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GaN Technology for Optoelectronics & Electronics

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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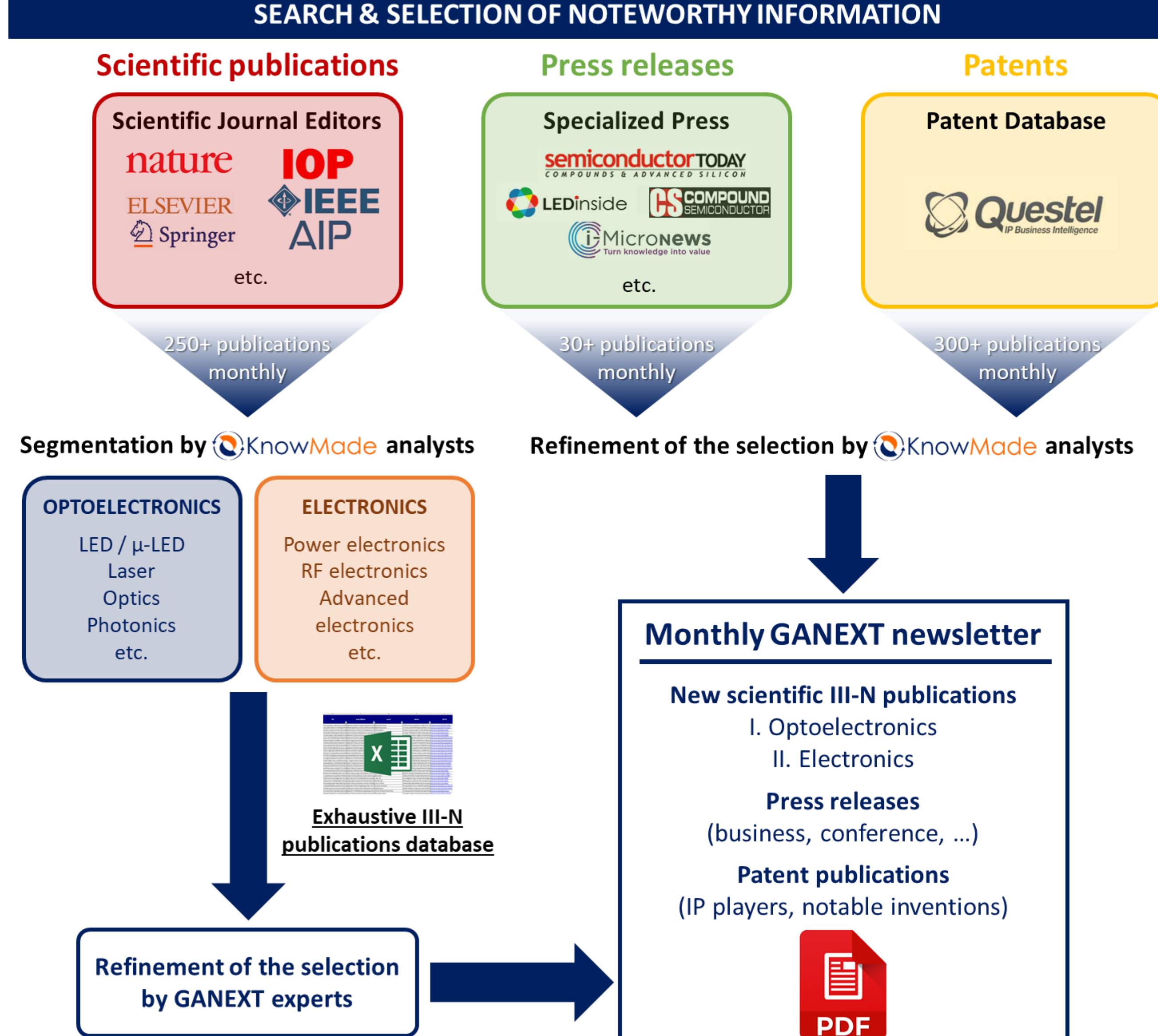
METHODOLOGY



SCIENTIFIC PUBLICATIONS

Selection of new scientific articles

OPTOELECTRONICS

Group leader: Bruno Gayral (CEA)

Information selected by Julien Brault (CNRS-CRHEA), Maria Tchernycheva (CNRS-C2N) and Thierry Guillet (CNRS-L2C)

A Compact Optical Pressure Sensor Based on a III-Nitride Photonic Chip with Nanosphere-Embedded PDMS

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Pressure sensing based on high-sensitivity and fast-response photonic devices is essential for various transient and dynamic processes in diverse fields. Therefore, a miniaturized device being capable of precise and reliable detection is highly desired for the development of optical pressure sensors. Here, we develop a compact pressure sensor, showing a sensitivity of 1 μA/kPa and a fast response time of <10 ms, based on a III-nitride photonic chip combined with a PDMS membrane on submillimeter-scale footprints. The emitter and detector are monolithically integrated on a GaN-on-sapphire chip consisting of InGaN/GaN multiquantum wells, enabling quantitative readout for pressure sensing. Self-assembled polystyrene nanospheres are embedded in the PDMS layer and function as an opal-based photonic crystal, transforming the received mechanical signals into optical signals which can be precisely determined through recorded photocurrent. This underlying mechanism of angle-dependent reflective characteristics via the photonic bandgap effect is well fitted by our theoretical simulation. Sensors with opal films embedded at different vertical positions are fabricated, and their corresponding performance is systematically studied and compared through a series of pressure loading/unloading tests. The demonstrated high repeatability, stability, and durability of the developed chip-scale optical pressure sensor, paving the way for its widespread usage.

The marvelous optical performance of AlGaN-based deep ultraviolet light-emitting diodes with AlInGaN-based last quantum barrier and step electron blocking layer

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Applied Physics A
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The optoelectronic characteristics of AlGaN-based deep ultraviolet light-emitting diodes (DUV LEDs) with quaternary last quantum barrier (QLQB) and step-graded electron blocking layer (EBL) are investigated numerically. The results show that the internal quantum efficiency (IQE) and radiative recombination rate are remarkably improved with AlInGaN step-graded EBL and QLQB as compared to conventional or ternary AlGaN EBL and last quantum barrier (LQB). This significant improvement is assigned to the optimal recombination of electron–hole pairs in the multiple quantum wells (MQWs). It is due to the decrease in strain and lattice mismatch between the epi-layers which alleviates the effective potential barrier height of the conduction band and suppressed the electron leakage without affecting the holes transportation to the active region. Moreover, to figure out quantitatively, the electron and hole quantity increased by ~ 25% and ~ 15%, respectively. Additionally, the IQE and radiative recombination rate are enhanced by 48% and 55%, respectively, as compared to conventional LED. So, we believe that our proposed structure is not only a feasible approach for achieving highly efficient DUV LEDs, but the device physics presented in this study establishes a fruitful understanding of III nitride-based optoelectronic devices.

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Measuring the surface temperature of light-emitting diodes by thermoreflectance

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Japanese Journal of Applied Physics
https://doi.org/10.35848/1347-4065/abf90c

As the latest applications of LEDs require more harsh operating conditions, understanding the device thermal properties becomes more essential for further improving the device efficiencies. In applications where heat dissipation can be a critical issue, thermoreflectance (TR) can be utilized as a useful noncontact measurement technique for analyzing the thermal properties. In this paper, we investigate the TR method of measuring the surface temperature, using a lateral-type blue LED chip under high-power operation. The TR we employ measures the change in reflectivity from the Au metal electrode. By comparing with surface/junction temperatures measured by other methods based on the thermocouple and the forward voltage, we find that the TR method can provide accurate and reliable results of measuring the surface temperature of modern LEDs. A useful insight can also be obtained from the temperature distribution on the LED chip surface.

Efficient Carrier Recombination in InGaN Pyramidal µ-LEDs Obtained through Selective Area Growth

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Photonics
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Pyramid-shaped InGaN/GaN micro-light-emitting diodes (µ-LEDs) were grown on a sapphire substrate using the selective area growth technique. A stable emission wavelength of a single µ-LED pyramid at 412 nm was observed under an injection current from 0.05 to 20 mA, despite the non-uniformity of the thickness and composition of the multiple quantum wells (MQWs) on the sidewall. An efficient carrier confinement and, thus, a high luminescence intensity were demonstrated in the middle of the sidewall through spatial-resolved cathodoluminescence (CL) characterization and were predicted by theoretical simulations. An ultra-high output power density of 1.37 kW/cm2 was obtained from the single µ-LED pyramid, illustrating its great potential for application in high-brightness micro-displays and in virtual reality and augmented reality (VR and AR) applications.

Monolithic Integration of Strained UV–Visible Dual Color Photodetectors on 4 in. Multilayer MoS2-on-Freestanding GaN Wafer by Direct van der Waals Growth

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MoS2/GaN van der Waals heterojunction is suitable for the multiband photodetection field due to the nearly lattice match and excellent response capabilities in ultraviolet and visible light regions. In this work, a multilayer MoS2/GaN van der Waals heterojunction was grown by the chemical vapor

deposition method and fabricated into an integrated ultraviolet–visible photodetector. Tensile strain was introduced on MoS2/GaN by depositing Al2O3 stress liner using atomic layer deposition. Owing to the tensile strain effect, excellent detection performances were demonstrated, including a responsivity as high as 1.4 × 105 A/W, a noise equivalent power of 5.63 × 10–21 W/Hz1/2, a normalized detectivity of 6.13 × 1021 jones for stress liner GaN photodetector under 280 nm illumination, and 453.3 A/W for stress liner MoS2 photodetector under 460 nm illumination. The shortened response time of the photodetector is attributed to the improved carrier mobility and the separation of MoS2 from air by Al2O3. This work has provided significant guidance for the development of integrated circuits and optical chips.

2D/3D Hybrid of MoS2/GaN for a High-Performance Broadband Photodetector

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Narrow spectral sensitivity in materials is one of the crucial challenges to develop high-performance broadband photodetectors. Here, we design a heterostructure of two-dimensional molybdenum disulfide (MoS2) and epitaxial gallium nitride (GaN) films to create an enhanced spectral absorption profile. This combination utilizes complementary optical absorption of MoS2 (visible) and GaN (UV) driven by type II band alignment at their interface to showcase highly sensitive photodetectors spanning across the UV–NIR regime. Concurrently, the heterostructure exhibits significantly enhanced responsivity (order of 104 A/W) and external quantum efficiency that are 500% higher than the bare GaN photodetectors. Given the available scalable synthesis approaches that have now been designed by the research community for both constituent materials, the demonstration of this heterostructure as a broadband photodetector with high figures-of-merit opens opportunities in designing efficient optoelectronic junctions and imaging applications.

Supercontinuum Generation in High Order Waveguide Mode with near-Visible Pumping Using Aluminum Nitride Waveguides

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ACS Photonics
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Optical sources emitting in the ultraviolet (UV) to near-infrared wavelength range are an enabling tools for a wide variety of applications. To achieve broadband coherent generation within visible and UV spectrum, one fundamental obstacle is the strong material dispersion which limits efficient frequency conversion. Previous works have addressed this challenge by either using high input energies or delicate resonant structures. In this work, a simple device system is proposed to tackle the problem. Single crystalline aluminum nitride material with a threading dislocation density less than 109 cm–2 was used to provide broadband transparency, and a high order waveguide mode (transverse electric, TE10) was used to create anomalous dispersion near 800 nm, in which soliton fission processes are supported. As a result, supercontinuum generation from 490 nm to over 1100 nm with a second harmonic generated band covering

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from 407 to 425 nm is achieved with the total on-chip pulse energy of 0.6 nJ.

Transverse Electric Lasing at a Record Short Wavelength 244.63 nm from GaN Quantum Wells with Weak Exciton Localization

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ACS Photonics
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We have demonstrated a record short wavelength lasing at 244.63 nm with TE dominant polarization from GaN quantum wells (QWs) at room temperature (RT). The optical threshold of 310 kW/cm2 is comparable to state-of-the-art AlGaN QW lasers at similar wavelengths. The sample was grown on the AlN/sapphire template pesudomorphically. X-ray diffraction (XRD) shows unambiguous higher-order satellite peaks indicating a sharp interface amid the active region. The excitonic localization was revealed and studied by the photoluminescence (PL) and time-resolved PL (TRPL) spectroscopy at temperatures ranging from 15 K to RT. At 15 K, the multiple-component PL decay curves with the decay time varying from 62.6 to 2.77 ns at different energies confirmed the localized excitons. The peak energy of the temperature-dependent PL spectra exhibited the "S-shape" behavior; and the weak exciton localization with a small localization energy of 14.3 meV was observed. Therefore, even in the low temperature region, the escape possibility of excitons increased as the temperature rose. As a result, the fwhm of the emission spectra changed significantly when the temperature was below 150 K. Above 150 K, the PL decay shape changed from the two-component exponential decay to the single exponential decay, indicating complete delocalization of excitons. The work demonstrates the weak localization and thus smooth interface in the GaN/AlN active region, which are desirable for DUV lasers operating at RT.

Study and Application of Birefringent Nanoporous GaN in the Polarization Control of Blue Vertical-Cavity Surface-Emitting Lasers

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ACS Photonics
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III-Nitride vertical-cavity surface-emitting lasers (VCSELs) have attracted much attention during the last two decades. Control of the laser polarization in VCSELs is one of the main challenges that needs to be addressed for real applications. In this work a novel polarization locking technique for GaN VCSELs is presented by employing birefringent nanoporous distributed Bragg reflectors (DBRs). The birefringence arises from a nanophotonic effect of evanescent field enhancement in the anisotropically aligned nanopores. Furthermore, the birefringence dependence over the nanopores morphology is explored. A fully electrically injected blue VCSEL with polarization locking is demonstrated. As presented, this technique allows to individually define the polarization angle in a planar array, opening the path to novel applications.

Origins of nanoscale emission inhomogeneities of high content red emitting InGaN/InGaN quantum wells

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Journal of Applied Physics
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The origin of the nanoscale emission inhomogeneities of red emitting InGaN/InGaN quantum wells (QWs) grown directly on a GaN template and on an InGaN on sapphire (InGaNOS) substrate is investigated. InGaNOS is a partly relaxed InGaN pseudo-substrate fabricated by Soitec. As the latter approach provides an interesting optical internal quantum efficiency of

6.5% at 624 nm at 290 K, a deeper study, at the microstructure level, was conducted. The emission inhomogeneities on InGaNOS were highlighted by cathodoluminescence wavelength mappings where three areas were chosen: one emitting at a shorter wavelength, i.e., 588 nm, and two at a longer wavelength, i.e., 607 and 611 nm. Specimens from these zones were extracted by focused ion beam milling to perform cross-sectional characterization techniques. High-angle annular dark field scanning transmission electron microscopy images demonstrated that, while red emitting areas present homogeneous QWs, shorter wavelength areas exhibit non-uniform QWs, in terms of thickness and In composition. Complementary deformation mappings in the growth direction obtained by geometrical phase analysis show that longer emission wavelengths are originating from homogeneous QWs with an InN mole fraction evaluated at 39.0 ± 1.5%. This result demonstrates the possibility of achieving red emission with a coherent (In,Ga)N alloy when using an adapted substrate. A comparison of identical QWs grown on a GaN template is also given.

Photoluminescence efficiency of zincblende InGaN/GaN quantum wells

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Journal of Applied Physics
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Growing green and amber emitting InGaN/GaN quantum wells in the zincblende, rather than the wurtzite, crystal phase has the potential to improve efficiency. However, optimization of the emission efficiency of these heterostructures is still required to compete with more conventional alternatives. Photoluminescence time decays were used to assess how the quantum well width and number of quantum wells affect the recombination rates, and temperature dependent photoluminescence was used to determine the factors affecting recombination efficiency. The radiative recombination lifetime was found to be approximately 600 ps and to increase weakly with well width, consistent with a change in the exciton binding energy. The relative efficiency at room temperature was found to increase by a factor of five when the number of wells was increased from one to five. Furthermore, the efficiency increased by factor 2.2 when the width was increased from 2.5 to 7.5 nm. These results indicate that thermionic emission is the most important process reducing efficiency at temperatures in excess of 100 K. Moreover, the weak dependence of the rate of radiative recombination on well width means that increasing well thickness is an effective way of suppressing thermionic emission and thereby increasing efficiency in zincblende InGaN/GaN quantum wells, in contrast to those grown in the wurtzite phase.

Rational construction of staggered InGaN quantum wells for efficient yellow light-emitting diodes

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Applied Physics Letters
https://doi.org/10.1063/5.0043240

High-efficiency InGaN-based yellow light-emitting diodes (LEDs) with high brightness are desirable for future high-resolution displays and lighting products. Here, we demonstrate efficient InGaN-based yellow (~570 nm) LEDs with optimized three-layer staggered quantum wells (QWs) that are grown on patterned sapphire substrates. Numerical simulations show that the electron–hole wavefunction overlap of staggered InGaN QWs with high In content exhibits a 1.7-fold improvement over that of square InGaN QWs. At the same injection current, LEDs with staggered QWs exhibit lower forward voltages and narrower full widths at half maximum than LEDs with square QWs. The light output power and external quantum efficiency of a staggered QW LED are 10.2 mW and 30.8%, respectively, at 15 mA. We combine atomic probe tomography (APT), time-resolved photoluminescence (TRPL), and transmission electron

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microscopy (TEM) with energy-dispersive x-ray (EDX) mapping spectroscopy to shed light on the origin of enhanced device performance. APT results confirm the staggered In profile of our designed staggered QWs structure, and TRPL results reveal decreased defect-state carrier trapping in staggered QWs. Furthermore, TEM with EDX mapping spectroscopy supports the viewpoint that staggered QWs exhibit uniform elemental distribution and improved crystal quality. Together, these factors above contribute to enhanced LED performance. Our study shows that staggered InGaN QWs provide a promising strategy for the development of LEDs that are efficient in the long-wavelength region.

Enhanced Heat Dissipation in Gallium Nitride-Based Light-Emitting Diodes by Piezo-phototronic Effect

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Nano Lett.
https://doi.org/10.1021/acs.nanolett.1c00999

As a new generation of light sources, GaN-based light-emitting diodes (LEDs) have wide applications in lighting and display. Heat dissipation in LEDs is a fundamental issue that leads to a decrease in light output, a shortened lifespan, and the risk of catastrophic failure. Here, the temperature spatial distribution of the LEDs is revealed by using high-resolution infrared thermography, and the piezo-phototronic effect is proved to restrain efficaciously the temperature increment for the first time. We observe the temperature field and current density distribution of the LED array under external strain compensation. Specifically, the temperature rise caused by the self-heating effect is reduced by 47.62% under 0.1% external strain, which is attributed to the enhanced competitiveness of radiative recombination against nonradiative recombination due to the piezo-phototronic effect. This work not only deepens the understanding of the piezo-phototronic effect in LEDs but also provides a novel, easy-to-implement, and economical method to effectively enhance thermal management.

Design and Simulation of Near-Terahertz GaN Photoconductive Switches–Operation in the Negative Differential Mobility Regime and Pulse Compression

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IEEE Journal of the Electron Devices Society
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The wide bandgap material, Gallium Nitride (GaN), has emerged as the dominant semiconductor material to implement high-electron mobility transistors (HEMTs) that form the basis of RF electronics. GaN is also an excellent material to realize photoconductive switches (PCSS) whose high-frequency performance could exceed that of RF HEMTs. In this paper, we numerically model the output characteristics of a GaN PCSS as a function of the input electrical and optical bias and the device dimensions. Importantly, we show that operating the GaN PCSS in the regime of negative differential mobility significantly benefits its high-frequency performance by compressing the temporal width of the output current pulse, while also enhancing its peak value. We find that when the optically excited carriers are generated in the middle of the active region, the bandwidth of the device is approximately 600 GHz, while delivering an output power exceeding 800 mW with a power gain greater than 35 dB. The output power increases to 1.5 W, and the power gain exceeds 40 dB with a near-terahertz bandwidth (≈ 800 GHz), as the laser source is moved closer to the anode. Finally, we elucidate that under high optical bias with significant electrostatic screening effects, the DC electric field across the device can be boosted to further enhance the performance of the GaN PCSS.

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A Highly Sensitive and Robust GaN Ultraviolet Photodetector Fabricated on 150-mm Si (111) Wafer

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2021.3073650

In this work, we demonstrate the potential of a gallium nitride (GaN)-based visible-blind ultraviolet (UV) photodetector (PD) on a commercially viable 150-mm Si wafer. The influence of thermionic field emission (TFE) and Poole-Frenkel (PF) mechanisms on the current transport of the PD has been analyzed. Conduction due to the TFE mechanism dominates in the moderate electric fields (1.25 kV/cm< E <10 kV/cm), while the influence of PF is prominent at higher electric fields. A bulk trap energy level of 0.374 eV is obtained with PF conduction analysis. A high responsivity of 33.3 A/W at 15 V with a 362-nm incident wavelength has been achieved in the presence of an internal gain. The internal gain of the PD is also assisted by TFE and PF mechanisms. The PD exhibits a low dark current of 4.7 nA as well as high detectivity of 4.6 x 10^{12} Jones at the abovementioned bias. The demonstrated robustness and high performance show the promise of III-nitride PDs for commercial applications.

Light-pulse splitting from nano-light-emitting diodes operating in noncarrier injection mode

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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2021.3077515

Noncarrier injection (NCI) mode is an emerging driving mode for nanoscale light-emitting diodes (LEDs). Here, we demonstrate that a single light pulse from NCI-LEDs can be split into multiple pulses with small pulse widths that cannot be obtained by using traditional driving technology. Light-pulse splitting is achieved by using a combined signal that is a superposition of a basic signal and a signal with small amplitude and high frequency. Theoretical equations regarding the conduction current and current-pulse splitting are provided to explain light-pulse splitting theoretically. Then, light-pulse splitting is experimentally proven with a capacitor–LED–capacitor construction that is used to simulate the luminescence in NCI mode physically. Finally, we demonstrate light-pulse splitting from nanorod GaN-LEDs and discuss the working mechanisms related to electron multiple-frequency oscillation. This work can deepen the understanding of the NCI mode and provides a potential approach for advanced light-pulse-based technology.

