350mA from a 220VAC to 277VAC input. In standby mode, system power consumption is less than 80mW, which provides substantial flexibility when designing lighting controls and particularly dim-to-off circuits.

“Power Integrations’ new PowiGaN-based LYTSwitch-6 ICs save lighting manufacturers space and system costs for smart-lighting power supplies,” says Hubie Notohamiprodjo, director of product marketing for LED lighting. “The company’s key design goals for our latest design report were high power factor, low harmonic content, high efficiency, and 3-in-1 dimming with zero-to-100% output current. The new LY6078C driver IC, combined with our HiperPFS-4 PFC controller, easily met these challenges,” he adds.

PowiGaN-based LYTSwitch-6 LED-driver ICs are available now, priced at $2.52 in 10,000 quantities.
Toyota Gosei develops DUV LED water purification module

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has developed deep-ultraviolet (DUV) LED light modules for use in eliminating viruses and bacteria (replacing mercury lamps, for which there are environmental concerns).

As the first mass-produced application, deep UV LED water purification units are being used on water recirculating WOSH portable washstands, which will be sold by WOTA Corp from November.

Founded in 2014 as a startup from Tokyo University, WOTA aims to create decentralized, autonomous water recirculation systems in society. Its business centers on R&D and the supply of next-generation independent water infrastructure.

WOSH portable washstands purify and reuse water many times, and so can be used outdoors, at store entrances and other places where the water supply is limited. In addition to regular filter and chlorine purification, the washstands use deep UV irradiation to achieve a higher level of purification.

The partnership between Toyoda Gosei and WOTA has been deepened in September by Toyoda Gosei’s purchase of convertible bonds from WOTA, the most recent of its corporate venture capital investments.

Picosun’s ALD boosts UVC LED reliability and lifetime

Picosun Group of Espoo, Finland says that its atomic layer deposition (ALD) thin-film coating equipment has been used to deposit passivation and barrier films in UVC (ultraviolet-C) LEDs that have achieved excellent reliability and lifetime improvements at customer and collaboration partner Taiwan’s National Chiao Tung University (NCTU).

Specifically, an UVC LED with 50nm ALD Al2O3 passivation and normal LED packaging (no hermetic seal) maintained 80% of its original efficiency even after 500 hours environmental test at 85% humidity and 85oC temperature.

ALD passivation layers could potentially replace the expensive hermetically sealed package of the LEDs and thus lower the costs of the final device.

To reach maximum light output and long operating lifetime, LED chips require surface passivation to eliminate parasitic currents caused by traps and defects. Also, barrier coating is typically needed, as LED materials are sensitive to moisture. ALD is a suitable technique for manufacturing both the passivation and barrier films and, when LED size diminishes to micron dimensions, the only coating method capable of producing sufficiently high-quality films on the required minuscule scale. Ultra-thin, pinhole-free ALD films do not suppress the LED light intensity and they provide reliable protection against ambient conditions, whereas their superior conformality ensures no thickness variations between the facets of the LED chip. Thickness variations (a typical side effect of other coating methods) can potentially lead to uneven distribution of film stress or thermal expansion behavior and risk physical damage of the chip.

“We have used Picosun’s ALD technology already for years with great success,” comments NCTU professor Hao-Chung Kuo. “Our Picosun ALD equipment yields superior quality films, which has helped us to achieve several breakthroughs in our LED research,” he adds. “Picosun has a local presence in Taiwan and we appreciate the
prompt response of their customer support if we ever have any issues. At the phase when R&D results are to be ramped up to industrial-level production, the scalability of Picosun’s ALD technology is a huge benefit.”

Short-wavelength UVC radiation destroys bacteria and viruses, so UVC LED technology is particularly topical now during the ongoing COVID-19 pandemic. Small, lightweight LEDs enable versatile design of portable, compact disinfecting equipment, they consume less power than other UVC sources, they are durable, and they pose no risk of hazardous material leaks such as mercury lamps, for example.

**Sharp to Launch New Display Spinoff for Strengthening Micro LED Technology**

*LEDInside*

Sharp is going to spin off its display business, setting up a new subsidiary named “Sharp Display Technology” (SDTC) on October 1, 2020, reported The Sankei News. The new spinoff will focus on novel display technology particularly Micro LED.

By establishing SDTC, Sharp plan to collect more external funds for Micro LED development, which will support the company to join the competition of next-gen display technology that currently ruled by Sony, Samsung and other competitors. It was revealed in August that Sharp has built Micro LED panels that are less than 1 inch for AR/VR smart glasses.

Headquarter of the new company SDTC will locate in Sharp’s Kamayama Office with Taimi Oketani appointed as chairman. The Foxconn Group will also appoint two managing directors.

Sharp is likely to utilize its newly acquired Hakusan Plant from JDI for Micro LED technology development.
More than 250 new patent families related to GaN technology were published in September 2020.