Transferable, flexible white light-emitting diodes of GaN p–n junction microcrystals fabricated by remote epitaxy

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Nano Energy
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The remote epitaxy of GaN p–n homojunction microcrystals (μCs) is demonstrated for fabricating transferable, flexible white light-emitting diodes (WLEDs). The GaN p–n junction μCs are randomly grown on graphene-coated Al2O3(0001), which are then delaminated for mass-transfer onto conducting copper tape. The μCs-LED shows electrical rectification and white electroluminescence (EL) emission. The μCs-WLED exhibits reliable LED performances after

repetitive bending deformations and cycling temperature environments. Based on the transferability, the μCs-WLEDs are patterned and assembled to matrix arrays, which exhibit homogeneous, reliable performances even at a bent form. We discuss that the origin of white EL emission is mixing of blue and yellow–red EL emissions from p-GaN and n-GaN sides, respectively, based on photoluminescence spectroscopic measurements. This study opens a way of fabricating the transferable, flexible, and modular light panels through remote epitaxy.

Achievement of 110-nm-Wide Spectral Width in Monolithic Tunnel-Junction Light-Emitting Diode

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IEEE Journal of Quantum Electronics
https://doi.org/10.1109/JQE.2021.3079419

Characterization and structural design on monolithic stacked InGaN light-emitting diode (LED) are investigated numerically in an attempt to pursue multicolor light emission and wide spectral width. Crucial physical properties such as the energy band configurations, carrier distributions, and interband transitions are analyzed in detail, which are also utilized as an aid to justify the desired characteristics of the LED structures under study. The compositions of multi-quantum wells, as well as the thicknesses of quantum barriers in each unit stacked LED are appropriately adjusted to simplify the tandem LED structure and optimize the overall emission spectra. Upon optimization, a monolithic tunnel-junction LED with an emission spectral width of approximately 110 nm, full width at half maximum, is demonstrated with only three unit stacked LEDs and two tunnel junctions.

Sandwiching electron blocking layer with p-AlInN layer to enhance hole injection in AlGaN-based deep ultraviolet light-emitting diodes

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Materials Research Bulletin
https://doi.org/10.1016/j.materresbull.2021.111389

This work reports the enhanced optoelectronic performance of AlGaN-based deep ultraviolet light-emitting diodes (DUV LEDs) by sandwiching p-EBL with thin p-AlInN layers. The simulated results show that the internal quantum efficiency (IQE) and radiative recombination rate are remarkably improved as compared to conventional AlGaN-based p-EBL. The primary cause of this enhancement is the reduction of lattice mismatch between the electron blocking layer (EBL) and p-AlGaN due to the insertion of thin p-AlInN layers, which ultimately decreases the polarization effect. Moreover, p-AlInN layers also improved the hole injection efficiency via intra-band tunneling while hindered the electron leakage to the p-type layer. Interestingly, the proposed structure not only increased the IQE but also suppressed the efficiency droop dramatically.

Reducing the polarization mismatch between the last quantum barrier and p-EBL to enhance the carrier injection for AlGaN-based DUV LEDs

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Optical Materials Express
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In this work, we report an AlGaN-based ~275 nm deep ultraviolet light-emitting diode (DUV LED) that has AlGaN based quantum barriers with a properly large Al composition. It is known that the increased conduction band barrier height helps to enhance the electron concentration in the active region. However, we find that the promoted hole injection efficiency is also enabled for the proposed DUV LED when the Al composition increases. This is attributed to the

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reduced positive polarization charge density at the last quantum barrier (LQB) and p-type electron blocking layer (p-EBL) interface, which can suppress the hole depletion effect in the p-EBL. Thus, the hole concentration in the p-EBL gets promoted, which is very helpful to reduce the hole blocking effect caused by the p-EBL. Therefore, thanks to the improved carrier injection, the proposed DUV LED increases the optical power and reduces the forward voltage when compared with the conventional DUV LED.

Characterization of dynamic distortion in LED light output for optical wireless communications

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Photonics Research
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Light-emitting diodes (LEDs) are widely used for data transmission in emerging optical wireless communications (OWC) systems. This paper analyzes the physical processes that limit the bandwidth and cause nonlinearities in the light output of modern, high-efficiency LEDs. The processes of carrier transport, as well as carrier storage, recombination, and leakage in the active region appear to affect the communications performance, but such purely physics-based models are not yet commonly considered in the algorithms to optimize OWC systems. Using a dynamic modeling of these phenomena, we compile a (invertable) signal processing model that describes the signal distortion and a parameter estimation procedure that is feasible in an operational communications link. We combine multiple approaches for steady-state and dynamic characterization to estimate such LED parameters. We verify that, for a high-efficiency blue GaN LED, the models become sufficiently accurate to allow digital compensation. We compare the simulation results using the model against optical measurements of harmonic distortion and against measurements of the LED response to a deep rectangular current modulation. We show how the topology of the model can be simplified, address the self-calibration techniques, and discuss the limits of the presented approach. The model is suitable for the creation of improved nonlinear equalizers to enhance the achievable bit rate in LED-based OWC systems and we believe it is significantly more realistic than LED models commonly used in communications systems.

Low threshold current density in GaInN-based laser diodes with GaN tunnel junctions

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Applied Physics Express
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We demonstrated room-temperature pulsed-operations of GaN-based blue edge-emitting laser diodes (LDs) with both the top and bottom AlInN cladding layers by using GaN tunnel junctions (TJs) grown by metalorganic vapor phase epitaxy. The LDs with a 1.2 mm cavity length and a 15 µm ridge width were fabricated. We obtained a low threshold current density of 0.9 kA cm−2 with facet coating. We found that while an optical absorption loss in the waveguiding layer was reduced with a low Mg concentration (3 × 1018 cm−3), that in a highly doped TJ could be an obstacle to obtain further improvements of the laser characteristics.

Monolithic microcavity second harmonic generation device using low birefringence paraelectric material without polarity-inverted structure

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Applied Physics Express
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We proposed a monolithic microcavity wavelength conversion device without a polarity-inverted structure. The device consists of a low birefringence paraelectric material and a dielectric material. A

fundamental wave intensity is enhanced significantly in the microcavity with two distributed Bragg reflectors, and a second-harmonic wave is efficiently generated in a very short region close to a coherence length. As a first step of this study, we used GaN as a device material, and succeeded in the blue second harmonic generation with a wavelength of 428 nm.

Stretchable Inorganic GaN-Nanowire Photosensor with High Photocurrent and Photoresponsivity

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To effectively implement wearable systems, their constituent components should be made stretchable. We successfully fabricated highly efficient stretchable photosensors made of inorganic GaN nanowires (NWs) as light-absorbing media and graphene as a carrier channel on polyurethane substrates using the pre-strain method. When a GaN-NW photosensor was stretched at a strain level of 50%, the photocurrent was measured to be 0.91 mA, corresponding to 87.5% of that (1.04 mA) obtained in the released state, and the photoresponsivity was calculated to be 11.38 A/W. These photosensors showed photocurrent and photoresponsivity levels much higher than those previously reported for any stretchable semiconductor-containing photosensor. To explain the superior performances of the stretchable GaN-NW photosensor, it was approximated as an equivalent circuit with resistances and capacitances, and in this way, we analyzed the behavior of the photogenerated carriers, particularly at the NW–graphene interface. In addition, the buckling phenomenon typically observed in organic-based stretchable devices fabricated using the pre-strain method was not observed in our photosensors. After a 1000-cycle stretching test with a strain level of 50%, the photocurrent and photoresponsivity of the GaN-NW photosensor were measured to be 0.96 mA and 11.96 A/W, respectively, comparable to those measured before the stretching test. To evaluate the potential of our stretchable devices in practical applications, the GaN-NW photosensors were attached to the proximal interphalangeal joint of the index finger and to the back of the wrist. Photocurrents of these photosensors were monitored during movements made about these joints.

Experimental Optical Properties of Single-Photon Emitters in Aluminum Nitride Films

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Single-photon emitters (SPEs) are one of the building blocks in quantum information processing. Here, we report detailed experimental optical properties of the SPEs in aluminum nitride (AlN) films at 10 K. The high-quality AlN films are grown by metal–organic chemical vapor deposition on graphene/sapphire substrates, which can conquer the large lattice and thermal mismatches between the sapphire and AlN. We report the defects in AlN with a relatively high Debye–Waller factor up to ∼29% and near-perfect linear polarization SPEs with a saturation count rate of 1.43 × 106 counts/s. The power-dependent second-order autocorrelation measurements are used to study the transition kinetics, which can be described using a three-level model. The polarization measurements of absorption and emission reveal the optical cycle mechanism, where a particular zero-phonon line may be excited via multiple mechanisms. This work provides some insight into the nature of the optical properties and energy-level structures of AlN defects, which pave the way to integrated on-chip quantum photonics.

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Enhanced Radiative Efficiency in GaN Nanowires Grown on Sputtered TiNx: Effects of Surface Electric Fields

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GaN nanowires grown by molecular beam epitaxy generally suffer from dominant nonradiative recombination, which is believed to originate from point defects. To suppress the formation of these defects, we explore the synthesis of GaN nanowires at temperatures up to 915 °C enabled by the use of thermally stable TiNx/Al2O3 substrates. These samples exhibit indeed bound exciton decay times approaching those measured for state-of-the-art bulk GaN. However, the decay time is not correlated with the growth temperature, but rather with the nanowire diameter. The inverse dependence of the decay time on diameter suggests that the nonradiative process in GaN nanowires is not controlled by the defect density, but by the field ionization of excitons in the radial electric field caused by surface band bending. We propose a unified mechanism accounting for nonradiative recombination in GaN nanowires of arbitrary diameter.

Phosphor-free InGaN nanopillar white LEDs by random clustering of mono-sized nanospheres

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Applied Physics Letters
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Nanosphere lithography with mono-sized nanospheres has been employed as a patterning tool of nanostructuring to achieve phosphor-free white-light emission in this study. Nanostructuring of InGaN/GaN quantum wells induces spectral blue shift due to strain relaxation, the extent of which depends on the sizes of the nanopillars. Nano-clusters of various sizes are formed as a result of random clustering of the mono-sized nanospheres, so that the clusters emit at different wavelengths as they are strain-relaxed to different levels. A Monte Carlo simulation has been employed to simulate the clustering patterns, while molecular dynamics and k·p Schrödinger calculations have been carried out to identify the appropriate nano-cluster distribution for phosphor-free white-light emission. The fabricated device achieves a color rendering index (CRI) of about 76 with an overall luminous efficacy of 2.6 lm/W under DC operation and 11.0 lm/W under pulsed operation.

Influence of plasmonic resonant wavelength on energy transfer from an InGaN quantum well to quantum dots

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Applied Physics Letters
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We demonstrated the enhanced nonradiative resonant energy transfer (NRET) process by localized surface plasmon (LSP) in the hybrid InGaN quantum well (QW) and CdSe/ZnS quantum dot (QD) structures. The LSP resonant wavelengths could be adjusted by silver (Ag) nanoparticle (NP) arrays annealed from different thicknesses of Ag films. The LSP resonant wavelengths that are close to the peak QD emission helped to enhance the NRET between the QW and QDs. Compared to the original NRET in the absence of Ag NPs, the LSP-enhanced NRET rate was improved by 6.9 times at the resonant wavelength of 600 nm. The calculated efficiency of the LSP-enhanced NRET was 73.1%, which was almost twice that of the original efficiency. Although Ag NPs exhibited a quenching effect, the LSP-enhanced NRET at the resonant wavelength of 465 nm enhanced QD luminescence, which demonstrated their potential use in energy conversion devices.

Origin of defect luminescence in ultraviolet emitting AlGaN diode structures

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Applied Physics Letters
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Light emitting diode structures emitting in the ultraviolet spectral range are investigated. The samples exhibit defect luminescence bands. Synchrotron-based photoluminescence excitation spectroscopy of the complicated multi-layer stacks is employed to assign the origin of the observed defect luminescence to certain layers. In the case of quantum well structures emitting at 320 and 290 nm, the n-type contact AlGaN:Si layer is found to be the origin of defect luminescence bands between 2.65 and 2.8 eV. For 230 nm emitters without such n-type contact layer, the origin of a defect double structure at 2.8 and 3.6 eV can be assigned to the quantum wells.

Improved Reliability of AlGaN-based Deep Ultraviolet LED with Modified Reflective N-type Electrode

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IEEE Electron Device Letters
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Cr/Al/Ti/Au stacks with two thicknesses of Al layers were employed as reflective n-type electrodes for 274 nm AlGaN-based flip-chip deep ultraviolet light-emitting diodes (DUV LEDs). Large bulges arose in the annealed n-type electrode with 120-nm-thick Al layer, resulting in cracks within the upper rugged SiO2 passivation layer after burn-in test. Sn atoms from solder paste migrated along the cracks and served as leakage current channels, which accelerated device degradation. In contrast, the annealed n-type electrode with 60-nm-thick Al layer retained uniform morphology. And the DUV LEDs with such n-type electrode exhibited good reliability and normalized optical power of 86.8% after burn-in test of 1000 h. This study provides insight into electrode defects related degradation behavior and helps to improve the reliability of AlGaN-based flip-chip DUV LEDs with reflective electrode.

606-nm InGaN amber micro-light-emitting diodes with an on-wafer external quantum efficiency of 0.56%

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IEEE Electron Device Letters
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We demonstrated amber InGaN 47 × 47 µ2 micro-light-emitting diodes (µLEDs) with the peak wavelength of 606 nm and full-width at maximum (FWHM) of 50 nm at 20 A/cm2. The amber µLEDs exhibited a 33-nm blue-shift of the peak wavelength and obtain broader FWHMs to approximately 56 nm at 5 to 100 A/cm2. The peak on-wafer external quantum efficiency was 0.56% at 20 A/cm2. The characteristic temperature was 50.80 K at 20 to 60 A/cm2 but increased to 120.140 K at 80 to 100 A/cm2. The strong increase in the characteristic temperature from 60 to 80 A/cm2 could mainly be attributed to the saturation of the Shockley-Read-Hall non-radiative recombination at high current densities.

Enhancing Efficiency of AlGaN Ultraviolet-B Light-Emitting Diodes with Graded p-AlGaN Hole Injection Layer

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physica status solidi a
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Ultraviolet-B (UVB) AlGaN light-emitting diodes (LEDs) with a hybrid hole injection layer comprising of a 5 nm thin p-AlxGa(1-x)N linearly graded layer (LGL), × from 0.65 to 0.50, and a 15 nm conventional p-AlGaN layer are proposed for ~284 nm wavelength emission. The introduced p-AlxGa(1-x)N LGL effectively improves the

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confinement of the electrons in the active region by effectively increasing the conduction band barrier height. Moreover, it enhances the hole injection capability into the active region by energizing the holes that minimize the effective valence band barrier height. As a result, the proposed LED structure exhibits an incredibly reduced electron leakage, 10 times lower than that of the conventional structure. Moreover, the output power and electroluminescence intensity of the proposed structure could enhance approximately twice at 60 mA current injection. Thus, the LGL LED structure can be a potential candidate for high-power UV light emitters.

Influence of silane flow rate on the structural and optical properties of GaN nanowires with multiple-quantum-shells

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In this study, we discuss the influence of SiH4 flow rates on the structural and optical properties of GaN nanowires (NWs) with multiple-quantum-shells (MQSs). To this end, we prepared two n-GaN core NW samples with different SiH4 flow rates. Subsequently, MQS active layers of the same structure were grown on each n-GaN core NW under identical growth conditions. The samples were characterized by scanning electron microscopy, scanning transmission electron microscopy, energy-dispersive X-ray, and cathodoluminescence (CL) mapping. From the experimental results, we ascertained that a Si-rich layer was created between the sidewall of the NWs and MQSs, in which the number of Si atoms was mainly determined by the SiH4 flow rate. These Si atoms diffused into the MQSs during the growth, and significantly impacted the structural and optical properties, such as the shape and crystalline quality of the MQSs and NWs, and the CL intensity of the MQSs. On the basis of experimental results, we conclude that the SiH4 flow rate during the NW growth plays a critical role in the performance of an MQS-based optoelectronic semiconductor device.

Multi-colour light emission from InGaN nanowires monolithically grown on Si substrate by MBE

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Nanotechnology
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InGaN nanostructures are among the most promising candidates for visible solid-state lighting and renewable energy sources. To date, there is still a lack of information about the influence of the growth conditions on the physical properties of these nanostructures. Here, we extend the study of InGaN nanowires growth directly on Si substrates by plasma-assisted molecular beam epitaxy. The results of the study showed that under appropriate growth conditions a change in the growth temperature of just 10 °C leads to a significant change in the structural and optical properties of the nanowires. InGaN nanowires with the areas containing 4%–10% of In with increasing tendency towards the top are formed at the growth temperature of 665 °C, while at the growth temperatures range of 655 °C–660 °C the spontaneously core–shell NWs are typically presented. In the latter case, the In contents in the core and the shell are about an order of magnitude different (e.g. 35% and 4% for 655 °C, respectively). The photoluminescence study of the NWs demonstrates a shift in the spectra from blue to orange in accordance with an increase of In content. Based on these results, a novel approach to the monolithic growth of InxGa1−xN NWs with multi-colour light emission on Si substrates by setting a temperature gradient over the substrate surface is proposed.

Electrical and optical characteristics of highly transparent MOVPE-grown AlGaN-based tunnel heterojunction LEDs emitting at 232 nm

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Photonics Research
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We present the growth and electro-optical characteristics of highly transparent AlGaN-based tunnel heterojunction light-emitting diodes (LEDs) emitting at 232 nm entirely grown by metalorganic vapor phase epitaxy (MOVPE). A GaN:Si interlayer was embedded into a highly Mg- and Si-doped $Al_{0.87}Ga_{0.13}N$ tunnel junction to enable polarization field enhanced tunneling. The LEDs exhibit an on-wafer integrated emission power of 77 µW at 5 mA, which correlates to an external quantum efficiency (EQE) of 0.29% with 45 µW emitted through the bottom sapphire substrate and 32 µW emitted through the transparent top surface. After depositing a highly reflective aluminum reflector, a maximum emission power of 1.73 mW was achieved at 100 mA under pulsed mode operation with a maximum EQE of 0.35% as collected through the bottom substrate.

Self-Powered MXene/GaN van der Waals Heterojunction Ultraviolet Photodiodes with Superhigh Efficiency and Stable Current Outputs

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Advanced Materials
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A self-powered, high-performance $Ti_3C_2T_x$ MXene/GaN van der Waals heterojunction (vdWH)-based ultraviolet (UV) photodiode is reported. Such integration creates a Schottky junction depth that is larger than the UV absorption depth to sufficiently separate the photoinduced electron/hole pairs, boosting the peak internal quantum efficiency over the unity and the external quantum efficiency over 99% under weak UV light without bias. The proposed $Ti_3C_2T_x$/GaN vdWH UV photodiode demonstrates pronounced photoelectric performances working in self-powered mode, including a large responsivity (284 mA W^{-1}), a high specific detectivity (7.06 × 10^{13} Jones), and fast response speed (rise/decay time of 7.55 µs/1.67 ms). Furthermore, the remarkable photovoltaic behavior leads to an impressive power conversion efficiency of 7.33% under 355 nm UV light illumination. Additionally, this work presents an easy-processing spray-deposition route for the fabrication of large-area UV photodiode arrays that exhibit highly uniform cell-to-cell performance. The MXene/GaN photodiode arrays with high-efficiency and self-powered ability show high potential for many applications, such as energy-saving communication, imaging, and sensing networks.

A novel hot carrier-induced blue light-emitting device

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Journal of Alloys and Compounds
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In this work, an InGaN/GaN multiple quantum well based Top-Hat Hot-Electron Light Emission and Lasing in a Semiconductor Heterostructure (Top-Hat HELLISH) is investigated. A heterojunction structure is designed based on an active InGaN quantum well placed in the n-type GaN region sandwiched by the n- and p-type GaN layers. The four quantum well structure of an InGaN/GaN heterojunction where the Indium ratio is 0.16 has been grown via Metal-Organic Chemical Vapor Deposition. In order to create an anisotropic potential distribution of the heterojunction, it is aimed to fabricate TH-HELLISH-GaN device in Top-Hat HELLISH (THH) geometry for four contacts with separate n- and p-channels. High-

speed I-V measurements of the device reveal an Ohmic characteristic at both polarities of the applied voltage. Integrated EL measurements reveal the threshold of the applied electric field at around 0.25 kV/cm. The emission wavelength of the device is around 440±1 nm at room temperature.

Circularly polarized light emission from a GaN micro-LED integrated with functional metasurfaces for 3D display

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Optics Letters
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This Letter proposes a circularly polarized (CP) light GaN micro-LED which is integrated with functional metasurfaces. The one-dimensional metallic nanograting can achieve a high transverse electric (TE) reflectivity (RTE) and extinction ratio (ER) of TE and transverse magnetic (TM) waves, which is highlypolarized output for micro-LEDs. Besides, the nanograting, which is integrated on the bottom of the GaN layer, can also support a resonant cavity, together with the top distributed Bragg reflector, which can shape the radiation pattern. By optimizing the structure parameters of nanograting, the RTE achieves over 80%, and the ER reaches higher than 38 dB at 450 nm for the GaN micro-LED. Additionally, the metasurface, which acts as a quarter-wave plate, was investigated to control the phase delay between the polarization state of the electric wave in two orthogonal components. Finally, the circular shape of the transmitted pattern denotes the high performance of the metasurface which is integrated in the micro-LED for CP light emission. The work reported in this Letter might provide potential application in a 3D polarized light display.

Demonstration of green and UV wavelength high Q aluminum nitride on sapphire microring resonators integrated with microheaters

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Applied Physics Letters
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We demonstrate a high Q aluminum nitride (AlN) on sapphire microring resonators at green (532 nm) and ultraviolet (UV) (369.5 nm), which are two important wavelengths for sensing and quantum information processing. The quality factors (Q) of these resonators are characterized using integrated microheaters and based on thermo-optic resonance sweeping around those wavelengths for which tunable lasers are typically less available. We measure a record of high intrinsic Q of 147 000 with a propagation loss of 7.3 dB/cm at 532 nm wavelength, and an intrinsic Q of 25 500 with a propagation loss of 60.4 dB/cm at UV 369.5 nm wavelength. We also investigate the thermal crosstalk between the adjacent resonators when temperature change is applied by the microheater of one of the resonators on the same chip. A large thermal crosstalk and resonance shift are observed on other microring resonators even at millimeter(s) distance away from a microheater. This study provides further insight on the functionalities and capabilities of this promising integrated photonic platform for the ultraviolet (UV) and visible range.

Thermophysical Characterization of Efficiency Droop in GaN-Based Light-Emitting Diodes

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Nanomaterials
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An efficiency droop in GaN-based light-emitting diodes (LED) was characterized by examining its general thermophysical parameters. An effective

suppression of emission degradation afforded by the introduction of InGaN/GaN heterobarrier structures in the active region was attributable to an increase in the capture cross-section ratios. The Debye temperatures and the electron–phonon interaction coupling coefficients were obtained from temperature-dependent current-voltage measurements of InGaN/GaN multiple-quantum-well LEDs over a temperature range from 20 to 300 K. It was found that the Debye temperature of the LEDs was modulated by the InN molar fraction in the heterobarriers. As far as the phonons involved in the electron–phonon scattering process are concerned, the average number of phonons decreases with the Debye temperature, and the electron–phonon interaction coupling coefficients phenomenologically reflect the nonradiative transition rates. We can use the characteristic ratio of the Debye temperature to the coupling coefficient (DCR) to assess the efficiency droop phenomenon. Our investigation showed that DCR is correlated to quantum efficiency (QE). The light emission results exhibited the high and low QEs to be represented by the high and low DCRs associated with low and high injection currents, respectively. The DCR can be envisioned as a thermophysical marker of LED performance, not only for efficiency droop characterization but also for heterodevice structure optimization.

Photonic band characterization in InGaN/GaN nanocolumn arrays with triangular and honeycomb lattices by angle-resolved micro-photoluminescence measurements

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Japanese Journal of Applied Physics
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We demonstrated photonic band characterization in photonic crystals (PhCs) based on InGaN/GaN nanocolumn (NC) arrays fabricated by Ti-mask selective area growth. Triangular and honeycomb latticed NCs with approximately the same diameter and closest distance were successfully fabricated. To effectively observe the photonic bands, we designed an angle-resolved micro-photoluminescence measurement system. The photonic bands in the honeycomb lattice were at longer wavelengths compared with those in the triangular lattice, indicating that, for the honeycomb lattice, narrower NCs were available to realize PhC effects in the long-wavelength region. Therefore, narrow honeycomb lattices with large nanocrystalline and PhC effects are suitable for long-wavelength emission.

ELECTRONICS

Group leader: Farid Medjoub (CNRS-IEMN)

Information selected by Farid Medjoub (CNRS-IEMN), Jean-Claude De Jaeger (CNRS-IEMN), Matthew Charles (CEA-Leti) and Yvon Cordier (CNRS-CRHEA)

Multiphysics Optimization of Thermal-Management Designs for Power Electronics Employing Impingement Cooling and Stereolithographic Printing

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IEEE Transactions on Power Electronics

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Meeting the stringent performance requirements for power-electronic converters in electric vehicles requires an integrated approach for optimizing the inherently-coupled electrical and thermal performances of converter systems. This paper presents a multidisciplinary thermal-management design methodology that utilizes genetic algorithms (GA) to generate topologically-optimized geometries for liquid-cooled heat sinks. These GA-generated heat sinks are based on impingement-cooling principles and leverage the flexibility of stereolithographic manufacturing techniques. The proposed optimization methodology incorporates the interdependence between the thermal and electrical aspects of the system, and it is capable of targeting performance metrics in either or both domains. This optimization process is demonstrated for a 6.6-kW integrated power-module design employing bare-die silicon-carbide devices on an FR4-based printed circuit board with embedded ceramic elements. Experimentally-validated electrothermal multi-physics simulations of the GA-optimized heat sinks targeting various performance metrics show successful optimization of targeted metrics relative to the initial seed design. The results demonstrate the importance of the multidisciplinary design approach and the effectiveness of the GA-based optimization methodology.

Analysis of High-Frequency Behavior of AlGaN/GaN HEMTs and MIS-HEMTs under UV Illumination

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The high-frequency characteristics of AlGaN/GaN high-electron-mobility transistors (HEMTs) and metal-insulator-semiconductor HEMTs (MIS-HEMTs) are investigated under ultraviolet (UV) radiation with 365 nm wavelength. When HEMTs and MIS-HEMTs are illuminated with an UV source, their drain currents increase apparently owing to the generated photocurrent. Nevertheless, they show different high-frequency response to the UV light. For HEMTs, the peak cutoff frequency (fT) and maximum oscillation frequency (fmax) of illuminated devices are 20% and 10% higher than those in dark condition, respectively, owing to the increased transconductance. For MIS-HEMTs, however, their high-frequency performances are degraded when transistors are subject to light exposure. The degradations of peak fT and fmax are around 3.7% and 18%, respectively. The small-signal model parameters relevant to the high-frequency characteristics were extracted to explain these phenomena. Additional trapped charges in the SiN gate dielectric induced by UV light would be responsible for the degraded high-frequency parameters in illuminated MIS-HEMTs. These experimental results are important for designing a suitable GaN-based HEMT for optoelectronic applications.

Understanding Electrical Parameter Degradations of p-GaN HEMT under Repetitive Short-Circuit Stresses

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In this letter, comprehensive static and dynamic electrical parameter degradations of p-GaN gate high electron mobility transistor (HEMT) under repetitive short-circuit (SC) stresses are presented. Meanwhile, the mechanisms behind those degradations are firstly distinguished. The results indicate that both the gate region and the access region are damaged by the SC stresses, which dominate the shifts of electrical parameters. Moreover, a method by modeling the output capacitance is proposed to characterize damages in access region. Finally, the switching characteristics after the stresses are investigated, the switching speed benefits from the increase of gate leakage current. Considering the aging of the p-GaN HEMT under long-term operation conditions, all the damages brought by repetitive SC stresses should be eliminated to prevent the failure of p-GaN gate and the increase of conduction loss.

Temperature-Sensitivity of Two Microwave HEMT Devices: AlGaAs/GaAs vs. AlGaN/GaN Heterostructures

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Electronics
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The goal of this paper is to provide a comparative analysis of the thermal impact on the microwave performance of high electron-mobility transistors (HEMTs) based on GaAs and GaN technologies. To accomplish this challenging goal, the relative sensitivity of the microwave performance to changes in the ambient temperature is determined by using scattering parameter measurements and the corresponding equivalent-circuit models. The studied devices are two HEMTs with the same gate width of 200 µm but fabricated using different semiconductor materials: GaAs and GaN technologies. The investigation is performed under both cooled and heated conditions, by varying the temperature from −40 °C to 150 °C. Although the impact of the temperature strongly depends on the selected operating condition, the bias point is chosen in order to enable, as much as possible, a fair comparison between the two different technologies. As will be shown, quite similar trends are observed for the two different technologies, but the impact of the temperature is more pronounced in the GaN device.

Obtaining impact ionization-induced hole current by electrical measurements in gallium nitride metal–insulator–semiconductor high electron mobility transistors

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In this paper, an extraction method for measuring impact ionization-induced hole current in gallium nitride (GaN) metal–insulator–semiconductor high electron mobility transistors (MIS-HEMTs) is proposed. The results show that the non-monotonic impact ionization current characteristic can be easily acquired by the extraction method. Further, different hot-carrier stress (HCS) conditions can be obtained based on the IG–VG curve, and the reliability tests can act as verification of the impact-ionization curve. In addition, electrical reliability tests indicate that the threshold voltage (VTH) shift and on-state current (Ion) degradation in the MIS-HEMTs have a positive correlation to impact ionization-generated hole current. During HCS operation, the VTH will shift positively and Ion decreases due to hot electrons

trapping into the GaN layer. This model is validated by TCAD simulation.

10 kV, 39 mΩ·cm2 Multi-Channel AlGaN/GaN Schottky Barrier Diodes

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This work demonstrates multi-channel AlGaN/GaN Schottky barrier diodes (SBDs) with a breakdown voltage (BV) over 10 kV, the highest BV reported in GaN devices to date. The epitaxial structure consists of a p-GaN cap layer and five AlGaN/GaN channels continuously grown on a low-cost 4-inch sapphire substrate. A novel device design is proposed for electric field management, i.e., the p-GaN reduced surface field (RESURF) structure, which balances the net charges in the multi-channel at reverse biases. The SBD with a 98-µm anode-to-cathode length (LAC) shows a BV of 9.15 kV and a specific on-resistance (RON) of 29.5 mΩ·cm2, rendering a Baliga's figure of merit (FOM) of 2.84 GW/cm2. The SBD with a 123-µm LAC shows a BV over 10 kV and a RON of 39 mΩ·cm2, which is 2.5-fold lower than the RON of the state-of-the-art 10-kV SiC junction barrier Schottky (JBS) diodes. The Baliga's FOMs of our 4.6-10 kV GaN SBDs well exceed the SiC unipolar limit. These results show the great promise of GaN for medium-and high-voltage power electronics.

Vertical polarization-induced doping InN/InGaN heterojunction tunnel FET with hetero T-shaped gate

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A novel vertical InN/InGaN heterojunction tunnel FET with hetero T-shaped gate as well as polarization-doped source and drain region (InN-Hetero-TG-TFET) is proposed and investigated by Silvaco-Atlas simulations for the first time. Compared with the conventional physical doping TFET devices, the proposed device can realize the P-type source and N-type drain region by means of the polarization effect near the top InN/InGaN and bottom InGaN/InN heterojunctions respectively, which could provide an effective solution of random dopant fluctuation (RDF) and the related problems about the high thermal budget and expensive annealing techniques due to ion-implantation physical doping. Besides, due to the hetero T-shaped gate, the improvement of the on-state performance can be achieved in the proposed device. The simulations of the device proposed here in this work show ION of 4.45 × 10−5 A/µm, ION/IOFF ratio of 1013, and SSavg of 7.5 mV/dec in InN-Hetero-TG-TFET, which are better than the counterparts of the device with a homo T-shaped gate (InN-Homo-TG-TFET) and our reported lateral polarization-induced InN-based TFET (PI-InN-TFET). These results can provide useful reference for further developing the TFETs without physical doping process in low power electronics applications.

Improved Electrical Properties of AlGaN/GaN High-Electron-Mobility Transistors by In Situ Tailoring the SiNx Passivation Layer

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In situ metal–organic chemical vapor deposition growth of SiNx passivation layers is reported on AlGaN/GaN high-electron-mobility transistors (HEMTs) without surface damage. A higher SiNx growth rate, when produced by higher SiH4 reactant gas flow, enables faster lateral coverage and coalescence of the initial SiNx islands, thereby suppressing SiH4-induced III-nitride etching. The effect of in situ SiNx passivation on the structural properties of AlGaN/GaN HEMTs has been evaluated using high-resolution X-ray diffraction. Electrical properties of the passivated HEMTs were evaluated by clover-leaf van der Pauw Hall measurements. The key findings include (a) a correlation of constituent gas chemistry with SiNx stoichiometry, (b) the degree of suppression of strain relaxation in the barrier layer

that can be optimized through the SiNx stoichiometry, and (c) optimum strain relaxation by tailoring the SiNx passivation layer stoichiometry that can result in near-ideal AlGaN/AlN/GaN interfaces. The latter is expected to reduce the carrier scatterings and improve electron mobility. Under optimized conditions, low sheet resistance and high electron mobility are obtained. At 10 K, a sheet resistance of 33 Ω/sq and a mobility of 16,500 cm2/V-s are achieved. At 300 K, the sheet resistance is 336 Ω/sq and mobility is 2020 cm2/V-s with a sheet charge density of 0.78 × 1013 cm−2.

GaN Integrated Bridge Circuits on Bulk Silicon Substrate: Issues and Proposed Solution

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A discrete GaN power transistor's substrate is typically connected to its source electrode. However, on the GaN-on-Si power IC platform, the high-side transistor (HS-transistor) and low-side transistor (LS-transistor) share a common substrate that cannot be simultaneously connected to both source electrodes of the two transistors. Thus, the termination of the common substrate remains an undecided issue. In this work, comprehensive TCAD simulations are exploited to reveal the influences of various substrate termination schemes. It is found the common substrate inevitably leads to severe degradation in the dynamic RON due to back-gating effects. The mechanisms for the degradations vary with the substrate termination scheme, and will be discussed in detail. To address these issues, we propose a new GaN power IC platform on an engineered bulk silicon substrate, and study the new platform with TCAD simulations. The proposed platform provides a local electrical substrate (a p+ island) for each GaN power transistor. The source electrode of each GaN transistor is connected to its local electrical substrate, while all devices share a common mechanical substrate. The junctions between the local substrates and the underlying n-layer provide an effective isolation between GaN transistors. The back-gating effects are completely suppressed for the GaN integrated bridge circuit.

Highly effective gating of graphene on GaN

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By using four-layered graphene/gallium nitride (GaN) Schottky diodes with an undoped GaN spacer, we demonstrate highly effective gating of graphene at low bias rendering this type of structure very promising for potential applications. An observed Raman G band position shift larger than 8.5 cm−1 corresponds to an increase in carrier concentration of about 1.2·1013 cm-2. The presence of a distinct G band splitting together with a narrow symmetric 2D band indicates turbostratic layer stacking and suggests the presence of a high potential gradient near the Schottky junction even at zero bias. An analysis based on electroreflectance measurements and a modified Richardson equation confirmed that graphene on n-GaN separated by an undoped GaN spacer behaves like a capacitor at reverse bias. At least 60% of G subband position shifts occur at forward bias, which is related to a rapid reduction of electric field near the Schottky junction. Our studies demonstrate the usefulness of few layer turbostratic graphene deposited on GaN for tracing electron-phonon coupling in graphene. Multilayer graphene also provides uniform and stable electric contacts. Moreover, the observed bias sensitive G band splitting can be used as an indicator of charge transfer in sensor applications in the low bias regime.

Decoupling of Forward and Reverse Turn-on Threshold Voltages in Schottky-Type p-GaN Gate HEMTs

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In a p-channel field-effect-transistor (p-FET) bridge HEMT device recently realized on a commercial p-GaN/AlGaN/GaN-on-Si power HEMT epi-wafer, it is revealed that the device's reverse-conduction turn-on voltage (VRT) can be effectively decoupled from the forward threshold voltage (VTH) of Schottky-type p-GaN gate HEMTs. Unlike the conventional Schottky-type p-GaN gate HEMTs, of which VRT is closely linked to VTH, the p-FET-bridge HEMT enables separate designs of VRT and VTH so that low-loss reverse conduction and high threshold voltage can be simultaneously realized. In addition, VRT can be further reduced by engineering the AlGaN barrier layer, which will also benefit a lower channel sheet resistance without lowering VTH.

Demonstration of Avalanche and Surge-Current Robustness in GaN Junction Barrier Schottky Diode with 600 V/10 A Switching Capability

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In this work, we achieved significantly enhanced avalanche ruggedness and surge current capability in GaN junction barrier Schottky (JBS) diode for highly reliable power operation. Based on the selective Mg-ion implantation technology, the GaN JBS diode obtains superior electrostatic performances, including 830 V breakdown voltage, 150 m specific on-state resistance, and 0.5 V turning on voltage. Meanwhile, zero reverse recovery behaviors are observed even under extreme switching conditions of 600 V/10 A. During the reliability evaluation in the inductive load circuits, crucial avalanche capability with avalanche breakdown voltage over 965 V, avalanche energy up to 57.8 mJ and more than 10,000 repetitive avalanche breakdown events are demonstrated. Together with the surge current tolerance up to 65 A and surge energy of 6.0 J, a large safe-operation-area under both forward and reverse inductive spikes is realized for the GaN based rectifier.

Cumulative Hot-Electron Trapping in GaN-Based Power HEMTs Observed by an Ultra-Fast (10V/ns) on-Wafer Methodology

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The goal of this paper is to advance the understanding of the impact of hard switching on the dynamic performance of GaN-based HEMTs. To this aim, we developed a fast (10 V/ns) on-wafer system for testing devices in hard switching. The system has been used to study the reliability of several WG = 2 mm p-type GaN HEMTs with different LGD or buffer properties. First, we show that by optimizing the drain node capacitance, we can speed-up the hard-switching transition to a few ns, even on-wafer level. Second, repeating the experiment by using multiple frequencies, from 1 kHz to 100 kHz, we demonstrate that, in real-world applications, cumulative turn-on stress has a much stronger effect on RON compared to off-state stress. Third, by comparing the results on identical devices having shorter LGD, we pinpoint hot electrons as the main mechanism in the device degradation, ruling out the contribution of self-heating. Finally, by comparing three wafers with different processing conditions (different passivation, different buffer) we suggest that trapping phenomena related to hot electrons happen in ns time scale and

that the properties of the buffer can significantly impact the dynamic performance of the devices in hard switching.

Co-Design and Validation Approach for Beam-Steerable Phased Arrays of Active Antenna Elements with Integrated Power Amplifiers

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An approach for designing a beam-steering active phased array of antenna elements with integrated power amplifiers (PAs) is presented. It is based on an amplifying active integrated unit cell (AiUC) concept, where the AiUC comprises a radiating slot element, a GaN high electron mobility transistor (HEMT), its input matching and DC biasing/feeding circuitry. The HEMT is embedded in the antenna element, being directly impedance-matched to HEMT's drain output, i.e. without using any intermediate and potentially lossy impedance matching network. The proposed co-design approach involves a full-wave analysis of the AiUC passive part (naturally including elements mutual coupling effects) along with the subsequent full-system harmonic balance simulations. Furthermore, we extend the standard definition of the scan element pattern (SEP) to the active scan element pattern (ASEP) that accounts for non-linear effects of PAs on AiUC performance. We show that the ASEP is, in general, power-dependent and has a different shape as compared to the SEP. The proposed approach has been demonstrated for a K-band AiUC design example. It was verified through an active waveguide simulator, which is equivalent to the 23.7° H-plane beam-steering case. Measurements are in good agreement with simulations, revealing AiUC 47% peak drain efficiency and 33 dBm maximum radiated power. The predicted scan range is ±60° and ±37° in the E- and H-plane, respectively.

Quantifying the Plasmonic Generation Rate of Non-Thermal Hot Carriers with an AlGaN/GaN High-Electron-Mobility Transistor

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Plasmonic generation of hot carriers in metallic nanostructures has attracted much attention due to its great potential in several applications. However, it is highly debated whether the enhancement is due to the hot carriers or the thermal effect. Here, the ability to exclude the thermal effect and detect the generation of non-thermal hot carriers by surface plasmon is demonstrated using an AlGaN/GaN high-electron-mobility transistor. This ultrasensitive platform, which demonstrates at least two orders of magnitude more sensitivity compared to the previous reports, can detect the hot carriers generated from discrete nanostructures illuminated by a continuous wave light. The quantitative measurements of hot carrier generation also open a new way to optimize the plasmonic nanoantenna design in many applications.

Dynamic characteristics after bias stress of GaN HEMTs with field plate on free-standing GaN substrate

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IET
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This paper investigates the electron trapping behaviour after bias stress in GaN high-electron-mobility transistors (HEMTs) fabricated on GaN substrate. On-resistance (RON) and electron-trap-induced threshold voltage shift (ΔVth) of GaN HEMTs on GaN substrate are determined by gate quiescent bias (Vgq) and independent of drain quiescent bias (Vdq). This result indicates that the current collapse of

GaN HEMTs is mainly attributed to the electron injection in barrier layer under gate region. Moreover, time constants of electron emission are dependent on the Vgq. At least two time constants (τ1 and τ2) are found to exist in the HEMTs after being switched from an off-state (Vgq ≤ −30 V, Vdq = 0 V) to an open channel condition. The τ1 and τ2 continue to increase with increasing |Vgq|. It is speculated that the presence of multi-trap energy states in barrier layer results in the quiescent bias-dependence of time constants.

A 2.4-6 GHz Broadband GaN Power Amplifier for 802.11ax Application

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This paper presents a 2.4-6 GHz highly integrated broadband GaN power amplifier (PA) with three stages for 2.4-/5-GHz dual-band 802.11ax application. A compact external output matching network is introduced to realize broadband output matching, while reducing the loss of the output matching network and saving the chip area. A novel topology of coupled resonators is exploited for the broadband inter-stage matching to cover the 802.11ax bands from 2.4 to 6 GHz. In the proposed topology, the coupling between the primary and secondary resonators is through a series inductor and a series capacitor. Compared with other conventional coupled resonators, the proposed topology produces an additional complex pole, further extending the bandwidth. The PA was designed and fabricated in Wolfspeed 0.25-µm GaN-on-SiC technology. The implemented PA achieves a saturated output power (Psat) of 35.2-36.3 dBm with a maximum power added efficiency (PAE) of 38-53% from 2.4 to 6 GHz. When tested with an 80-MHz, 256-quadratic-amplitude modulation (QAM) 802.11ax signal, the PA delivers an average output power of 27.1 and 25.7-27.2 dBm with a PAE of 20.9% and 18.4-24.6% in the 2.4-GHz and 5-GHz wireless local area network (WLAN) bands, respectively, while meeting the specification of error vector magnitude (EVM) below -32 dB.

Recent progress of physical failure analysis of GaN HEMTs

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Gallium nitride (GaN)-based high-electron mobility transistors (HEMTs) are widely used in high power and high frequency application fields, due to the outstanding physical and chemical properties of the GaN material. However, GaN HEMTs suffer from degradations and even failures during practical applications, making physical analyses of post-failure devices extremely significant for reliability improvements and further device optimizations. In this paper, common physical characterization techniques for post failure analyses are introduced, several failure mechanisms and corresponding failure phenomena are reviewed and summarized, and finally device optimization methods are discussed.

Comprehensive Annealing Effects on AlGaN/GaN Schottky Barrier Diodes with Different Work-Function Metals

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IEEE Transactions on Electron Devices
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In this article, we have systematically investigated the effect of annealing of fabricated GaN Schottky barrier diodes (SBDs) and anode metals with various work-functions on the performance of AlGaN/GaN SBDs. It is found that after annealing of fabricated GaN SBDs, the interface states between the metal and GaN etching surface are suppressed, the device stability is enhanced, and the turn-on voltage (Von) shows

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negligible degradation. Meanwhile, high-performance AlGaN/GaN SBDs with various work-function metals as anode have been achieved by adapting the annealing treatment. The calculated Schottky barrier heights of the fabricated SBDs with Cr, W, and Ni anode is 0.27, 0.68, and 0.98 eV, respectively, which are almost the same as those estimated from XPS measurements. A low turn-on voltage of 0.42 V and low leakage current of 0.3 µA/mm are obtained by using the low work-function metal W (4.6 eV) as anode. Furthermore, the SBDs fabricated with the high work-function metal Ni (5.1 eV) shows an extremely low-leakage current of 6 nA/mm and exhibit a current on/off ratio of 10^9 while also showing great characteristics at high temperature.