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

PCT applications (WO)

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

**Nitride semiconductor element**

**Publications Numbers:** [US20200287354](#), [CN111668697], [JP2020150252]

**Patent Applicant:** Asahi Kasei

A nitride semiconductor element is provided with a nitride semiconductor active layer made of Al$_x$Ga$_{1-x}$N and a composition change layer made above the nitride semiconductor active layer and made of Al$_x$3Ga$_{1-x}3$N in which an Al composition ratio x3 decreases in a direction away from the nitride semiconductor active layer. The composition change layer has a first composition change region having a thickness larger than 0 nm and smaller than 400 nm and a second composition change region which is a region further away from the nitride semiconductor active layer than the first composition change region and in which the change rate of the Al composition ratio x3 in the thickness direction of the film thickness of the composition change layer is higher than that of the first composition change region, in which, in the first composition change region, the Al composition ratio continuously changes in the thickness direction of the film thickness.

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**Ultra low parasitic inductance integrated cascode gan devices**

**Publications Numbers:** [US20200295045]

**Patent Applicant:** IBM

A four-terminal GaN transistor and methods of manufacture, the transistor having source and drain regions and preferably two T-shaped gate electrodes, wherein a stem of one of the two T-shaped gate electrodes is more closely located to the source region than it is to a stem of the other one of the two T-shaped gate electrodes and wherein the stem of the other one of the two T-shaped gate electrodes is more closely located to the drain region than it is to the stem of said one of the two T-shaped gate electrodes. The gate closer to the source region is a T-gate, and the proximity of the two gates is less than 500 nm from each other. The spacing between the stem of the RF gate and source region and the stem of the DC gate and drain region are preferably defined by self-aligned fabrication techniques. The four-terminal GaN transistor is capable of operation in the W-band (75 to 100 GHz).
Power semiconductor device with a series connection of two devices
Publication Number: US20200287536
Patent Applicant: Cambridge Enterprise

A device includes a heterojunction device, a unipolar power transistor operatively connected in series with said heterojunction device; an external control terminal for driving said unipolar power transistor and said heterojunction device; and an interface unit having a plurality of interface terminals. A first interface terminal is operatively connected to an active gate region of the heterojunction device and a second interface terminal is operatively connected to said external control terminal. The heterojunction device includes a threshold voltage less than a threshold voltage of the unipolar power transistor, wherein the threshold voltage of the heterojunction device is less than a blocking voltage of the unipolar power transistor.

Wafer bonding for laser lift-off
Publication Number: US10790408
Patent Applicant: Facebook

A micro-light emitting diode (LED) is manufactured using a lift-off substrate that is removed using a laser-lift-off process. A method for manufacturing the LED may include forming an epitaxial structure of the LED on a growth substrate, and attaching an open side of the epitaxial structure with a gallium-based layer and a lift-off substrate, the gallium-based layer between the epitaxial structure and the lift-off substrate. The growth substrate is separated from the epitaxial structure, and the epitaxial structure may be processed into the LED. Light is applied to the gallium-based layer through the lift-off substrate to debond the second portion of the gallium-based layer and the lift-off substrate. The lift-off substrate is separated from the second portion of the gallium-based layer to expose a light emitting surface of the LED on the second portion of the gallium-based layer.

Heterostructure and light-emitting device employing the same
Publication Number: US20200287079
Patent Applicant: Bolb

Heterostructures containing one or more sheets of positive charge, or alternately stacked AlGaN barriers and AlGaN wells with specified thickness are provided. Also provided are multiple quantum well structures and p-type contacts. The heterostructures, the multiple quantum well structures and the p-type contacts can be used in light emitting devices and photodetectors.
Micro-LED structures with improved internal quantum efficiency

Publication Number: US20200303586
Patent Applicant: Intel

A micro-light emitting diode (LED) pixel element and a method of fabricating the same. The pixel element includes a mask layer and a N-type core partially in an opening of the mask layer; a quantum well structure on the N-type core including at least one quantum well, each quantum well including an active layer, and at least two barrier layers including a first barrier layer and a second barrier layer, and a P-cladding layer on the quantum well structure. The active layer includes at least one of AlInN, InGaN, InGaNY or InGaNSc. The at least two barrier layers include: GaScN, wherein the active layer is in contact with and between the first barrier layer and the second barrier layer; or a GaN-based material, wherein the first barrier layer includes GaN, and is in contact with a surface of the active layer facing away from the N-type core, and the second barrier layer is a cap layer that includes at least one of AlGaN or ScGaN, and is in contact with a surface of the first barrier layer facing away from the N-type core. The cap layer is grown using pulse metalorganic chemical vapor deposition at a temperature below 600 degrees C.

Vertical superlattice transistors

Publication Number: US20200303536
Patent Applicant: Northrop Grumman Systems

A vertical transistor is provided that includes a base structure and a superlattice structure overlying the base structure. The superlattice structure comprises a multichannel ridge having sidewalls. The multichannel ridge comprises a plurality of heterostructures that each form a channel of the multichannel ridge. The vertical transistor also includes a source region that overlies the base structure and is in contact with a first end of the superlattice structure, a floating drain that overlies the base structure and is in contact with a second end of the superlattice structure, and a drain. When the vertical transistor is in an ‘ON’ state, current flows from the source region through the channels of the multichannel ridge to the floating drain, which funnels the current to the drain through at least a portion of the base structure.