Study of $In_xGa_{1-x}N$/GaN Homotype Heterojunction IMPATT Diodes

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In this work, a novel n-$In_xGa_{1-x}N$/N-gallium nitride (GaN) homotype heterostructure is proposed instead of P-GaN/N-GaN homostructure to produce impact-ionization-avalanche-transit-time (IMPATT) diode. Conventional GaN IMPATT device will lose its working ability due to the immature p-type GaN, so this work predicts that the n-In_xGa_{1-x} N/N-GaN IMPATT diode can be an alternative to the GaN p-n IMPATT diode; thus, the difficulty of the p-type doping process is avoided. The dc and RF large-signal output characteristics with different compositions are investigated in detail. The simulation results show that the power and efficiency of the novel structure device increase when the In composition increases. When the In composition is greater than 0.4, the performance of the homotype heterojunction IMPATT is better than that of p-n IMPATT. Moreover, homotype heterojunction IMPATT is better in frequency bandwidth, and it can hold greater bias current density than p-n IMPATT. Meanwhile, the performance of homotype heterojunction IMPATT does not depend on the thickness of the InGaN layer, but it decreases as the thickness of the p-type region in p-n IMPATT increases. As it has greater potential in the application, this work brings a reference for the design and manufacture of IMPATT devices based on wide bandgap semiconductor materials, especially GaN materials.

High-Voltage Quasi-Vertical GaN Junction Barrier Schottky Diode with Fast Switching Characteristics

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IEEE Electron Device Letters
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In this letter, we report a quasi-vertical GaN junction barrier Schottky diode on low-cost sapphire substrate. With the high quality GaN epitaxy and selective-area p-islands formed via Magnesium ion implantation at the anode region, reverse leakage in level of 10-7 A/cm2 was achieved, as well as a high on/off current ratio of 1010 and a high breakdown voltage of 838 V. Meanwhile, advantageous characteristics as expected in vertical GaN Schottky barrier diode were realized, including a low turn-on voltage of 0.5 V and fast switching performance under 400 V/10 A operation condition. Along with the improved heat dissipation via substrate thinning and packaging techniques, the diode retains a relatively low thermal resistance, enabling high current rectification level over 60 A, power efficiency up to 98.7%, while maintaining low case temperatures.

Deep Source Metal Trenches in GaN-on-Si HEMTs for Relieving Current Collapse

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The dynamic on-resistance increase during power switching is one of the challenges of GaN-based HEMTs (high-electron-mobility transistors) for power electronic applications. Both the surface traps and

buffer traps reduce channel carriers, resulting in decreased operating current during power switching. In this work, we propose a source metal trench toward the buffer region to alleviate channel carriers' trapping in the buffer region. We compare the dynamic behaviors of the HEMTs with the source trench fabricated within and out of the mesa region. The results indicate less dynamic on-resistance increase at higher drain and gate stress voltages of the device with source trench in the mesa, as compared with the device with source trench fabricated away from mesa, or the one without a trench. We further develop physical models, including multiple current-conducting paths, reduction of buffer traps through source trench, and the re-distribution of the electric field profile, to explain the phenomenon.

Analysis and Control of Critical Conduction Mode High-Frequency Single-Phase Transformerless PV Inverter

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This paper presents a critical conduction mode (CRM) single-phase transformerless full-bridge inverter in a residential photovoltaic system. The CRM full-bridge inverter in bipolar mode features zero-voltage switching capability for the whole line cycle. This enables the inverter to push switching frequency up to hundreds of kHz and achieve high power density with high efficiency. However, CRM operation incurs non-constant common mode (CM) voltage during the resonant period, causing high frequency leakage current. To minimize the leakage current, a new switching modulation strategy is proposed introducing triangular current mode (TCM) near the ac voltage zero crossing. The switching modulation scheme alleviates CM voltage by shortening the resonant period and consequently reduces the leakage current. Then, discontinuous conduction mode is inserted in between CRM and TCM operation regions to improve light load efficiency. In this paper, the basic operation principle of the CRM full-bridge inverter, impacts of CRM operation on the leakage current, and details of the proposed switching modulation method are discussed. Experimental results with a 2.4-kW prototype built with GaN devices validate its performance.

Multi-channel AlGaN/GaN Schottky barrier diodes with a half through-hole

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The cutoff frequency of Schottky barrier diode (SBD) depends on its junction capacitance and series resistance. The two-dimensional electron gas (2DEG) at AlGaN/GaN interface has high carrier mobility and carrier concentration. However, AlGaN/GaN heterostructure SBD usually shows a high series resistance because of the thin 2DEG channel. In this work, multiple AlGaN/GaN heterojunctions are vertically stacked for forming multiple parallel 2DEG channels to reduce the series resistance. Multi-channel AlGaN/GaN-based air-bridge structure planar SBDs with a half through-hole are demonstrated. The series resistance of quintuple-channel SBD is only 39.5% of the single-channel SBD's. Moreover, a low capacitance is obtained by the Schottky electrode with a half through-hole structure. The low series resistance and the low capacitance contribute to a 16 GHz cutoff frequency in millimeter-wave band.

Comprehensive GaN-on-Si power device platform: epitaxy, device, reliability and application

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Semiconductor Science and Technology
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In this paper, we discuss possible solutions to overcome the critical issues for GaN-on-Si power

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device popularization including cost competitiveness to Si power MOSFETs, system level reliability verification, and electromagnetic interference (EMI) mitigation at high switching frequency without compromising the switching loss. Both an advanced epitaxy technology and a comprehensive power device technology platform of 200 mm GaN-on-Si high electron mobility transistors (HEMTs) for mass production are presented. A novel strain engineering is reported to realize enhancement-mode HEMTs with ultralow specific on-resistance. The Si based Joint Electron Device Engineering Council reliability test, Dynamic High Temperature Operating Life, and switching accelerated lifetime test were carried out to evaluate the device reliability and lifetime. It is proved that our GaN device is robust and stable in power conversion applications. A balancing technique to mitigate EMI of the high switching frequency GaN power converter is demonstrated.

Investigation of the passivation-induced VTH shift in p-GaN HEMTs with Au-free gate-first process

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Microelectronics Reliability
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In this work, we observe the distinct VTH characteristics in the Au-free gate-first processing p-GaN/AlGaN/GaN HEMTs with two commonly used passivation layers, i.e., SiN and SiO2. The lower incorporated H was found in the p-GaN/AlGaN/GaN heterostructure with higher activation anneal temperature (i.e., 700 °C). Furthermore, Photoluminescence (PL) spectrum demonstrates a higher blue luminescence (BL) intensity after higher annealing treatment. The X-ray photoelectron spectroscopy (XPS) spectrum near valence band edge depicts a similar valence band maximum (VBM) characteristic, by means no impact on p-GaN surface bending by using distinct thermal treatment. The device with SiN shows a depletion-mode (D-mode) characteristic (VTH ~ -5 V) whereas the device with SiO2 passivation exhibits an enhancement-mode (E-mode) characteristic (VTH ~ +0.7 V). Moreover, Transmission Line Model (TLM) devices are fabricated to investigate the effects of the passivation on two-dimensional electron gas (2DEG) in p-GaN/AlGaN/GaN stack. The results indicate that a low Rsh is obtained while passivating device surface with SiN layer, suggesting that 2DEG is present, which is most probably due to an unfunctional p-GaN layer. The secondary ion mass spectrometry (SIMS) results indicate a high hydrogen intensity in the p-GaN/AlGaN/GaN stack with a SiN passivation layer. Thus, the p-GaN deactivation process that correlates to the formation of complex Mgsingle bondH after SiN passivation is proposed to explain the D-mode characteristic in the device with a SiN passivation layer.

Distinguishing various influences on the electrical properties of thin-barrier AlGaN/GaN heterojunctions with in-situ SiNx caps

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Understanding the individual contributions of the factors that influence the electrical properties of a material is important for controlling these properties. In this study, the effects of multiple factors on the electrical properties of thin-barrier AlGaN/GaN heterojunctions with in-situ SiNx caps were investigated using step etching and annealing treatments. The sheet density of the two-dimensional electron gas decreased by 5.9% and 29.5% due to the decrease in the piezoelectric polarization of the AlGaN barrier and the variations in interface charges during SiNx removal, respectively, and it recovered greatly by 72% after annealing-induced surface reconstruction. Capacitance-voltage results clearly revealed few

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interface traps on the heterojunction with the in-situ SiNx cap. Moreover, a maximum output current of 705 mA/mm and threshold voltage hysteresis below 50 mV were achieved by optimizing the in-situ SiNx interlayer on a thin-barrier metal-insulator-semiconductor structure. This study presents an efficient method for modulating the properties of two-dimensional electron gas and provides insights into the functionality of in-situ SiNx passivation on thin-barrier AlGaN/GaN heterojunctions.

Passivation-layer thickness and field-plate optimization to obtain high breakdown voltage in AlGaN/GaN HEMTs with short gate-to-drain distance

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A two-dimensional analysis of the off-state breakdown characteristics in field-plate AlGaN/GaN HEMTs is performed. The gate-to-drain distance is 1.5 µm, and the parameters are the SiN passivation-layer thickness d and the field-plate length LFP. For a moderate d of 0.1 µm, the breakdown voltage Vbr increases with LFP, and takes an maximum value (~400 V) around LFP = 0.3 µm, and decreases when LFP becomes even longer. This decrease is attributed to the fact that the drain voltage is almost applied along the region between the field plate and the drain. For thin d ≤ 0.03 µm, Vbr becomes relatively low (≤150 V) when LFP becomes long (≥ 0.6 µm). This is attributed to the fact that when d is very thin, the field plate acts like a gate electrode. When d is relatively thick (≥0.3 µm), Vbr decreases at LFP = 0.3 µm as compared to the case of d = 0.1 µm, and it decreases to 250 V at d = 0.5 µm. This is because the field-plate effects become weak for thick d. The optimum thickness of the SiN passivation layer is approximately 0.1–0.2 µm and Vbr peaks at approximately 400 V when LFP = 0.3 µm. The novelty of this paper is to show the dependence of Vbr on the passivation-layer thickness d and the field-plate length LFP when the gate-drain distance is short.

Fabrication of All-GaN Integrated MIS-HEMTs with High Threshold Voltage Stability Using Supercritical Technology

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Micromachines
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In this paper, a novel method to achieve all-GaN integrated MIS-HEMTs in a Si-CMOS platform by self-terminated and self-alignment process is reported. Furthermore, a process of repairing interface defects by supercritical technology is proposed to suppress the threshold voltage shift of all GaN integrated MIS-HEMTs. The threshold voltage characteristics of all-GaN integrated MIS-HEMTs are simulated and analyzed. We found that supercritical NH3 fluid has the characteristics of both liquid NH3 and gaseous NH3 simultaneously, i.e., high penetration and high solubility, which penetrate the packaging of MIS-HEMTs. In addition, NH−2 produced via the auto coupling ionization of NH3 has strong nucleophilic ability, and is able to fill nitrogen vacancies near the GaN surface created by high temperature process. The fabricated device delivers a threshold voltage of 2.67 V. After supercritical fluid treatment, the threshold voltage shift is reduced from 0.67 V to 0.13 V. Our demonstration of the supercritical technology to repair defects of wide-bandgap family of semiconductors may bring about great changes in the field of device fabrication.

An Experimental and Systematic Insight into the Temperature Sensitivity for a 0.15-µm Gate-Length HEMT Based on the GaN Technology

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Micromachines
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Presently, growing attention is being given to the analysis of the impact of the ambient temperature on

the GaN HEMT performance. The present article is aimed at investigating both DC and microwave characteristics of a GaN-based HEMT versus the ambient temperature using measured data, an equivalent-circuit model, and a sensitivity-based analysis. The tested device is a 0.15-µm ultra-short gate-length AlGaN/GaN HEMT with a gate width of 200 µm. The interdigitated layout of this device is based on four fingers, each with a length of 50 µm. The scattering parameters are measured from 45 MHz to 50 GHz with the ambient temperature varied from −40 °C to 150 °C. A systematic study of the temperature-dependent performance is carried out by means of a sensitivity-based analysis. The achieved findings show that by the heating the transistor, the DC and microwave performance are degraded, due to the degradation in the electron transport properties.

Reverse blocking p-GaN gate AlGaN/GaN HEMTs with hybrid p-GaN ohmic drain

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Superlattices and Microstructures
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A normally-off reverse blocking high electron mobility transistor (HEMT) with p-GaN gate and hybrid p-GaN ohmic drain (p-GaN RB-HEMT) has been fabricated and investigated to achieve reverse blocking capability. Compared with conventional p-GaN gate HEMT with ohmic drain (p-GaN HEMT), the proposed device features that a p-GaN layer is embedded into the ohmic drain. This could realize not only the reverse blocking capability, but also the effective suppression of reverse leakage current based on the formed pn junction drain, and an ultralow reverse leakage current of < 1 nA/mm at -100 V and a reverse breakdown voltage of -688 V at 1 µA/mm have been achieved in the fabricated p-GaN RB-HEMT. In addition, the device shows a positive threshold voltage of 1.6 V and a forward breakdown voltage of 666 V. Meanwhile, the Von and Ron have a linear relationship with the increase in p-GaN drain dimension.

Impedance Characterization of AlGaN/GaN/Si High Electron Mobility Transistors

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Silicon
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AlGaN/GaN HEMTs grown on high resistive silicon (111) substrate grown by molecular beam epitaxy have been investigated using impedance measurements. Passivation of the HEMT devices is made in order to improve the electron transport. As has been found from conductance data, the electron traps are eliminated after passivation. The impedance spectroscopy has been, on the other hand, studied from the electrical transport. As a result, a complex impedance plot was revealed an equivalent circuit models indicating single semicircles and the solid interface.

Design optimization of high-frequency AlGaN/GaN HEMT on BGO substrates

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Applied Physics A
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In this paper, a T gate head AlGaN/GaN high-electron-mobility transistor (HEMT) on BGO substrate is proposed and optimization is done for channel length, gate length and gate position. The dc and ac characteristics of the devices under consideration are analysed using Silvaco TCAD software. The threshold voltage and transconductance of the proposed HEMT are extracted from the DC characteristics. The unity gain cut-off frequency (fT) and maximum oscillation frequency (fmax) are analysed for comparing the radio frequency characteristics. The T gate AlGaN/GaN HEMT on BGO substrate with channel length of 200 nm, gate length of 20 nm, gate source distance of 100 nm and gate drain distance of 80 nm exhibits optimum values for fT and fmax of 265 GHz and 900 GHz. The RF

performance of the optimized device is compared with other related recent technologies and found that the proposed device is superior among them.

Ku and Ka-band Gallium Nitride Monolithic Integrated Circuits on Silicon Substrates

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For the first time in Russia, the Mokerov Institute of Ultra High Frequency Semiconductor Electronics, Russian Academy of Sciences (IUHFSE, RAS) developed, manufactured, and investigated three types of monolithic integrated circuits for the Ku and Ka-bands based on gallium nitride heterostructures on silicon substrates with a diameter of 100 mm. The measured microwave characteristics of the obtained microcircuits are presented.

Polarization induced interface and electron sheet charges of pseudomorphic ScAlN/GaN, GaAlN/GaN, InAlN/GaN, and InAlN/InN heterostructures

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The piezoelectric and spontaneous polarization of wurtzite ScxAl1−xN, GaxAl1−xN, and InxAl1−xN ternary compounds dramatically affects the electrical properties of pseudomorphic MexAl1−xN/GaN, MexAl1−xN/AlN, and MexAl1−xN/InN heterostructures and devices (Me: = Sc, Ga, In), due to bound interface charges caused by gradients in polarization at surfaces and heterointerfaces. We have calculated the piezoelectric and spontaneous polarization of undoped, metal polar ScxAl1−xN barrier layers ($0 \le x \le 0.5$) pseudomorphically grown on InN, GaN, and AlN buffer layers, in order to compare the polarization induced surface and interface charges determined to the ones predicted and measured in heterostructures with GaxAl1−xN and InxAl1−xN barriers ($0 \le x \le 1.0$). To facilitate the inclusion of the predicted polarization in future simulations, we give explicit prescriptions to calculate polarization induced bound interface charges for arbitrary x and barrier thicknesses up to 50 nm in each of the ternary III-N alloy heterostructures. In addition, we predict the electron sheet charges confined in heterostructures with positive polarization induced interface charges taking limitations for the epitaxial growth by strain and critical barrier thicknesses into account. Based on these results, we provide a detailed comparison of the sheet resistances and current-carrying capabilities of the heterostructures investigated, pointing to a superior potential of ScAlN/GaN based heterostructures for processing improved high electron mobility transistors for high-frequency and power electronic applications.

Non-polar true-lateral GaN power diodes on foreign substrates

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Applied Physics Letters
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We have demonstrated non-polar GaN power diodes (Schottky barrier diode and p–n junction diode) on foreign substrates featuring the true-lateral p–n and metal–semiconductor junctions. The diodes were fabricated on GaN islands laterally overgrown on the mask-patterned sapphire and Si substrates by metalorganic vapor phase epitaxy. The anode and cathode were formed on the opposed a-plane sidewalls of the island, making the device architecture essentially like the 90° rotation of the desired true-vertical power diodes. The ideality factor of the Schottky barrier diode remained 1.0 (from 1.00 to 1.05) over 7 decades in current. Specifically, a high

critical electric field of 3.3 MV/cm was demonstrated on the p–n junction diode with avalanche capability. These performances reveal a strong potential of non-polar GaN with the true-lateral junctions for high power applications.

Impact ionization coefficients and critical electric field in GaN

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Avalanche multiplication characteristics in a reverse-biased homoepitaxial GaN p–n junction diode are experimentally investigated at 223–373 K by novel photomultiplication measurements utilizing above- and below-bandgap illumination. The device has a non-punch-through one-side abrupt p–-n+ junction structure, in which the depletion layer mainly extends to the p-type region. For above-bandgap illumination, the light is absorbed at the surface p+-layer, and the generated electrons diffuse and reach the depletion layer, resulting in an electron-injected photocurrent. On the other hand, for below-bandgap illumination, the light penetrates a GaN layer and is absorbed owing to the Franz–Keldysh effect in the high electric field region (near the p–n junction interface), resulting in a hole-induced photocurrent. The theoretical (non-multiplicated) photocurrents are calculated elaborately, and the electron- and hole-initiated multiplication factors are extracted as ratios of the experimental data to the calculated values. Through the mathematical analyses of the multiplication factors, the temperature dependences of the impact ionization coefficients of electrons and holes in GaN are extracted and formulated by the Okuto–Crowell model. The ideal breakdown voltage and the critical electric field for GaN p–n junctions of varying doping concentration are simulated using the obtained impact ionization coefficients, and their temperature dependence and conduction-type dependence were discussed. The simulated breakdown characteristics show good agreement with data reported previously, suggesting the high accuracy of the impact ionization coefficients obtained in this study.

Modeling of Bias-Dependent Effective Velocity and Its Impact on Saturation Transconductance in AlGaN/GaN HEMTs

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In this article, we present a surface-potential-based approach to model the bias-dependent effective velocity observed in AlGaN/GaN high-electron-mobility transistors (HEMTs) due to optical phonon scattering. Our model precisely reproduces the progressive decrease in the saturation velocity in GaN HEMTs with increasing gate voltages, as reported in the literature, which is predominantly due to the scattering of electrons, forming the high-density two-dimensional electron gas (2DEG), by optical phonons at high overdrive voltages. We show that this dependence differs from the traditional mobility degradation models in terms of its impact on the device current-voltage (I-V) characteristics and illustrate how the inclusion of a velocity saturation model also provides the model users with an additional handle for parameter extraction. The model is explicit and, by virtue of its Simulation Program with Integrated Circuit Emphasis (SPICE) compatibility, is readily implemented in the industry-standard Advanced SPICE Model for HEMTs (ASM-HEMTs) model and has been validated against experimental dc I-V and RF S-parameter measurements of an in-house GaN device.

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Effects of p-GaN Body Doping Concentration on the ON-State Performance of Vertical GaN Trench MOSFETs

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IEEE Electron Device Letters
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In this letter, we report the influence of p-GaN body doping concentration on the ON-state performance of vertical GaN trench MOSFETs. Decreasing the p-GaN body doping concentration leads to an enhanced maximum drain current (ID,max), reduced specific on-resistance (RON,sp), but also a decreased threshold voltage (Vth), suggesting that the p-GaN doping plays an important role in balancing the Vth, RON,sp and ID,max in vertical GaN trench MOSFETs. Resulting from the tuning of Mg concentration in the p-GaN, we demonstrate high ON-performance including a high ID,max of 2.8 kA/cm2, a low RON,sp of 0.87 mΩ·cm2, a large Vth of 4.8 V in a quasi-vertical GaN trench MOSFET on sapphire with a 2.5-µm-thick drift layer, while maintaining a breakdown voltage of 273 V.

Carrier Diffusion Lengths in Continuously Grown and Etched-and-Regrown GaN pin Diodes

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IEEE Electron Device Letters
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Advanced GaN power devices are promising for many applications in high power electronics but performance limitations due to material quality in etched-and-regrown junctions prevent their widespread use. Carrier diffusion length is a critical parameter that not only determines device performance but is also a diagnostic of material quality. Here we present the use of electron-beam induced current to measure carrier diffusion lengths in continuously grown and etched-and-regrown GaN pin diodes as models for interfaces in more complex devices. Variations in the quality of the etched-and-regrown junctions are observed and shown to be due to the degradation of the n-type material. We observe an etched-and-regrown junction with properties comparable to a continuously grown junction.

Temperature-Dependent Dynamic Degradation of Carbon-Doped GaN HEMTs

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Temperature-dependent dynamic degradation was investigated for C-doped GaN high electron mobility transistor (HEMT) from 300 to 20 K. Pulsed I-V measurements with various off-state quiescent bias voltages revealed that current collapse (C.C.) induced by charge-trapping effect at room temperature was greatly suppressed and monotonously declined as decreasing temperatures. This was attributed to reduced number of electrons which were injected into the C-doped layer and capable of overcoming capture potential barrier. Drain current transient measurements were employed to investigate temperature-dependent and time-resolved carrier capture/emission process. Based on the extracted time constants, an activation energy of 0.36 eV was identified for the electron capture process. For carrier emission process, both current-based and capacitance-based transient analysis indicated an activation energy around 0.20 eV. Furthermore, the traps were confirmed to be located in the C-doped layer by varying the pulse stimulus in deep-level transient spectroscope (DLTS). The measurement results showed that C-doped HEMTs grown on Si substrates exhibited high-saturation current, stabilized threshold voltage, and minor C.C. at cryogenic temperatures, particularly in comparison with those at room temperature.

Schottky Gate Induced Threshold Voltage Instabilities in p-GaN Gate AlGaN/GaN HEMTs

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IEEE Transactions on Device and Materials Reliability
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We present detailed on-state gate current characterization of Schottky gate p-GaN capped AlGaN/GaN s (s) on two distinct gate processes. The threshold voltage is monitored from 10 µs up to 100 s under positive gate bias stress and during recovery. The threshold voltage stability is affected by the balance between hole and electron current in the gate stack. More specifically, devices with uniform hole conduction across the p-GaN gate area demonstrate stable threshold voltage behavior up to Vg=5 V, whereas devices with a dominating gate perimeter electron conduction demonstrate larger instabilities. Finally, the threshold voltage stability during off-state pulsed stress is investigated and correlated to the excess gate-to-drain charge extracted from capacitance curves.

Generalized Frequency Dependent Small Signal Model for High Frequency Analysis of AlGaN/GaN MOS HEMTs

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IEEE Journal of the Electron Devices Society
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Traditional lumped small signal equivalent circuit models of AlGaN/GaN metal oxide semiconductor high electron mobility transistors (MOS-HEMTs) are made up of constant valued circuit elements. Such models are unable to capture the high frequency behavior (above 20 GHz) of the device. In this work, a modified small signal equivalent circuit model of AlGaN/GaN MOS-HEMTs is presented. The key feature of the proposed model is that the values of the different circuit elements in the model are considered to be frequency dependent in nature and not constants. The frequency dependent value of each circuit element is mathematically represented using polynomial functions where the coefficients of the functions are determined via a least-square curve fitting approach. This frequency dependent attribute of the circuit element values ensures that the proposed model is very accurate at high frequencies without sacrificing the compactness of the model topology. The accuracy of the proposed model has been verified up to 50 GHz using experimentally measured Y-parameters of AlGaN/GaN MOS-HEMTs having a different gate dielectric and gate length.

AlN/GaN Superlattice Channel HEMTs on Silicon Substrate

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High-electron-mobility transistor (HEMT) with AlN/GaN superlattice (SL) channel has been demonstrated on a silicon substrate. High off-state breakdown voltage VBR of 670 V (gate-drain spacing LGD = 8 µm) along with a maximum output current of 196 mA/mm, a channel electron total mobility of 507 $cm^2/V\cdot s$, and an on/off ratio of over 10^7 was achieved in this novel HEMT. For the HEMT with LGD = 22 µm, a high VBR of 1700 V was obtained with substrate floated. The influence of LGD, the gate-source voltage VGS, the isolated pattern, and substrate grounded and floated type was discussed to analyze the breakdown characteristics of HEMT. We investigated the trap states in the AlN/GaN SL channel of HEMTs by frequency-dependent capacitance and conductance measurements. A trap state density of 7.4 x 10^{12}-1.2 x 10^{13} $cm^{-2}eV^{-1}$ is located at ET in a range of 0.29-0.33 eV of the main channel, while the trap state density in the parasitic channel decreases from 3.9 x 10^{11} $cm^{-2}eV^{-1}$ at an energy of 0.27 eV to 1.1 x 10^{11} $cm^{-2}eV^{-1}$ at an energy of 0.38 eV. The fabricated AlN/GaN SL channel HEMTs in this work reveal a great step toward the realization of the SL channel HEMTs on cost-effective silicon substrate and provide a novel technology for AlGaN multichannel devices to obtain high output current.

A scalable large-signal model with self-heating effect based on a hybrid-scaling rule for GaN high-electron-mobility transistors

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In this paper, a novel hybrid-scaling rule for GaN high-electron-mobility transistors (HEMTs) scalable large-signal model with self-heating effect is proposed. Due to the complex parasitic characteristics of large gate-width GaN HEMT devices, nonlinear scaling rules are used to consider the dependence of the extrinsic inductances, extrinsic resistances, and thermal resistance on the gate width. In addition, a drain-source current model and gate capacitance models are proposed to improve the accuracy of traditional Angelov model. A one stage resistor-capacitor network is attached in the current model to characterize self-heating effect. Therefore, a scalable large-signal model based on a hybrid-scaling rule is presented for the first time. Compared with traditional linear scalable model, the proposed model has a good prediction for multi-bias S-parameters and direct current (DC) I-V curves of different size devices, and can also significantly improve the fitting degree of S22 parameter at high frequency. Moreover, the proposed scalable model shows a good prediction of large-signal characteristics for large size GaN HEMT devices.

Hybrid Load-Modulated Balanced Amplifier With High Linearity and Extended Dynamic Range

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IEEE Microwave and Wireless Components Letters
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A novel hybrid load modulation (LM) architecture of power amplifier (PA) is presented in this paper, in which three amplifiers are combined through a quadrature coupler in properly defined phase offsets. Together with the well-aligned turning-on sequence, the PA can operate as a Doherty PA (DPA) and load modulated balanced amplifier (LMBA) at different power levels, whose overall behavior is similar to a three-way DPA. This unique hybrid LM mode effectively extends the dynamic power range of efficiency enhancement, which is further compatible with the high-linearity design. This concept is experimentally validated using a GaN-based prototype at 3.56 GHz. The CW measurement shows an efficient PA performance with 49%–63% of efficiency from PMax to 9-dB back off. Under the modulated evaluation using 20-MHz LTE signal, an adjacent channel leakage ratio of -37.5 dB is measured together with 45% average efficiency.

Fabrication and Characterization of GaN-based Nanostructure Field Effect Transistors

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Solid-State Electronics
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Two different types of GaN-based nanostructure FETs, such as FinFETs and gate-all-around (GAA) nanowire FETs, have been investigated along with discussing their important performances for a possible new application. The GaN-based FinFETs have better electrostatic control compared to conventional planar-type GaN-based HEMTs, which offers great performance improvement such as very low off-state leakage current, high breakdown voltage, high linearity with broad transconductance. Recent investigation demonstrated that an appropriately designed AlGaN/GaN-FinFETs could exhibit low saturation drain voltage and very fast switching characteristics with subthreshold swing of sub-60 mV dec, which indicates that they can be a promising candidate for low voltage/power logic application. GAA GaN nanowire FETs have even better electrostatic control and exhibit excellent device performances showing their potential low voltage/power logic applications. For clear understanding of the device performances, simulation including two models concerning the multi-level trapping effects and the self-heating effects has been conducted, which leads to good agreement with the experimental results. Negative transconductance and offset-like output characteristics, observed in the narrow nanowire devices, have been well explained

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using the deep trapping effect and the built-in potential at ohmic contact. Scaling of the nanowire FET has been implemented such as channel length, doping concentration, and diameter of nanowire, which helps to predict further improvement of the device performance.

An Envelope Tracking Supply Modulator Utilizing a GaN-Based Integrated Four-Phase Switching Converter and Average Power Tracking-Based Switch Sizing With 85.7% Efficiency for 5G NR Power Amplifier

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This article proposes a supply modulator (SM) that uses high switching frequency gallium-nitride (GaN) devices to achieve a four-phase fast step-down converter for the fast-tracking ability of the envelope tracking (ET). The ET signal is reshaped to generate an average power tracking (APT)-based signal to control the size of GaN switches to further increase light-load efficiency due to reduced switching loss. Moreover, a high-bandwidth and low-loss linear amplifier (LA) is used to supply the power amplifier (PA) to sufficiently provide fast-tracking speed for 5th generation (5G) NR ET. At a power of 3.5 W for 5G mobile phones, the peak efficiency that is tested with NR -130 MHz in the ET mode is as high as 85.7% over a wide load range.

Gate Dielectric Material influence on DC behavior of MO(I)SHEMT devices operating up to 150 °C

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Solid-State Electronics
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In this work, the DC behavior of AlGaN/GaN Metal-Insulator-Semiconductor high electron mobility transistors (MO(I)SHEMTs) with two different gate dielectrics (Al2O3 and Si3N4) is analyzed through the experimental comparison of their basic and analog parameters. The transistors with Si3N4 insulator are more closely related to the normally-off devices (less negative threshold voltage) and less affected by the short channel effects (better DIBL behavior). Although the devices with Si3N4 layer presented a double conduction, that results in anomalous transconductance behavior, it is more suitable for analog applications since the Al2O3 devices suffer large self-heating. The very high gate leakage of Si3N4 MISHEMT degrades the subthreshold regime, which decreases the transistor efficiency at weak inversion. On the other hand, the devices with Si3N4 insulator present relatively large Early voltage and consequently high intrinsic voltage gain in strong inversion, reaching 84 V/V (38.5 dB). Even at high temperatures the intrinsic voltage gain is practically the same, degrading only 1.5 dB from 25 oC to 150 oC for a long channel device.

Demonstration of vertically-ordered h-BN/AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors on Si substrate

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Materials Science and Engineering: B
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AlGaN/GaN metal–insulator-semiconductor high-electron-mobility transistors (MISHEMTs) have been demonstrated with 22 nm thick vertically ordered (VO) h-BN by high-power impulse magnetron sputtering deposited at room temperature for the first time. About two orders of magnitude lower gate leakage current was observed in VO h-BN/AlGaN/GaN MIS-diodes compared to conventional Schottky diodes. The fabricated MISHEMT and HEMT with 2 µm gate-length exhibited a maximum drain current density (IDmax) of 685 and 467 mA/mm and a maximum extrinsic transconductance (gmmax) of 93 and 134 mS/mm, respectively. The VO h-BN/AlGaN/GaN MISHEMT with improved characteristics is due to an enhanced sheet carrier density (from 7.29 × 1012 cm−2 to 1.10 × 1013 cm−2) by surface passivation of VO h-BN as well as the good VO h-BN/GaN interface

quality with a minimum interface state density of 2.6 × 1012 cm-2eV−1.

Electrical properties of 90-nm InAlN/GaN HEMT on silicon substrate

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GaN high-electron-mobility transistors (HEMTs) on silicon substrate have attracted much attention owing to the low-cost and the large area availability of the Si substrate. In this paper, the 90-nm-gate-length InAlN/GaN HEMT on silicon was fabricated and the device electrical properties were studied. The device presents a low drain-induced barrier lowing (DIBL) of 43 mV/V, a parasitic source resistance (RS) of 0.91 Ω·mm, and a peak of the intrinsic transconductance (gm0) of 553 mS/mm. To the best of our knowledge, this is the lowest DIBL value among the reported GaN HMET on Si with gate length (Lg) below 100 nm. The low-filed two-dimensional electron gas (2DEG) electron mobility (μn) was extracted and the dominated polarization Coulomb field scattering contributed to the increased μn with the increased of two-dimensional electron gas electron density (n2D). A current gain cutoff frequency (fT) of 175 GHz was achieved on InAlN/GaN HEMTs with a gate length of 90-nm.

Analog Performance of GaN/AlGaN High-Electron-Mobility Transistors

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Solid-State Electronics
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In this paper, the analog properties of advanced GaN/AlGaN High-Electron-Mobility Transistors (HEMTs) are studied as a function of temperature (T). The drain current, the threshold voltage, the transconductance and the output conductance are experimentally investigated under saturation operation. Moreover, important figures of merit for the analog performance such as transconductance-over-drain current, Early voltage and intrinsic voltage gain are analyzed for different channel lengths in the temperature range of 25°C till 200°C. The results indicate that due to change in the Fermi potential, the analog parameters reduce with increasing T. Furthermore, the performance increase for longer channel devices is correlated directly with the lower drain electric field penetration.

Accurate Statistical Extraction of AlGaN/GaN HEMT Device Parameters Using the Y-function

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A new protocol based on Y-function is used for accurate statistical extraction of electrical parameters of High Electron Mobility Transistor (HEMT) devices for GaN technology. This protocol presented here is used for extraction of relevant electrical parameters such as oxide capacitance, threshold voltage, effective mobilities and access resistance. This study has been verified over a large range of channel lengths for two normally-off HEMT GaN wafers having different levels of access resistances.

Low-Frequency Noise Investigation of AlGaN/GaN High-Electron-Mobility Transistors

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Solid-State Electronics
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In this paper, the noise Power Spectral Density (PSD) of AlGaN/GaN High-Electron-Mobility Transistors (HEMTs) has been experimentally investigated in

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linear operation (VD = 50 mV) for different channel lengths (L) and widths (W) at different temperatures (5.32°C till 100°C). The origin of the noise will be analyzed to understand the physical mechanisms involved. It is shown that the Low-Frequency (LF) noise is dominated by 1/f noise, originating from number fluctuations. Additionally, in shorter devices, a higher 1/f noise PSD is found. The LF noise characteristics indicate that the AlGaN/GaN HEMTs on silicon substrates can be a promising candidate for analog and Radio Frequency applications (RF).

Improved on-state performance in AlGaN-channel heterojunction field-effect transistors with a quaternary AlGaInN barrier layer and a selectively grown n++-GaN contact layer

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Materials Science in Semiconductor Processing
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Al0.19Ga0.81N-channel metal-insulator-semiconductor heterojunction field-effect transistors (MIS-HFETs) with a quaternary AlGaInN barrier layer and a selectively regrown n++-GaN contact layer were fabricated using the self-alignment selective-area growth (SAG) technique. The self-alignment SAG process was accomplished by the local-area etching process and the subsequent refilling process with a highly-Si-doped n++-GaN layer by metalorganic chemical vapor deposition (MOCVD). It was confirmed that the ohmic contact resistance was drastically reduced from 10.5 Ωmm to 2.5 Ωmm via the self-alignment SAG contacts. Further, fabricated MIS-HFETs with a gate length of 1.5 µm and a drain-to-source length of 9.5 µm exhibited a high drain current density of over 300 mA/mm with a drain-to-source resistance of approximately 25 Ω mm. The fabricated devices also showed a high off-state breakdown voltage of 1220 V at a gate-to-drain length of 10 µm, corresponding to a breakdown field of 122 V/µm.

Selective area regrowth and doping for vertical gallium nitride power devices: Materials challenges and recent progress

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This paper reviews materials challenges and recent progress for selective area regrowth and doping for vertical gallium nitride (GaN) power devices. The purpose is to realize randomly placed, reliable, contactable, and generally useable laterally patterned p-n junctions, which are the building blocks for various advanced power rectifiers and transistors. The general regrowth process and regrowth dynamics in trenches were discussed, where the effects of trench geometries, growth methods, and bulk substrates were elucidated. Comprehensive materials characterization techniques were utilized to analyze the regrown structures, including scanning electron microscopy, transmission electron microscopy, atom probe tomography, scanning probe microscopy, and secondary-ion mass spectrometry. Cathodoluminescence and secondary electrons in scanning electron microscopy and atom probe tomography were used to achieve lateral and vertical dopant profiling at a sub-micron scale. The regrowth interface after dry etching accumulated a high density of impurities and charges, contributing to the formation of a p+-n+ tunneling junction. This hypothesis was further confirmed by the electrostatic potential profile at the regrowth interface using electron holography. Novel etching technologies were investigated to improve the regrowth interface. It was found that low-power dry etching significantly reduced the interfacial charges and the reverse

leakage currents of regrown p-n junctions. Photoelectrochemical wet etching was found to be effective in reducing deep-level defects near the regrowth interface. Atomic layer etching uses self-limiting chemical processes, thus removing the damaged layers without inducing further etching damage. Tertiarybutylchloride-based in situ etching may serve as an alternative etching method to dry etching with reduced etching damage. In terms of devices, regrown p-n junctions with low leakage currents and vertical junction field-effect transistors were demonstrated. Further improvements in selective area regrowth and associated devices can be expected using regrowth optimization and regrowth interface engineering via surface treatments and low-damage etching. These results represent an important step towards realizing selective area regrowth and doping for high performance GaN power electronics devices and systems.

Electrical and thermal analysis of AlGaN/GaN HEMTs transferred onto diamond substrate through an aluminum nitride layer

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Microwave and Optical Technology Letters
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In this paper, electrical and thermal analysis of short gate length AlGaN/GaN HEMTs (high electron mobility transistors) transferred onto diamond substrate through aluminum nitride (AlN) layer are provided. The specific transfer technology uses sputtered AlN as bonding layer. An improvement in maximum DC current density of 14% is observed after transfer on the diamond substrate, with attractive RF performances as well. Lag effects are evaluated thanks to pulsed measurement. Thermal analysis is also proposed to quantify the effects of bonding on self-heating. Both electrical and thermal characterizations are used as markers to evaluate the impact of the transfer process on the developed HEMT.

Generation of two-dimensional electron gas to normally depleted AlGaN/GaN hetero-interface by SiO2 deposition and subsequent high-temperature annealing

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Electronics Letters
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SiO2 film deposition and subsequent high-temperature annealing resulted in the generation of a two-dimensional electron gas (2DEG) at Al(Ga)N/GaN hetero-interfaces, of which the 2DEG was originally fully depleted. The obtained mobilities and sheet carrier concentrations were over 1100 cm2/Vs and 3.0 × 1012 cm–2, respectively. Surface energy lowering, which is proof of the generated 2DEG, was observed by electron state analysis using hard X-ray photoelectron spectroscopy. This damage-less method that selectively generates a 2DEG can contribute not only toward improving some characteristics in existing devices but also toward creating entirely novel devices.

Ridge-channel AlGaN/GaN normally-off high-electron mobility transistor based on epitaxial lateral overgrowth

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Semiconductor Science and Technology
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A ridge-channel AlGaN/GaN high-electron mobility transistor (HEMT) utilizing selective-area growth and epitaxial lateral overgrowth (ELO) technique is proposed in this work to achieve high-performance normally-off devices. It has a c-plane platform for the source and the drain contacts, and sidewalls of $\left\{

{10-11} \right\} lattice plane for the gate contact. The sidewalls have characteristics of weak polarization and thin barrier, which are advantageous for realizing normally-off operation. Two ridge HEMTs with triangular and trapezoid channel are designed. Theoretical simulation demonstrates a threshold voltage of 0.03 V for the sidewall channel with reduced polarization and barrier thickness, and a threshold voltage of 1.1–1.3 V for the ridge HEMTs assuming no polarization charge in sidewall channel. The ridge-channel device also exhibits high saturation drain current. The ELO-based ridge-channel opens a new way to achieve normally-off AlGaN/GaN HEMT.

Modeling dislocation-related reverse bias leakage in GaN p–n diodes

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

Finite element analysis software was used to model and visualize two p-n junction models: one with a single threading dislocation (TD) and a control without one. TDs are modeled as a Gaussian distribution of trap states with a full width at half maximum value of 5 nm localized around the $r = 0$ line in a cylindrical coordination such that the linear trap state density was 1 trap c−1-translation; this model allows the cylindrical symmetry of the c-plane GaN crystal orientation to be used to avoid more computationally intensive 3D models. In this work, a vertical p–n diode with typical doping characteristics and an equivalent threading dislocation density of ${10^8}{\textrm{ c}}{{\textrm{m}}^{ - 2}}$ was modeled in reverse bias. Our simulations show that the dislocation-mediated leakage mechanism for reverse bias leakage in GaN p–n diodes is the generation of electron–hole pairs via a trap-assisted tunneling mechanism whereby electrons from the valence band use the intermediate trap state to traverse the band gap. This mechanism results in electron–hole pairs that are swept out of the junction by the reverse bias electric field. This behavior results in a measurable leakage current within the model with behavior consistent with experimental values.

Design of PAMBE-based selective-area growth compliant ultra-low leakage GaN mixed-conduction vertical diodes for high-power applications

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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/abfe19

Modern high-speed power applications require diodes with high-current capacity, larger reverse blocking voltage, lower reverse recovery transients, and lower leakage. GaN mixed-conduction vertical diodes are an attractive option for these operations. Experimentally reported GaN diodes have two major shortcomings, namely, higher leakage due to non-optimum design and conventional processing methods (e.g. ion implantation and dry etching), introducing huge leakage components. In this work, we design ultra-low leakage GaN buried p-base merged p–i–n Schottky and buried p-base merged p–i–n junction barrier controlled Schottky diodes, capable of reducing leakage current by more than five orders of magnitude by virtue of strong reduced surface field effect. Moreover, these designs are fully compliant with our earlier reported silicon nitride shadowed selective-area growth (SNS-SAG) methodology, capable of reducing the leakage by at least four orders of magnitude. In combination with SNS-SAG and highly efficient dielectric vertical sidewall edge termination scheme, these designs provide attractive options for higher performance.

Effects of Dielectric Passivation on Device Performance of AlGaN/GaN High-Electron-Mobility Transistors

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ECS Journal of Solid State Science and Technology
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Various dielectrics deposited on the surfaces of AlGaN/GaN-based metal-gate high-electron-mobility transistors (HEMTs) were investigated to understand

their effects on the device characteristics. The observed increase by 30% in the two-dimensional electron gas (2DEG) sheet carrier density by the deposition of SiO_2, Si_3N_4, or Al_2O_3 was in line with the improved output and transfer characteristics of the HEMT devices with the deposited dielectrics, as compared to those of the bare HEMT device without dielectric. The improvements seemed to result from the strain accumulation in AlGaN due to the difference in thermal expansion between AlGaN and the dielectric and from the effective treatment of surface electrical passivation by the deposited dielectric. Furthermore, suppression of current collapse was observed in the SiO_2− and Si_3N_4−deposited samples, as compared to the bare HEMT device.