Nitride semiconductor device

Publication Number: WO2020/188846
Patent Applicant: Panasonic

A field effect transistor 100 includes a substrate 101 that comprises gallium nitride having conductivity, a buffer layer 102 that is provided on the substrate 101 and comprises C-doped GaN, a drift layer 103 that is provided on the buffer layer 102 and comprises undoped GaN, and a channel layer 104 that is provided on the drift layer 103, comprises undoped AlGaN, and forms a heterojunction with the drift layer 103. A gate electrode 106 is provided on the channel layer 104, and a source electrode 108 and a drain electrode 109 are respectively provided in regions on both sides of the gate electrode 106 on the channel layer 104.
Gallium nitride (GaN) based transistor with multiple p-GaN blocks

Publication Number: US20200287033, WO2020/180913
Patent Applicant: Texas Instruments

In some examples, a gallium nitride (GaN)-based transistor, comprises a substrate (163); a GaN layer (143) supported by the substrate; an aluminum nitride gallium (AlGaN) layer (130) supported by the GaN layer; a p-doped GaN structure (128) supported by the AlGaN layer; and multiple p-doped GaN blocks (124) supported by the AlGaN layer, each of the multiple p-doped GaN blocks physically separated from the remaining multiple p-doped GaN blocks, wherein first and second contours (144) of a two-dimensional electron gas (2DEG) of the GaN-based transistor are at an interface of the AlGaN and GaN layers.

Semiconductor device and method for manufacturing same

Publication Number: JP2020150141, US20200295169, CN111697053
Patent Applicant: Toshiba

According to one embodiment, a semiconductor device includes first to third electrodes, first to third nitride regions, and first and second insulating films. The first nitride region includes AlxGa1-x1N, and includes first and second partial regions, a third partial region between the first and second partial regions, a fourth partial region between the first and third partial regions, and a fifth partial region between the third and second partial regions. The first nitride region includes first to fifth partial regions. The second nitride region includes Alx2Ga1-x2N, and sixth and seventh partial regions. At least a portion of the third electrode is between the sixth and seventh partial regions. The first insulating film includes silicon and oxygen and includes first and second insulating regions. The third nitride region includes Alx3Ga1-x3N, and first to seventh portions. The second insulating film includes silicon and oxygen and includes third to seventh insulating regions.

III-N transistors with local stressors for threshold voltage control

Publication Number: US20200295172, DE102020102940
Patent Applicant: Intel

Disclosed herein are IC structures, packages, and device assemblies with III-N transistors that include additional materials, referred to herein as “stressor materials,” which may be selectively provided over portions of polarization materials to locally increase or decrease the strain in the polarization material. Providing a compressive stressor material may decrease the tensile stress imposed by the polarization material on the underlying portion of the III-N semiconductor material, thereby decreasing the two-dimensional electron gas (2DEG) and increasing a threshold voltage of a transistor. On the other hand, providing a tensile stressor material may increase the tensile stress imposed by the polarization material, thereby increasing the 2DEG and decreasing the threshold voltage. Providing suitable stressor materials enables easier and more accurate control of threshold voltage compared to only relying on polarization material recess.
Semiconductor device and production method

Patent Applicant: Toyoda Gosei

The present invention provides a Group III nitride semiconductor device in which current concentration at the corners of the trench is suppressed. The semiconductor device has a pattern in which regular hexagonal unit cells are arranged in a honeycomb pattern. The semiconductor layer is sectionalized into regular hexagonal patterns by the trench. The recess has a small regular hexagonal pattern contained in the regular hexagonal pattern of the semiconductor layer sectionalized by the trench, which is obtained by reducing the regular hexagon of the semiconductor layer with the same center. Moreover, the regular hexagonal pattern of the recess is rotated by 30° with respect to the regular hexagon of the semiconductor layer. The Mg activation ratio is lower in the vicinity of corners of the trench than that in other regions in the vicinity of side walls of the trench of the p-type layer.

Optoelectronic semiconductor structure comprising a p-type injection layer based on InGaN

Publication Number: FR3093862, WO2020/182457
Patent Applicant: Soitec

The invention relates to an optoelectronic semiconductor structure (SC) comprising an InGaN-based active layer (5) disposed between an n-type injection layer (6) and a p-type injection layer (7), the p-type injection (7) layer comprising a first InGaN layer (7a) presenting a thickness comprised between 50 and 350 nm and, disposed on the first layer (7a), a second layer (7b) having a GaN surface portion.

Integrated design for III-nitride devices

Publication Number: WO2020/191357
Patent Applicant: Transphorm

A semiconductor device comprises a III-N device and a Field Effect Transistor (FET). The III-N device comprises a substrate on a first side of a III-N material structure, a first gate, a first source, and a first drain on a side of the III-N material structure opposite the substrate. The FET comprises a second semiconductor material structure, a second gate, a second source, and a second drain, and the second source being on an opposite side of the second semiconductor material structure from the second drain. The second drain of the FET is directly contacting and electrically connected to the first source of the III-N devices, and a via-hole is formed through a portion of the III-N material structure exposing a portion of the top surface of the substrate and the first gate is electrically connected to the substrate through the via-hole.