Investigation of Multiple-Mesa-Nanochannel Array GaN-Based MOSHEMTs with Al2O3 Gate Dielectric Layer

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In this work, an atomic layer deposition system was used to deposit Al_2O_3 high-k dielectric film as the gate insulator of GaN-based metal-oxide-semiconductor high-electron mobility transistors (MOSHEMTs). By using the Al_2O_3 gate dielectric layer, compared to planar channel structure, the direct current, high frequency, and flicker noise performances were improved in the GaN-based MOSHEMTs with fin-nanochannel array. For the GaN-based 80-nm-wide fin-nanochannel array MOSHEMTs, they exhibited superior performances of maximum extrinsic transconductance of 239 mS mm^{-1}, threshold voltage of –0.4 V, unit gain cutoff frequency of 7.3 GHz, maximum oscillation frequency of 14.1 GHz, normalized noise power of 2.5 × 10^{-14} Hz^{-1}, and Hooge's coefficient of 1.4 × 10^{-6}. The enhanced performances were attributed to the features of fin-nanochannel array of better gate control capability, enhanced pinch-off effect, and better heat dissipation driven by lateral heat flow within the space between fin-channels.

The influence of polarization Coulomb field scattering on the parasitic source resistance of E-mode P-GaN/AlGaN/GaN heterostructure field-effect transistors

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E-mode P-GaN/AlGaN/GaN heterostructure field-effect transistors (HFETs) of various sizes were fabricated, and their parasitic source resistance (RS) was measured. The measurement results showed that RS varied greatly with changing gate bias, and the degree of RS change also differed with the gate bias of different-sized device samples. Through theoretical analysis, it is found that polarization Coulomb field (PCF) scattering caused by the device process and gate bias can affect electron mobility (µGS) in the gate-source region, which causes the variations in µGS for different-sized devices and same-sized devices under different gate biases. When µGS changes with the device size and gate bias, the RS will change accordingly. Our study is the first to discover the gate bias dependency of RS for E-mode P-GaN/AlGaN/GaN HFETs due to PCF scattering, which provides a new idea for further in-depth studies on the RS of E-mode P-GaN/AlGaN/GaN HFETs and device performance optimization.

E/D-Mode GaN Inverter on a 150-mm Si Wafer Based on p-GaN Gate E-Mode HEMT Technology

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Micromachines
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AlGaN/GaN E/D-mode GaN inverters are successfully fabricated on a 150-mm Si wafer. P-GaN gate technology is applied to be compatible with the commercial E-mode GaN power device technology platform and a systematic study of E/D-mode GaN inverters has been conducted with detail. The key electrical characters have been analyzed from room temperature (RT) to 200 °C. Small variations of the inverters are observed at different temperatures. The logic swing voltage of 2.91 V and 2.89 V are observed at RT and 200 °C at a supply voltage of 3 V. Correspondingly, low/high input noise margins of 0.78 V/1.67 V and 0.68 V/1.72 V are observed at RT and 200 °C. The inverters also demonstrate small rising edge time of the output signal. The results show great potential for GaN smart power integrated circuit (IC) application.

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

ST introduces GaN product family for automotive applications

SemiconductorToday

STMicroelectronics of Geneva, Switzerland has launched a new family of ST intelligent and integrated gallium nitride (GaN) solutions. STi2GaN combines power and intelligence in compact, high-performance solutions required by the automotive industry as it shifts to electrified platforms.

Building on ST's automotive experience, innovations in smart power technology, wide-bandgap semiconductor materials and packaging expertise, the STi2GaN family combines a monolithic power stage along with drivers and protections in GaN technology as well as system-in-package (SiP) solutions for application-specific ICs with additional processing and control circuitry. The STi2GaN solutions use ST's novel bond-wire-free packaging technology to provide what is claimed to be high robustness, reliability and performance.

"Initial offering of STi2GaN solutions suit on-board chargers, LiDAR [light detection & ranging] for autonomous driving, bidirectional DC-DC converters, Class-D amplifiers and power conversion systems," says Alfio Russo, group VP & general manager Low Voltage and STi2GaN Solutions Macro Division, at STMicroelectronics. "The new product family aims to leverage the high power density and efficiency of GaN to offer an industry-unique range of devices in 100V and 650V clusters that ensure scalability, compactness, and outstanding performance."

ST says that it is already engaged with key partners.

Transphorm's revenue grows 20% in Q1 to record $2.4m, driven by increased GaN adoption

SemiconductorToday

In preliminary results for first-quarter 2021, Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V and 900V gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications — expects revenue of about $2.4m (up 20% on Q4/2020's $2m), driven by increased adoption of the firm's GaN power device products in applications ranging from 45W fast chargers/adapters to 1-4kW crypto-mining power supplies, gaming and data-center servers, and higher-power industrial, UPS (uninterruptible power supply) and automotive converter/inverter applications.

"We also achieved a key milestone of shipping more than 1 million GaN devices that address power ranges from 45W to 10kW, which is an industry first," says president & co-founder Primit Parikh. "The doubling of our volume shipments from the third quarter to the fourth quarter of 2020, and then doubling shipments again sequentially in the first quarter of 2021 demonstrates customers' growing recognition of the differentiating performance and reliability of Transphorm's GaN power devices as well as our robust supply-chain capabilities."

Also, Transphorm expects GAAP operating expenses to rise by about 10% in Q1/2021, from Q4/2020's $4.5m.

After approval by its board of directors, Transphorm completed the change of its fiscal year-end from 31 December to 31 March as part of preparations for a planned uplist to the Nasdaq Capital Market.

The Next Wave of Gallium Nitride

PowerElectronicsNews

At PCIM – this year in digital version – several companies are showing their latest innovations. The GaN power market doubled in 2020 according to Yole report, highlighting the impressive growth of smartphone fast chargers and leading the way for telecom and automotive markets.

"In the new GaN Power 2021: Epitaxy, Devices, Applications and Technology Trends report, in the consumer market, GaN enjoyed a successful year in 2020 thanks to several companies, such as Xiaomi, Lenovo, Samsung, Realme, Dell and LG, as well as other Chinese aftermarket companies that adopted GaN technology," said Ahmed Ben Slimane, PhD, Technology & Market Analyst, Compound Semiconductors and Emerging Substrates and Poshun Chiu, Technology & Market Analyst specializing in Compound Semiconductor and Emerging Substrates at Yole Développement (Yole).

Yole expects the GaN consumer power supply market to be the main driver representing more than 60% of market share in 2026. The total GaN device market is forecast to grow from US$46 million in 2020 to around US$1.1 billion in 2026 with a CAGR of 70%. "GaN is critical to helping meet energy efficiency initiatives, including the EU Lot 9 requirements for Titanium efficiency power supply units," said Paul Wiener, VP of Strategic Marketing, GaN Systems.

Alex Lidow, CEO at EPC, highlighted three particular devices: EPC9146, EPC9137, EPC9149. "The EPC9146 is a 400 W motor drive demonstration. GaN provides the fast switching, small size, and low cost needed to further reduce the size and weight of BLDC motors, reduce audible noise, improve torque for faster reaction times, and increase efficiency. The EPC9137 is shown at PCIM for a GaN-based 3 kW 48 V to 12 V DC-DC converter. The higher switching frequency of GaN results in a solution that is 35% smaller, it results in 10 W lower inductor DCR losses, and it reduces the cost of the system by about 20% over the MOSFET solution. The EPC9149 is a 1 kW eGaN FET-based LLC resonant converter in the 1/8th power brick size for 48 V server applications. Silicon-based solutions need to be in the ¼ brick format to reach 1 kW! The EPC9149 1 kW LLC resonant converter achieves 97.6% peak efficiency and 96.5% full-load efficiency," said Lidow.

GaN Systems announced a few big things in the year from an industry and product perspective. "We recently announced shipment of our 20 millionth GaN transistor and a 40X capacity expansion (completed this year). We announced that GaN, for some applications, is now under $100 (USD). We introduced a new 650V, 60A transistor (GS-065-060-5-T-A) for the automotive market for wide-ranging applications from OBCs, DC-DC converters, EV traction inverters, and electronic power steering. It meets our industry-leading AutoQual+ qualification process providing lifetimes consistent with the automotive industry requirements," said Wiener.

nexperia

Nexperia has announced its latest second-generation GaN technology. With RDS(on) performance down to 35 mΩ (typical), the new power GaN FETs target single phase AC/DC and DC/DC industrial switched mode power supplies (SMPS), ranging from 2 kW to 10 kW, especially server and telecoms supplies that must meet 80 PLUS Titanium efficiency regulations. The devices are also an excellent fit for solar inverters and servo drives in the same power range. "One of the great things about emerging technologies like GaN, giant leaps in performance from one generation to the next. All the

big wins have already been achieved in silicon, much more about incremental advances at this point in the technology life cycle," said Chris Boyce, Marketing & Product Group Director at Nexperia.

EPC's GaN technology for time-of-flight/lidar is used in an increasing array of applications from drones to robotics to autonomous vehicles and even vacuum cleaners. Lidow pointed out that high density computing, particularly in the 48 V architecture, has taken off and here GaN offers a significant advantage in efficiency, size, and system costs. "A high growth area is in motor drives for robotics, drones, escooters, and ebikes where GaN offers a smaller/lighter, low-cost solution with reduced audible noise, increases efficiency, and higher precision movement. Another high growth area is in the space market where GaN has an enormous advantage in terms of electrical performance and radiation performance over the incumbent Rad Hard MOSFET," said Lidow.

Nexperia is pushing GaN technology in car industry: on-board chargers, DC-DC and traction inverters; Industrial: Switched Mode Power Supplies (SMPS), especially 80 PLUS Titanium (highest) class efficiency @ 2KW and solar inverters and servo motor control.

"We launch CCPAK to market in early Q4. Bringing our proven 20+ years of developing robust copper-clip package technology to our GaN FETs portfolio. CCPAK1212 (12mm x 12mm) will be available in AEC-Q101 qualified top and bottom side package options," said Boyce.

EPC has continued to push towards integrated solutions. "There will also be an expansion of the ePower Stage family (EPC2152) which integrates the entire half-bride power stage into a single device. Integrated devices in a single chip are easier to design, easier to layout, easier to assemble, save space on the PCB, increase efficiency, and reduce cost," said Lidow.

Paul Wiener said that one new solution debuting around PCIM is a new 3kW full-bridge LLC resonant converter design. "It pairs with our 3kW bridgeless totem-pole PFC reference design for data center, telecom, and industrial switching mode power supply (SMPS) applications. It exceeds the 80 PLUS Titanium standard for power supply units, achieving high power density (PFC+DC/DC) above 100W/inch3 and high efficiency of more than 96 percent, meeting Lot 9 and new requirements for data centers. Additionally, we're featuring the industry's smallest and smartest 100W GaN Charger reference design. It has the industry's highest power density and smartest power distribution to maximize efficiency dependent upon the number and power of devices plugged into the charger," said Wiener.

Navitas

Stephen Oliver, VP Corporate Marketing & Investor Relations at Navitas Semiconductor, said to Power Electronics News that with silicon chips in short supply, it's up to GaN to ramp up production very quickly to meet extreme demand and also to initiate new applications and markets that silicon can't reach. "GaN chargers dominate the mobile consumer space. The Mobility space is very busy for prototyping, but for immediate mass production we'll see industrial applications (including 5G base stations) and data centers for AC-48V and 400V input DC-DC. For Gallium Nitride, 2021 is all about intense adoption rate, steep production ramp and high quality. As of April 1st, Navitas had shipped over 18,000,000 GaN power ICs and with zero failures," said Oliver.

power integrations™

During several panels at PCIM, Doug Bailey, Vice President Marketing, Power Integrations highlighted that with the new Gan technology, we're able to build power supplies that are very highly efficient, and don't require heat sinks at all. "It's a fact of physics, that as size increases, your conduction losses will drop, because now you've got more area to conduct. But your switching losses go up because the capacitance of the device goes up. So there's really a limit to what you can do with

MOSFETs and GaN changes the equation because as device size gets bigger, obviously your conduction goes down, but your switching losses go down," said Bailey.

Philip Zuk, Vice President Technical Marketing, Transphorm, during PCIM pointed out the ability to build strategic relationships with other complimentary semiconductor suppliers, as well as different market opportunity customers. "We have formed a cooperation with microchip and their DSP technology. This allows transform to focus on GaN core competency and Microchip to focus on its core DSP competency with their microcontrollers and development environment. The winner here is the end customer. The true key to the success of any semiconductor supplier is being able to deliver massive amounts of product into the market."

The ability of GaN to maximize power density is due to its superior switching performance, as highlighted by Steve Tom, Product Line Manager GaN at Texas Instruments. What this means for the system is that the switching frequency can be much faster, resulting in much smaller magnetics. "GaN enables the highest power density and efficiency at lowest costs, both compared to existing Mosfet technologies as well as emerging silicon carbide devices. Moreover, GaN lends itself well to higher levels of integration. For example, integrating the gate driver can reduce power loss and can simplify and solve system challenges by monitoring voltage, current and temperature," said Tom.

Ran Soffer, SVP Sales and Marketing, VisIC Technologies, highlighted that the superior potential of GaN and specifically GaN high electron mobility transistor over silicon carbide comes from several advantageous physical properties such as higher critical electric field.

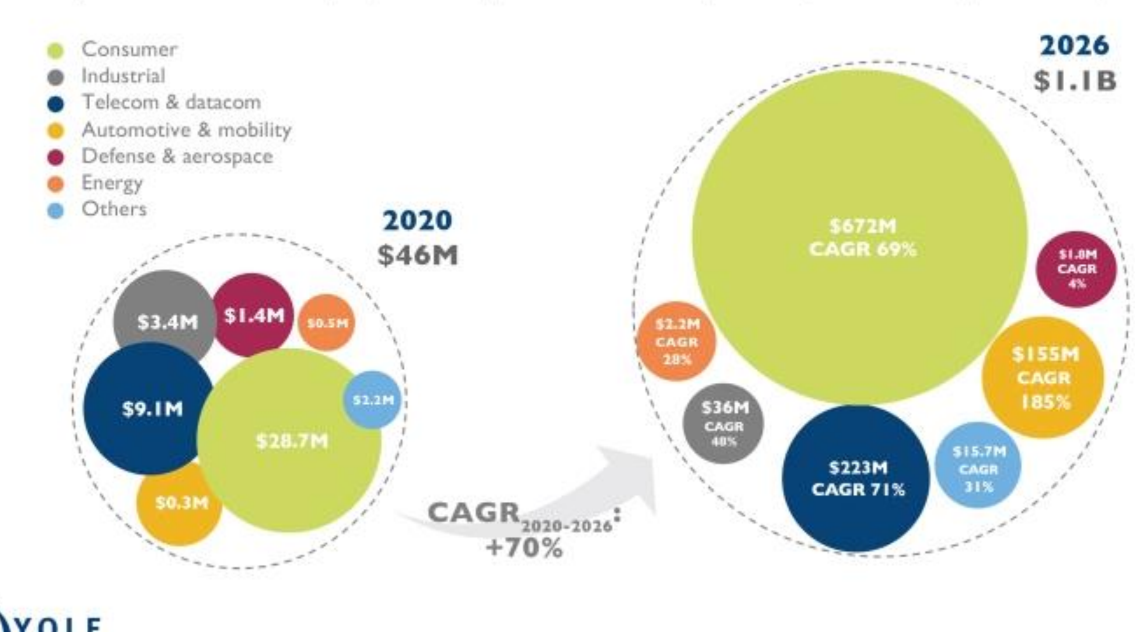


Figure 1: 2020-2026 Power GaN Market Forecast (Source: Yole)

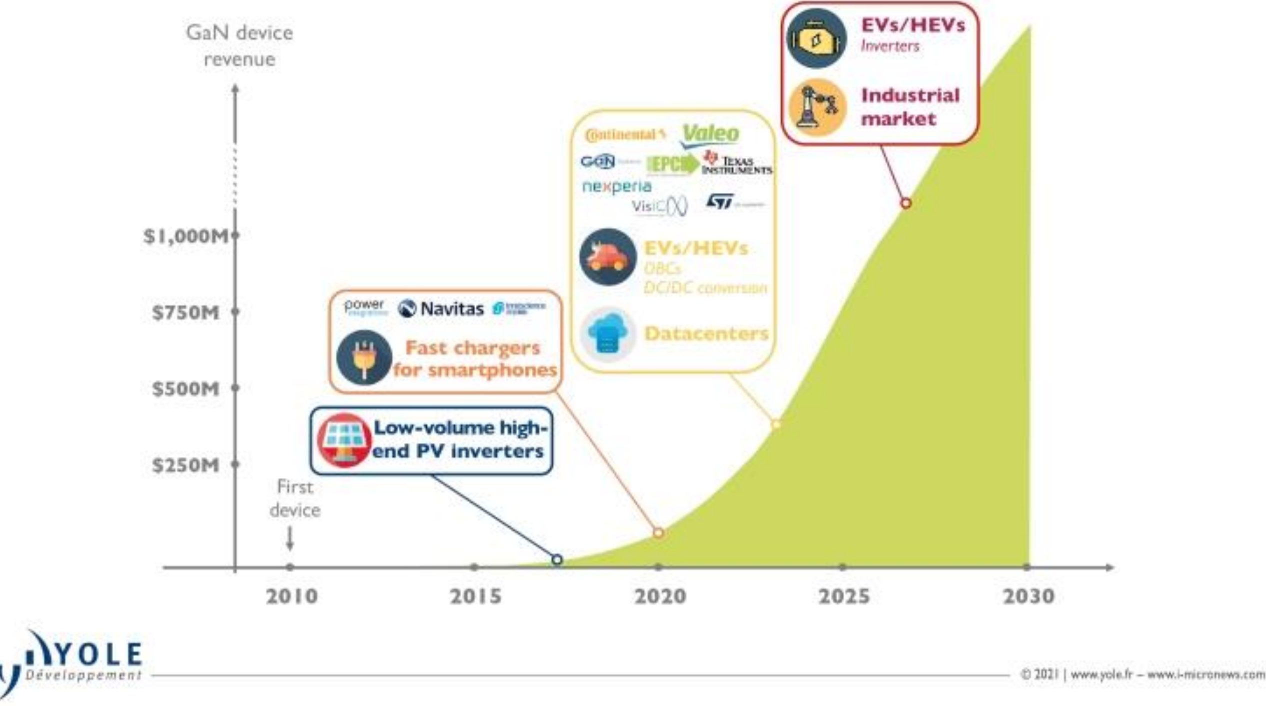


Figure 2: Roadmap for GaN Power (Source: Yole)

What next?

As discrete devices achieve increasingly higher power densities, it will no longer be possible to extract the current in and out of the bumps and bars on the devices. Therefore, Lidow highlighted that integration into small, multi-chip, multi-function integrated circuits will be necessary. “There are some challenges remaining before complete system-on-chip solutions in GaN can be achieved. What is required to overcome these challenges is the extremely rapid development of process design kits that automate the design function of the IC, and iterations of design kits that keep pace with the rapid pace of technology development,” said Lidow.

Boyce pointed out that the core Power GaN proposition is all about scale. “The scale advantage of power GaN will really be seen as volumes increase because power GaN devices can be processed in existing silicon fabs (unlike SiC). Not everyone gets this at the moment because SiC and GaN are only just getting started in mass production terms. But just look at the forecasted EV ramp up in the coming years! We have seen in recent months just how dependent nearly everything is on semiconductors and the supply disruption across multiple product categories that occurs when there are shortages. Supply security for automotive manufacturers making the strategic transition from internal combustion engines to EVs will be the #1 priority and this is where power GaN solutions will excel,” said Boyce.

SiC has great thermal performance as Oliver highlited, “but with an expensive SiC-on-SiC vertical construction that can’t be monolithically integrated, and with significant speed limits, it’s restricted to high-current applications like wind turbines and railway locomotives. GaN’s lateral structure and low-cost GaN-on-Si manufacturing make high-speed, high-feature GaN power ICs possible that enable next-generation power for everything from fast mobile chargers and 8K TVs to fast on-board chargers for EVs.”

Wiener added, “We will continue to see more companies offer GaN solutions now that we have established the market. This is a good sign, further validating that GaN is the preferred solution. Regarding SiC, we see now that customers go to GaN as the default; it has better performance and is known to be lower cost. They select SiC where they must use it, typically in 800V and higher applications. Overall, GaN has many advantages over SiC, including reliability and cost.”

Yole highlighted that, in the long term, in cases where GaN has proven its reliability and high-current capabilities at a lower price, it can penetrate the more challenging EV/HEV inverter market and the conservative industrial market, which could create remarkable high-volume opportunities for GaN. In fact, Nexperia and VisIC are working on GaN solutions for xEV inverters to compete with SiC and Si.

Navitas to go public via Live Oak II

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA and Dublin, Ireland has entered into a definitive agreement to combine with Live Oak Acquisition Corp II (Live Oak II), a publicly traded special-purpose acquisition company (SPAC). The transaction, which values the combined entity at a pro forma equity value of $1.4bn, will result in Navitas becoming a publicly traded company on a national exchange under a new ticker symbol.

GaN is reckoned to run up to 20x faster than silicon, and enables up to 3x more power or 3x faster charging in half the size and weight. Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs, which monolithically integrate GaN power field-effect transistors (FETs) with drive, control and protection circuits, enabling faster charging, higher power density and greater energy savings.

Driven by increasing demand for connectivity, electrification away from fossil fuels, and efficient sustainable energy sources, Navitas predicts that GaN ICs can address markets that are estimated to grow to over $13bn in 2026. Markets include mobile, consumer, enterprise (data center, 5G), renewables (solar, energy storage) and electric vehicles (EVs)/eMobility.

Navitas is in mass production and ramping shipments to many major OEMs and after-market suppliers, including Dell, Lenovo, LG, Xiaomi, OPPO, Amazon, Belkin and dozens of others. Over 18 million GaNFast power ICs have been shipped, with zero reported field failures.

With a proprietary process design kit (PDK) and over 120 patents granted or pending, Navitas reckons that it has an early-mover advantage in the GaN market. A robust roadmap for new GaN generations and continued cost reductions is helping to accelerate the transformation away from CO2-burdened fossil fuels. Navitas estimates that GaN can impact up to 2.6Gtons of CO2 reduction annually by 2050.

“Navitas was formed with the vision to revolutionize the world of power electronics while addressing significant sustainability challenges for our planet,” says Navitas’ co-founder & CEO Gene Sheridan. “Not only has Navitas’ world-class team invented and patented revolutionary new technology, but we have also overcome all the key hurdles associated with successfully bringing it to market. We are proud to enter the public capital markets with strong operating momentum and investor partners who share our enthusiasm for our long-term mission,” he adds.

“This is the most compelling opportunity we have seen in the semiconductor industry, and we are delighted that Navitas’ solutions contribute meaningfully to reduced carbon emissions through more efficient power delivery,” comments Live Oak’s CEO Rick Hendrix. “The capital raised through this transaction will allow Navitas to accelerate

that vision as they expand from mobile and consumer markets into even more power-intensive applications like data centers, solar energy and electric vehicles – all while delivering a significant CO2 reduction as part of their Net Zero initiative."

Navitas was originally funded by the company's management team, along with venture capitalists with long-term track records, focused on disruptive businesses in the clean-tech and electronics industries. Capricorn Investment Group, Atlantic Bridge and seed investor Malibu IQ, along with all current investors, are rolling 100% of their equity in this transaction. "With a doubling of electrical energy demand driving the global energy transition, Navitas' GaN power ICs are already having a powerful, positive energy-efficiency impact, benefiting all of us globally," comments Malibu IQ founder David Moxam.

Overview of transaction

The transaction is expected to deliver up to $398m of gross proceeds to the combined company, assuming minimal redemptions by Live Oak II's public stockholders. This includes an oversubscribed and upsized $145m private placement of Class A common stock in Live Oak II at $10 per share (the 'PIPE' private investment in public equity), from a diversified group of institutional investors.

Proceeds of the transaction will be used to fund Navitas' future growth initiatives. Existing Navitas shareholders will roll 100% of their equity into the combined company. The transaction, which has been unanimously approved by the boards of Live Oak II and Navitas, is expected to close in third-quarter 2021, subject to approval by Navitas' shareholders, which has been secured through support agreements, Live Oak II's shareholders and other customary closing conditions, including any applicable regulatory approvals.

Pasternack debuts GaN-based input-protected LNAs

SemiconductorToday

Pasternack Inc of Irvine, CA, USA (an Infinite Electronics brand that makes both passive and active RF, microwave and millimeter-wave products) has launched a new series of low-noise amplifiers (LNAs) suitable for use in electronic warfare (EW), electronic counter-measures (ECM), microwave radio, VSAT, SATCOM, radar, space systems, R&D, prototype/proof-of-concept, and test & measurement applications.

Pasternack's new series of input-protected LNAs feature gallium nitride (GaN) technology, which provides robust input power protection. GaN ensures state-of-the-art performance with excellent power-to volume ratio that is suitable for broadband high-power applications. The amplifiers offer excellent thermal properties and a significantly higher breakdown voltage that results in tolerating higher RF input power signal levels while maintaining excellent low noise-figure performance. This is done without the need for an input protective limiter circuit that is required for other semiconductor technologies and could contribute to higher noise figure levels.

The new input-protected low-noise amplifiers cover desirable microwave and mm-wave frequency bands that complement Pasternack's existing portfolio of input-protected LNAs that cover lower RF frequencies. Features and options include broadband frequencies ranging from 1GHz to 23GHz, high gain up to 46dB typical, noise figures as low as 1.5dB typical, and high RF input power handling up to 10W CW. Additionally, the LNAs have a rugged, mil-grade compact coaxial design and SMA connectors.

“Our new, innovative line of input-protected low-noise amplifiers offer the desirable benefit of rugged GaN semiconductor technology to withstand higher RF input power handling without incurring damage,” says product line manager Tim Galla. “RF designers will find these industry-leading GaN low-noise amplifiers extremely useful in receive chains that may be sensitive to higher RF input signal conditions,” he reckons.

The new input-protected LNAs are in-stock and available for immediate shipping with no minimum order quantity (MOQ) required.

EPC launches scalable 1.5kW two-phase 48V/12V DC-DC demo board

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) and integrated circuits for power management applications – has announced the availability of the EPC9137 demonstration board, a 1.5kW, two-phase 48V–12V bidirectional converter that operates with 97% efficiency in a very small footprint.

The design is scalable; i.e. two converters can be paralleled to achieve 3kW or three converters can be paralleled to achieve 4.5kW. The board features four EPC2206 100V eGaN FETs and is controlled by a module that includes the Microchip dsPIC33CK256MP503 16-bit digital controller.

By 2025, one of every 10 vehicles sold worldwide is projected to be a 48V mild hybrid. 48V systems boost fuel efficiency, deliver four times the power without increasing engine size, and reduce carbon dioxide emissions without increasing system costs. These systems will require a 48V–12V bidirectional converter, with power ranging from 1.5kW to 6kW. The design priorities for these systems are size, cost and high reliability.

EPC’s eGaN FETs can operate with 97% efficiency at 250kHz switching frequency, enabling 800W/phase compared with silicon-based solutions, which are limited to 600W/phase due to the limitation on the inductor current at 100kHz maximum switching frequency. By using GaN FETs, it is possible to reduce the number of phases from five to four for a 3.5kW converter while increasing efficiency, says EPC. The efficiency of a four-phase GaN converter operating at 250kHz is 1.5% higher than a five-phase silicon MOSFET-based converter operating at 100kHz.

Overall, the DC-DC converter is three times faster, greater than 35% smaller and lighter, and offers greater than 1.5% higher efficiency compared with silicon MOSFET solutions. Also, the overall system cost is lower. Additionally, the efficiency and thermal performance of GaN FETs enables air cooling instead of water cooling, and the small size of the GaN FETs strongly reduces heat-dissipating aluminium housing for additional system cost saving.

“eGaN FETs provide the fast switching, small size and high efficiency needed to further reduce the size and weight of 48V–12V automotive power system converters,” says CEO Alex Lidow. “The demonstrated superior reliability of GaN FETs make them ideal for this very demanding application,” he reckons. “The EPC9137 is an ideal example of the capabilities of GaN FETs to increase frequency and efficiency to allow smaller inductance for less phases and higher power density.”

The EPC9137 demonstration board is priced at $510.72 and is available for immediate delivery from distributor Digi-Key Corp.

Silanna and Transphorm develop 65W USB-C PD GaN adapter reference design

SemiconductorToday

transphorm Silanna Semiconductor

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V and 900V gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications — and Silanna Semiconductor of San Diego, CA, USA, which makes AC/DC and DC/DC power converter ICs, have announced a GaN power adapter reference design.

The solution is an open-frame 65W USB-C power delivery (PD) charger that combines Transphorm's SuperGaN Gen IV platform with Silanna's proprietary Active Clamp Flyback (ACF) PWM controller. Together, the technologies yield peak efficiency of 94.5% with an uncased power density of 30W/in3. These performance levels are said to outpace currently available competing solutions using silicon superjunction MOSFETs or e-mode GaN transistors, and furthermore utilize a smaller GaN FET from Transphorm. Silanna and Transphorm's universal GaN adapter design is suitable for powering laptops, tablets, smartphones and other Internet of Things (IoT) devices.

The SuperGaN FET in the new reference design is Transphorm's TP65H300G4LSG, a 650V 240mΩ device in an industry-standard PQFN88 package. It leverages the SuperGaN Gen IV platform, which uses advanced epi and patented design technologies to improve performance. The robust GaN FET also offers high reliability, including what is claimed to be the industry's best gate robustness. Also, unlike enhancement-mode (E-mode) devices, protective external circuitry such as additional bias rails or level shifters are not needed — an advantage that produces higher efficiency. Collectively, these and other features further increase the adapter system's overall power density and reduce bill-of-materials (BoM) costs.

Silanna's SZ1130 is claimed to be the first fully integrated ACF PWM controller that integrates an adaptive digital PWM controller, an active-clamp FET, an active-clamp gate driver, and a UHV startup regulator. As an ACF solution, it is claimed to deliver higher performance than competing quasi-resonant (QR) controllers and offer the simplest design in the smallest PCB area among all ACF controllers on the market. Silanna's technology-agnostic design focuses on the ultimate power management challenges with what is claimed to be best-in-class power density and efficiency, yielding unprecedented BoM savings, it is reckoned.

"Transphorm and Silanna Semiconductor offer best-in-class performance in a complete GaN-based reference solution for USB-C PD adapter customers by pairing our SuperGaN devices with Silanna Semiconductor's novel and highly integrated active-clamp flyback controller," says Tushar Dhayagude, VP field applications & technical sales, Transphorm. "Our GaN FETs are known to improve efficiency, power dissipation and size of AC/DC chargers, particularly when compared to competitive E-mode GaN and integrated GaN IC solutions. Our partnership is a powerful combination of two innovators that will positively impact the adoption of GaN in power adapters worldwide," he adds.

"Our ACF controllers are versatile and provide the design flexibility for the charger manufacturers to select their preferred FET technology," says Ahsan Zaman, Silanna's director of marketing. "The ACF controller is delivering 94.5% efficiency with the combination of our SZ1130 and Transphorm's TP65H300G4LSG, achieving industry-leading performance," he claims. "At Silanna Semiconductor, we are extremely excited to further advance the best-in-class efficiency and power density results by combining our knowledge and expertise with technology ecosystem partners."

The 65W USB-C PD GaN power adapter reference design's schematic, design files, and bill of materials are available from the website's of both manufacturers.

Cree's quarterly revenue growth of 21% year-on-year driven by 50% growth for devices

SemiconductorToday

For fiscal third-quarter 2021 (ended 28 March), for continuing operations, Cree Inc of Durham, NC, USA has reported revenue of $137.3m, up 8% on $127m last quarter and up 21% on $113.9m a year ago, and above the $127-133m guidance range.

Fiscal	Q3/2020	Q4/2020	Q1/2021	Q2/2021	Q3/2021
Revenue	$215.5m	$205.7m	$216.6m	$127m	$137.3m

"We are building solid momentum, and during our fiscal third quarter we continued to execute and drive our strategy, delivering strong top-line performance as customers continue to realize the benefits of silicon carbide," comments CEO Gregg Lowe.

On 1 March, Cree completed the divestiture of its LED Products business (announced in October) to SMART Global Holdings Inc for up to $300m. This follows Cree's sale in May 2019 of its Lighting Products business unit.

"With the sale of our LED business now complete, we accomplished a critical milestone in our journey to becoming a pure-play semiconductor powerhouse [focused on the silicon carbide (SiC) and gallium nitride (GaN) power & RF solutions of the continuing business Wolfspeed] and have an even greater focus on converting opportunities in our pipeline and expanding our manufacturing capacity," says Lowe.

"In power, we delivered a solid performance driven by continued momentum of our solutions across a number of sectors," says chief financial officer Neill Reynolds. "Looking at RF, we are encouraged to see improving trends driven by increased 5G activity as communications infrastructure providers expand their activities," he adds. "The strong demand across our device portfolio showed a notable year-over-year revenue increase of more than 50%."

On a non-GAAP basis, gross margin has fallen, from 39% a year ago and 35.4% last quarter to 35% (slightly below the midpoint of the 34.5-36.5% guidance), due to temporarily higher factory costs as Cree ran up capacity in its Durham fab (ramping up new products - including some RF products – in manufacturing space vacated by the now outsourced LED products) as well as ongoing COVID-19 safety measures.

Operating expenses were $80m, up slightly from $78m (61.4% of revenue) last quarter. "As we invest in our operations to capitalize on the tremendous growth opportunity ahead, we will remain disciplined in our cost control across the business," notes Reynolds.

Net loss was $24.7m ($0.22 per diluted share), up from $18.4m ($0.17 per diluted share) a year ago but cut from $26.6m ($0.24 per diluted share) last quarter, and towards the positive end of the guidance range of $23-28m ($0.21-0.25 per diluted share).

Net cash used in operating activities was $26.8m (cut from $29m last quarter). Including patent spending of $1.7m, capital expenditure (CapEx) was $138.2m (down slightly from $144.7m). Free cash flow was hence -$165m (cut from -$173.7m, although still up on -$93.3m a year ago).

During the quarter, cash, cash equivalents and short-term investments rose from $969m to $1293m. So, Cree has a strong balance sheet, with liquidity to support its growth strategy, zero withdrawn on its line of credit, and convertible debt with a total face value of $1bn.

“We further bolstered our financial position this quarter with the successful completion of an at-the-market equity offering with gross proceeds of approximately $500m. This equity offering provides us with additional liquidity as we grow the Wolfspeed business, particularly our capacity expansion efforts,” notes Reynolds.

“We are seeing more demand in our core automotive and RF markets, as well as additional interest in new areas across energy, industrials, and aerospace & defense,” says Lowe. “Our device pipeline stands at more than $10bn and our team is identifying more opportunities at a rapid pace. Additionally, our sales team continues to generate new business, securing more than $580m in design-ins during the quarter. A significant portion of these were for automotive products and the rest were spread across industrial, communications infrastructure, energy, and aerospace and defense,” he adds. This represents a total of about $2.5bn in design-ins secured over the last five quarters, including applications such as air conditioners, compressors, motor drives and a robotic arm.

“A year ago, we launched our portfolio of 650V silicon carbide MOSFET products, exclusively with [distributor] Arrow Electronics,” notes Lowe. “We are extremely pleased with the success of this partnership, which has since generated an opportunity pipeline of more than $800m, with dozens already in the design-in stage and some even transitioning to design win. Our sales team continues to partner closely with Arrow to execute on these opportunities, including the introduction of our 1200V WolfPACK module portfolio. And we remain well positioned to continue to sell our superior solutions to customers across industrials and geographies through this partnership,” he reckons.

“At the end of March, we launched four new multi-stage, high-efficiency X-band GaN-on-SiC devices, which are used in a diverse array of applications, including marine, weather surveillance and unmanned aerial system radars,” Lowe adds.

“We expect the momentum we’re seeing in our Power and RF device product lines to continue as we enter the final quarter of the fiscal year,” says Reynolds. “Our [order] backlog underscores the growing opportunity we have as 5G rolls out across the globe,” he adds. “Our materials product line is expected to post modest improvements, supported by a better order flow.”

For fiscal fourth-quarter 2021 (to end-June), Cree expects revenue to grow to $142-148m. Nevertheless, gross margin is expected to fall further, by about 200 basis points to 32-34%. About 150 basis points of that drop is from an unfavorable product mix, due to the growth in demand for devices that currently have lower profitability. “We view the gross margin impact as short-term in nature due to the suboptimal [higher-cost] production footprint we have in North Carolina and expect it to modestly improve going forward as we work through factory transitions and eventually shift production to our new Mohawk Valley fab in calendar year 2022,” says Reynolds. Also, in the early stages of increasing capacity in the device business, productivity is lower while hiring and training staff (before picking back up to the mid-30s in the second half of the year).

Operating expenses should rise to $82-83m, fueled by investments in R&D including development projects underway at the Mohawk Valley pilot line in order to support the firm’s 200mm SiC wafer launch as well as increased sales & marketing expense as Cree pursues new business opportunities.

Cree hence expects net loss to rise back up slightly, to $25-30m ($0.22-0.26 per diluted share).

“We continue to expect fiscal 2021 to be our peak investment year, with capital expenditures of approximately $550m to support our capacity expansion plan, including the launch of our Mohawk Valley Fab at 200mm,” says Reynolds. “We are making great and steady progress in this development, which will be critical to ensure we are

able to support our long-term strategy, particularly given the steepening demand curve for silicon carbide that we are seeing in 2024 and beyond," he adds.

"As we focus on executing across our business, we are pleased to see our strategy is further supported by developments in the broader market," says Lowe. "Just a few months ago, the European Commission unveiled its mobility strategy as part of its $2 trillion green deal, aiming to have at least 30 million zero-emission cars in operation on European roads by 2030. At the same time, European automakers are pushing for new taxes on gasoline and diesel vehicles to promote the competitiveness and the adoption of electric vehicles. Finally, new European regulations could also lead to the potential phasing out of plug-in hybrid vehicles, further benefiting full-electric vehicles. In the USA, the administration recently unveiled a proposed $2 trillion infrastructure plan, of which a significant portion has been directed towards electric vehicles, including sales rebates, tax credits and charging stations. We anticipate this will have a significant impact on the adoption of electric vehicles. We are now seeing US automakers make big commitments to ramp their EV efforts. For instance, General Motors and LG Chem recently announced plans to invest $2.3bn to build a battery cell plant to support the automaker's efforts to expand its electric vehicle. We've had a number of conversations with our customers regarding these developments. And the enthusiasm reinforces the long-term opportunity here, as well as the necessity of our capacity expansion investments to ensure we can deliver on the increased demand that we are seeing," Lowe adds.

"Additionally, in the USA, the proposed infrastructure plan also includes $100bn dedicated to increasing broadband access with a special emphasis on 5G infrastructure. This development, combined with strong sales of 5G smartphones during the pandemic, underscores how 5G is continuing to gain momentum and offers a global opportunity in the years ahead."

"We remain well positioned to capitalize on these opportunities," reckons Lowe. "Importantly, we're on track with our investment plans to begin production in Mohawk Valley's 200mm fab in early 2022, which will support increased adoption across a wide range of industry sectors [as well as driving gross margin up to the targeted 50% in the 2024 time frame]. We are very pleased with the strong progress we've made in our R&D projects that are fueling our 200mm development as well," he adds.

"Additionally, with the equity raise we completed earlier in the quarter, we are further bolstering our financial position through this period of increased investment. By making these investments in our operations now, we are securing our long-term leadership position in silicon carbide," Lowe reckons.

MasterGaN reference design from ST demonstrates heatsink-free 250W resonant converter

SemiconductorToday

STMicroelectronics of Geneva, Switzerland has released the first reference design for its MasterGaN power packages, demonstrating how the new highly integrated devices increase power density, boost energy efficiency, simplify design, and accelerate time to market.

The EVLMG1-250WLLC reference design is a 250W resonant converter with a 100mm x 60mm board outline and 35mm maximum component height. It features the MasterGaN1, which contains one half-bridge STDRIVE gate driver optimally connected to two 650V normally-off GaN transistors with matched timing parameters, 150mΩ on-resistance (Rds(on)), and 10A maximum current rating. The logic inputs are compatible with signals from 3.3V to 15V.

MasterGaN1 is suitable for high-efficiency soft-switching topologies including resonant converters, active clamp flyback or forward converters and bridgeless totem-pole PFC (power-factor correction) in AC/DC power supplies, DC/DC converters, and DC/AC inverters up to 400W.

The primary side runs heatsink-free, leveraging the high efficiency of the GaN power transistors. In addition, GaN's superior switching performance allows a higher operating frequency than ordinary silicon MOSFETs, permitting smaller magnetic components and capacitors for greater power density and reduced bill of materials.

Designed for a nominal 400V supply, the EVLMG1-250WLLC provides a 24V/10A output and achieves maximum efficiency above 94%. Benefiting from MasterGaN's integrated safety features, the converter output is protected against short circuit and overcurrent. There is also brown-out protection and an input-voltage monitor that permits sequencing within an array of DC/DC converters and prevents a motor from starting under low-voltage conditions.

ST's MasterGaN family comprises pin-compatible integrated half-bridge products including symmetrical and asymmetrical configurations, housed in a 9mm x 9mm low-profile GQFN package. Containing circuitry rated up to 650V, the packages have over 2mm creepage distance between high-voltage and low-voltage pads. MasterGaN modules are available in various power ratings, allowing engineers to scale their designs with minimal hardware changes.

The EVLMG1-250WLLC is available now from st.com and distributors, for $230.

GaN Systems expands automotive product line

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 expanded its family of automotive-grade 650V transistors by launching the GS-065-060-5-B-A, a 60A bottom-side-cooled transistor for demanding high-power electric vehicle (EV) applications such as on-board chargers, traction inverters, and DC-DC converters.

The high-frequency properties of GaN combined with GaN Systems' proprietary Island Technology layout, and GaNPX packaging provides the high-power, low-loss performance required in today's power electronics. Power engineers take advantage of GaN power transistor features to make their products 50% smaller and lighter and reduce system costs. The new product is AEC-Q101- and AutoQual+-qualified; has a low RDS(on) (25mΩ) and ultra-low-loss figure of merit (FOM); a 60A IDS rating; and a small, 11mm x 9mm PCB footprint with dual gate pads for optimal board layout.

"We're setting high benchmarks with our new automotive products and qualification testing that exceed industry standards," says CEO Jim Witham. "Automotive is a key market for GaN Systems, where reducing battery size, extending driving range, and keeping the power electronics systems small and lightweight are all imperative to current and future EV design."

GaN & SiC power semiconductor market to exceed $4.5bn by 2027

SemiconductorToday

The gallium nitride (GaN) and silicon carbide (SiC) power semiconductor market is set to exceed $4.5bn by 2027, driven by growing adoption in all-electric vehicles (EVs), according to a report by Global Market Insights Inc.

Compared with traditional silicon-based power semiconductors, GaN and SiC power semiconductors offer several benefits, such as high-power efficiency, high thermal conductivity and reduced footprint. These high-end features have increasingly led them to be integrated into on-board chargers, electronic control units (ECUs), DC-DC converters and traction inverters in electric vehicles (EVs).

However, the design complexity associated with manufacturing GaN and SiC power semiconductors is one of the major factors restraining market expansion. Deposition of GaN and SiC layers onto the substrate is difficult and requires high-precision manufacturing equipment such as PVD and CVD tools, which are high cost, further increasing the overall manufacturing cost of GaN and SiC power semiconductors. Furthermore, the low cost and simpler design associated with conventional silicon-based power semiconductors will pose a major challenge to market progression during the forecast timeline.

The SiC power module segment held more than 40% market share in 2020 and will see a 35% growth rate through 2027, driven by several features such as high reliability, greater electrical stability and optimized energy consumption compared with discrete GaN and SiC power semiconductors. SiC-based power modules are integrated with dedicated ICs, which helps the overall module to execute self-protection functions such as short circuit, supply under voltage, and over-temperature. These features increase their acceptance for high-power electrical systems such as smart grids and smart energy meters. Market players are focusing extensively on increasing the energy efficiency, achieving low-noise operations, and reducing device footprint.

Increasing usage of industrial motor drives in robotics and automation equipment to propel market

The industrial motor drive segment captured 3% of the market in 2020 and is expected to rise at a compound annual growth rate (CAGR) of 35% through 2027 on account of the increasing adoption of industrial motor drives for robotics and automation equipment in manufacturing and process industries. The manufacturing sector is extensively incorporating industrial robots, automated assembly lines, conveyors, CNC machines etc, which require industrial motor drives. SiC and GaN embedded motor drives deliver high power efficiency and help to drive heavy loads in the starting position in industrial machinery. The proliferation of industrial robots across developed economies will fuel the acceptance of industrial motor drives in the market, it is reckoned.

Expansion of renewable energy sector in US to foster market revenue

The North America GaN and SiC power semiconductor market is projected to grow at a CAGR of 29% through 2027 due to the proliferation of solar power plants in the USA. According to the Solar Energy Industries Association last December, in third-quarter 2020 US solar energy producers accounted for the installation of 3.8GW of solar PV capacity. The country reached a total installed capacity of 88.9GW in 2020. This will increase demand for GaN and SiC power semiconductors in PV converters, inverters, PV modules, generators, and solar battery systems, it is forecasted.

GaN Systems' transistors used in Syng's Cell Alpha wireless speaker

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) says that its transistors are being used in Syng's Cell Alpha wireless speaker.

Audio company Syng was founded by former Apple designer Christopher Stringer (who helped to develop the HomePod, iPhone, iPad and MacBook) and entrepreneur Damon Way (co-founder of DC Shoes and Incase). The brand has debuted its high-fidelity spatial sound system for the home audio marketplace.

The Cell Alpha features two woofers in opposing configuration; three-element, two-way beamforming array; and three built-in microphones that can calibrate the audio to a room's acoustics. Multiple Cell Alphas can also be networked for surround sound.

"With GaN power semiconductors, our designers were able to build something entirely new and revolutionary without being hindered by an inferior power supply," comments Dave Turnbull, Syng's head of engineering.

GaN Systems says that the recent collaboration with Syng highlights the growing use of GaN in the audio market, from amplifiers to companion power supplies. By replacing legacy silicon transistors with GaN, audio companies can make vast design improvements including higher audio quality, smaller size, more power, and higher efficiency, the firm adds.

The Cell Alpha's sound and features stem from its unique design, which requires extreme performance from the electronics – they must fit into a small space and deliver huge transients while generating minimal heat. GaN Systems says that this type of challenge is a fitting application for its transistors, which offer what is claimed to be unparalleled switching performance in an extremely small package. The Cell Alpha's internal power supply uses GaN Systems 650V and 100V transistors in a design that is optimized to meet Syng's demanding technical requirements at low cost and eliminates the need for a heatsink or external cooling.

Navitas powers Baseus GaN2 100W charger

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA says that a first charger with Qualcomm Quick Charge 5 technology fast-charging protocol has been launched by Chinese consumer electronic brand Baseus, featuring Navitas' GaNFast power ICs. With 100W of power, and with Quick Charge 5 plus USB-PD and USB-PPS control protocols, the new Baseus charger can power any phone or laptop including Samsung's 45W S21 Ultra and Apple's 96W MacBook Pro 16".

Gallium nitride (GaN) is reckoned to run up to 20x faster than silicon, and Navitas' proprietary GaNFast power ICs deliver up to 3x faster charging in half the size and weight, and with up to 40% energy savings compared with legacy silicon chips. Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs, which monolithically integrate GaN power field-effect transistors (FETs) and drive plus control and protection circuits, enabling faster charging, higher power density and greater energy savings for mobile, consumer, enterprise, eMobility and new energy markets.

The Baseus GaN2 100W charger has a single USB-C output and measures only 67mm x 30mm x 55mm (111cc), weighs just 178g, and retails for only $34. These specifications make it 40% smaller, 40% lighter and 50% lower retail price than premium silicon-based chargers, it is reckoned.

"With 100W of charging power, users can charge a 4500mAh battery phone from 0 to 50% in just five minutes," says Long Kou Chen, Baseus' vice general manager, Tech Charger Products. "Moreover, Quick Charge 5 enables 100W of charging power to provide better performance in areas like fast-charging laptops. With thanks to the Navitas team for their help bringing the GaN2 100W to market so quickly, users can replace the original large laptop charger – plus phone and tablet chargers – with one, small, light device," he adds.

"Baseus are a future-facing company, with a laser-focus on user experience, which means that they are at the leading edge of not only power semiconductor technology with Navitas, but also in terms of control and fast-charging with Qualcomm Technologies Inc," comments Stephen Oliver, Navitas' VP of corporate marketing & investor relations. "The mobile fast-charger market is only the start for GaN, as we expand into higher-power markets like TVs, home connectivity, data centers, electric vehicles (EVs)/eMobility and solar, attacking an estimated $13bn power semiconductor market by 2026."

The GaN2 100W (model #CCGAN100CS) uses the NV6125 650V GaNFast power IC, running in a high-speed, soft-switching circuit. Alternative discrete GaN solutions require increased component count, larger PCB footprints and higher system cost without integrated protection circuits, creating inherent reliability risks, says Navitas. In contrast, GaNFast power ICs have integrated drive, control and protection circuits that enable unparalleled energy efficiency, robustness & reliability, operating frequencies, design simplicity, system cost and PCB footprint reduction, says the firm.

Raytheon Partners with GLOBALFOUNDRIES to Develop New GaN-on-Si Semiconductor Technology

EverythingRF

Raytheon Technologies and GLOBALFOUNDRIES (GF) are working together to develop and commercialize a new gallium nitride on silicon (GaN-on-Si) semiconductor that will enable game-changing radio frequency performance for 5G and 6G mobile and wireless infrastructure applications.

Under the agreement, Raytheon Technologies will license its proprietary GaN on Si technology and technical expertise to GF, which will develop the new semiconductor at its Fab 9 facility in Burlington, Vermont. Gallium nitride is a unique material used to build high-performance semiconductors that can handle significant heat and power levels. This makes it ideal to handle 5G and 6G wireless signals, which require higher performance levels than legacy wireless systems.

Mark Russell, Raytheon Technologies' chief technology officer said that Raytheon Technologies was one of the pioneers advancing RF gallium arsenide technology which has been broadly used in mobile and wireless markets, and they have similarly been at the forefront of advancing gallium nitride technology for use in advanced military systems. He said that their agreement with GLOBALFOUNDRIES not only demonstrates their common goal to make high performance communications technologies available at an affordable cost to their customers, it also continues to prove how investments in advanced defense technologies can improve lives, as well as defend them.

Senator Patrick Leahy, Chairman of the Senate Appropriations Committee said that he is proud that GLOBALFOUNDRIES' fab in Essex is leading the way in domestic production of this important 5G-enabling technology and beyond. He said that this is a win for Vermont and a win for the United States. This collaboration between a world-class manufacturer, GLOBALFOUNDRIES, and Raytheon Technologies, a leader in technological

innovation, is good news for America's semiconductor supply chain and competitiveness. The technology that will be produced by Vermonters will be a revolution.

GF CEO Tom Caulfield said that GLOBALFOUNDRIES' innovations have helped drive the evolution of four generations of wireless communications that connect over 4 billion people. He also said their collaboration with Raytheon Technologies is an important step to ensuring the development and manufacturing capability of solutions for critical future 5G applications. This partnership will enable everything from AI-supported phones and driverless cars to the smart grid, as well as governments' access to data and networks which are essential to national security.

Combined with GF's manufacturing excellence and differentiated services in RF, testing, and packaging, the new GaN offering will increase RF performance while maintaining production and operational costs, enabling customers to achieve new levels of power and power-added efficiency to meet evolving 5G and 6G RF millimeter-wave operating frequency standards.

This collaboration with Raytheon Technologies is the latest of several strategic partnerships for GF and is further evidence of the company's commitment to redefine the leading-edge by delivering differentiated solutions, while the rest of the industry continues to pursue traditional and increasingly difficult technology scaling.

As a Trusted semiconductor manufacturing facility since 2005, GF employs nearly 2,000 people at Fab 9, and more than 7,000 people across the U.S. Over the past 10 years the company has invested $15 billion in U.S. semiconductor development and is doubling its planned investment in 2021 to expand global capacity and support growing demand from the U.S. government and industry customers for secure processing and connectivity applications.

RF GaN device market surpasses $1bn in 2020

SemiconductorToday

STRATEGY ANALYTICS

Revenue from RF gallium nitride (GaN)-enabled devices experienced another year of fast growth, increasing by almost 30% in 2020 to cross the $1bn barrier for the first time, according to the Strategy Analytics Advanced Semiconductor Applications (ASA) and Advanced Defense Systems (ADS) report ‘RF GaN Device Market Forecast 2020-2025’, which identifies base-station and defense applications as the prime drivers of growth. The report forecasts that the long-term prospects for RF GaN revenue growth look good, with 5G base-station and defense applications pushing revenue to almost $2bn in 2025.

“Base stations continue to be the largest and fastest-growing opportunity for RF GaN revenue,” notes Eric Higham, director of the Advanced Semiconductor Applications (ASA) and Advanced Defense Systems (ADS) services. “Last year saw Huawei continue their aggressive buying patterns for base-station deployments in China as a buffer to US trade sanctions,” he adds. “We may see some short-term volatility depending on China’s 5G deployment plans, but the fundamentals for RF GaN devices in commercial and defense applications remain strong, and I expect revenue to approach $2bn by 2025.”

Power Integrations launches InnoSwitch4-CZ flyback switcher ICs for mobile chargers

SemiconductorToday

Power Integrations of San Jose, CA, USA, which provides high-voltage integrated circuits for energy-efficient power conversion, has launched the InnoSwitch4-CZ family of high-frequency, zero-voltage switching (ZVS) flyback switcher ICs.

InnoSwitch4-CZ devices incorporate a robust 750V primary switch using Power Integrations' PowiGaN technology and a novel high-frequency active clamp flyback controller to facilitate a new class of ultra-compact chargers suitable for phones, tablets and laptops. The first consumer devices based on InnoSwitch4-CZ devices have been introduced by mobile charger product maker Anker.

"PowiGaN switches, in conjunction with our active clamp solution – ClampZero – enable a highly efficient design and an extremely compact form factor," says CEO Balu Balakrishnan.

"We are excited to work with Power Integrations as their exclusive launch partners for their InnoSwitch4 chipsets," says Anker's CEO Steven Yang. "The InnoSwitch4-CZ was a natural choice for Anker's new Nano II series of USB-C chargers," he comments. "Its outstanding levels of integration and efficiency are key to the Nano II series' extremely compact design."

The InnoSwitch4-CZ family incorporates 750V switch, primary and secondary controllers, ClampZero interface, synchronous rectification, and safety-rated feedback in a single, compact InSOP-24D package. A steady-state switching frequency of up to 140kHz minimizes transformer size, further increasing power density.

In contrast with older active clamp flyback approaches, the InnoSwitch4-CZ and ClampZero combination provides up to 95% efficiency and maintains very high efficiency across variations in line voltage, system load and output voltage. This is achieved with variable-frequency asymmetrical control of the active clamp with intelligent zero-voltage switching, enabling both discontinuous and continuous conduction modes of operation, greatly enhancing design flexibility and maximizing efficiency across the entire operating envelope.

The new flyback switcher ICs enable what is claimed to be exceptional CV/CC accuracy, independent of external components, and consume less than 30mW no-load including line-sensing safety and protection features.

Targeting high-efficiency compact USB PD adapters, high-density flyback designs up to 110W and high-efficiency CV/CC power supplies, InnoSwitch4-CZ ICs provide variable output voltage and constant current profiles. Devices are fully protected, featuring auto-restart or latching fault response for output over-voltage and under-voltage protection, multiple output under-voltage fault thresholds and latching or hysteretic primary over-temperature protection.

The new InnoSwitch4-CZ ICs are priced at $3.85 per unit in 10,000-unit quantities.

EPC and uPI partner on GaN half-bridge driver for Americas and Europe

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 – and Taiwan-based IC design house uPI Semiconductor Corp are partnering to offer the uP1966 GaN half-bridge driver to the Americas and European markets.

The uP1966E is an 85V dual-channel gate driver designed to drive both high-side and low-side eGaN FETs in half-bridge and full-bridge topologies. The driver integrates an internal bootstrap supply and UVLO in a small 1.6mm x 1.6mm wafer-level chip-scale package (WLCSP) form factor.

The uP1966E can be used together with EPC eGaN FETs in bridge topologies including DC-DC buck and boost converters, LLC DC-DC converters, buck-boost, or bidirectional converters for battery charging and motor drives.

The uP1966E is rated at 85V and is therefore suitable for input voltages up to 60V and can be paired with EPC 80V and 100V FETs and integrated half-bridges.

The uP1966E driver is featured on many EPC evaluation boards including the DC-DC buck converters EPC9143 and EPC9153, the DC-DC LLC converter EPC9149, and most of the generic 80V and 100V half-bridge evaluation boards, of which the EPC9097 and EPC90123 are among the most popular.

Pairing the u1966E to EPC GaN transistors offers a very cost-effective driver, reduces total solution cost, and accelerates time to market for GaN-based designs, it is said.

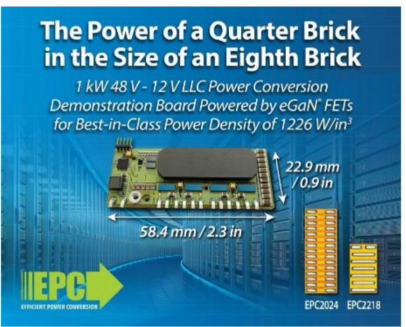
The uP1966E is available for immediate delivery from distributor Digi-Key Corp, and is priced in high volume (>100Ku) at $0.50.

EPC's 1kW, 48V-to-12V LLC power conversion demo board delivers

SemiconductorToday

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – has announced availability of the EPC9149, a 1kW-capable 48V input-to-12V output LLC converter that operates as a DC transformer with a conversion ratio of 4:1. The demonstration board features the 100V EPC2218 and 40V EPC2024 GaN FETs.

The board is the size of the DOSA-standard ⅛th-brick format, measuring only 58.4mm by 22.9mm. This is reckoned to be considerably smaller than alternative silicon-based solutions that are generally sized in the ¼th-brick format, or twice as large, for 1kW of output power. Total thickness of the converter without heatsink is only 10mm. To make it simple for a power supply designer to easily replicate this design, all supporting materials for this board including schematic, bills of materials, and Gerber files are available on the EPC website.



The high-power density of 1226W/in3 is achieved due to EPC's GaN FET technology, the firm says. eGaN FETs enable high switching frequency (in this case 1MHz) and they are very small (a third the size of silicon MOSFETs with similar on-resistance). The EPC9149 board features four 100V-rated EPC2218 eGaN FETs for the primary rectification and eight 40V-rated EPC2024 eGaN FETs for the secondary synchronous rectification. The board also features a 4mm x 4mm Microchip dsPIC33CKMP102T-I/M6 for flexibility, configuration, communications and programmability.

The new demonstration board can operate from an input voltage of 36-60V and delivers up to 83.3A load current. The peak efficiency from 48V to 12V is 98% and the full load efficiency, at 12V when delivering 1kW, is 97%. The highest temperature in steady-state operation at maximum load with 400LFM airflow is 88°C, which relates to a maximum junction temperature of 95°C.

"eGaN FETs and integrated circuits increase power density for 48V-to-12V converters and address data-center application demands for higher power in a small size," says CEO Alex Lidow. "The use of a Microchip digital controller allows flexibility for programming and configuration of the EPC9149 demonstration board."

The EPC9149 demonstration board is priced at $381.60 each and is available for immediate delivery from distributor DigiKey Corp. The EPC9149 ships with a motherboard to simplify testing.

Higher voltage GaN; vertical GaN wafers; GaN defects

Semiengineering.com

Higher voltage GaN

Imec and Aixtron have demonstrated the ability to extend gallium-nitride (GaN) to new voltage levels in the power semiconductor market, enabling the technology to compete in much broader segments.

Imec and Aixtron have demonstrated epitaxial growth of GaN buffer layers qualified for 1,200-volt applications on specialized 200mm substrates with a hard breakdown exceeding 1,800 volts. This could be a major breakthrough. GaN-based power semiconductors are widely used in applications at 900 volts and below, but it's been challenging to go beyond those levels due to several issues.

GaN and other technologies are used in power electronics. Using solid-state devices, power electronics control and convert electrical power in systems. These include cars, cellphones, power supplies, solar inverters, trains and wind turbines.

Power semiconductors are specialized transistors that boost the efficiencies and minimize the energy losses in systems. Power semis operate like a switch in systems, allowing the electricity to flow in the "on" state and stop it in the "off" state.

The power semiconductor market is dominated by silicon-based devices. But power semiconductor devices based on GaN as well as silicon carbide (SiC) materials are making significant inroads. GaN and SiC power semis are based on wideband-gap technologies, which are more efficient with higher breakdown electric field strengths than silicon.

GaN, a binary III-V material, is used for LEDs, power semis and RF devices. GaN-based power semis are used in automotive, data centers, military-aerospace and other apps. GaN power semis range from 15 to 900 volts. GaN has a 3.4 electronvolt bandgap, which is higher than SiC. GaN has a breakdown field that is ten times higher than silicon, according to Infineon. The electron mobility for GaN is double as compared to silicon, according to Infineon.

GaN power semis are lateral devices. In the process flow, a thin layer of aluminum nitride (AlN) is deposited on a substrate, followed by a GaN layer. A source, drain and gate are formed on the structure, forming a lateral GaN device.

The problem? In some cases, GaN-based power semis run into issues beyond 650 or 900 volts. It has become difficult to increase the buffer thickness to the levels required for higher breakdown voltages and low leakage levels. This is due to a mismatch in the coefficient of thermal expansion (CTE) between the GaN/AlGaN epitaxial layers and the silicon substrate.

As a result, SiC and silicon-based power semiconductors remain the products of choice for 650 to 1,200-volt applications. Generally, GaN is stuck in markets below that. Imec and Aixtron hope to break down those barriers for GaN, thereby extending the range for the technology.

Vendors developed a process using Qromis' GaN substrate technology. The substrate technology, called QST, enables power devices at 650 volts and above. The QST substrates from Qromis have a thermal expansion that

closely matches the thermal expansion of the GaN/AlGaN epitaxial layers, paving the way for thicker buffer layers – and hence higher voltage operation.

Using these substrates, Imec and Aixtron demonstrated epitaxial growth of GaN buffer layers qualified for 1,200 volts applications. The result comes after the qualification of Aixton's G5+ C metal-organic chemical vapor deposition (MOCVD) reactor at Imec. The MOCVD tool is used to integrate the material epi-stack.

This opens the door for higher voltage GaN-based power devices in applications such as electric cars and other products. Currently, lateral e-mode devices are being processed to prove device performance at 1,200 volts, and efforts are ongoing to extend the technology towards even higher voltage applications. "GaN can now become the technology of choice for a whole range of operating voltages from 20V to 1200V. Being processable on larger wafers in high-throughput CMOS fabs, power technology based on GaN offers a significant cost advantage compared to the intrinsically expensive SiC-based technology," said Denis Marcon, senior business development manager at Imec.

Vertical GaN wafers

Today, though, lateral GaN-based power semiconductors are limited in terms of voltages, prompting the need for a next-generation technology like vertical GaN.

In vertical GaN devices, the electrons flow from the top to the bottom. But bulk GaN substrates are limited to small sizes and are expensive.

In response, Kyma has begun offering vertical GaN epiwafers. To developed these wafers, Kyma has devised a hydride vapor phase epitaxy (HVPE) process. HVPE enables the growth of GaN-on-GaN with various free carrier concentrations. This in turn enables the growth of thick films of doped GaN films for power electronics applications.

"Such films are difficult to grow using traditional growth techniques such as MOCVD, due to challenges with doping control and much lower growth rates," according to Kyma. "With such lightly doped films now available, device manufacturers can develop GaN-based power devices with vertical architectures for applications at 1.2kV and higher such as electric vehicle chargers, onboard DC-DC converters, industrial motors, solar PV inverters, and much more."

GaN defects

Osaka University has created a new non-destructive technique to characterize and evaluate GaN's crystalline properties using multiphoton excitation photoluminescence (MPPL).

Researchers published its findings in Applied Physics Express.

Multiphoton excitation photoluminescence evaluates the properties of GaN using lasers that penetrate into the sample. One defect that occurs within GaN is threading dislocations. Threading dislocations are imperfections in the crystalline structure that serve as leakage current paths.

The MPPL laser highlights these defects in the GaN, even deep within the sample, making it ideal for 3D evaluations. MPPL's method also allowed for statistical classification of defects within the GaN.

GaN has applications in automotive, data centers, and other markets. GaN power switching devices can provide high-power operations, high-speed switching, low on-resistance, and high breakdown voltage. However, the defect density in GaN must be low for it to be advantageous.

MPPL will make it possible to study and analyze GaN samples in-depth in a non-destructive way. It will also make it easier to identify defects that affect the reliability of GaN, improve yields and provide more efficient paths to GaN devices.

Ultraview Introduces GaN-Based Microwave Comb Generator for EW and Antenna Testing

EverythingRF

Ultraview has introduced a new class of microwave comb generators featuring formerly unattainable output power levels, low jitter and spectral content programmability. The Ultracomb-8G is designed for antenna range testing, communications, and electronic warfare (EW) jamming applications.

A comb generator is a signal generator that produces multiple harmonics of its input signal. Based on a custom ultra-high-repetition-rate GaN differential pulser IC, the palm-sized Ultracomb-8G is powered from any USB3.0/3.1 port through which the user can program comb amplitude, comb picket spacing and low/high-frequency spectral weighting.

Comb picket spacing can be software-programmed to any frequency from 10 MHz to 2 GHz in single-ended-output mode (10-50 MHz in differential output mode) in 0.01 Hz steps, generated by an on-board LMX2594 synthesizer driven from an internal 150fs-jitter reference clock or external 10-500 MHz reference. The unit can also be programmed in 1:1 clock mode, enabling the pulse repetition rate of the comb generator (and the comb tooth spacing) to be the same as the external reference/clock input. Its differential outputs enable direct antenna connections without the use of a BALUN, and 3dB higher total output level.

The Ultracomb-8G has the further unique ability to create strings of pulses with widths varying from 100 ps to 800 ps, enabling it to generate relatively flat combs with usable energy to 10 GHz or, alternatively, combs with much higher power, but with most of the energy concentrated below 2GHz. This is useful, for example, in antenna testing, in which low frequency antennas can be tested over very long ranges or transmitting through lossy media, while retaining the ability to test over a wider bandwidth when using shorter ranges.

GUI software, with full QT source, is included for Windows10, OSX, Linux Mint 18 and RHEL/Centos 7.x.

ROHM’s develops 150V GaN HEMT with 8V gate breakdown voltage

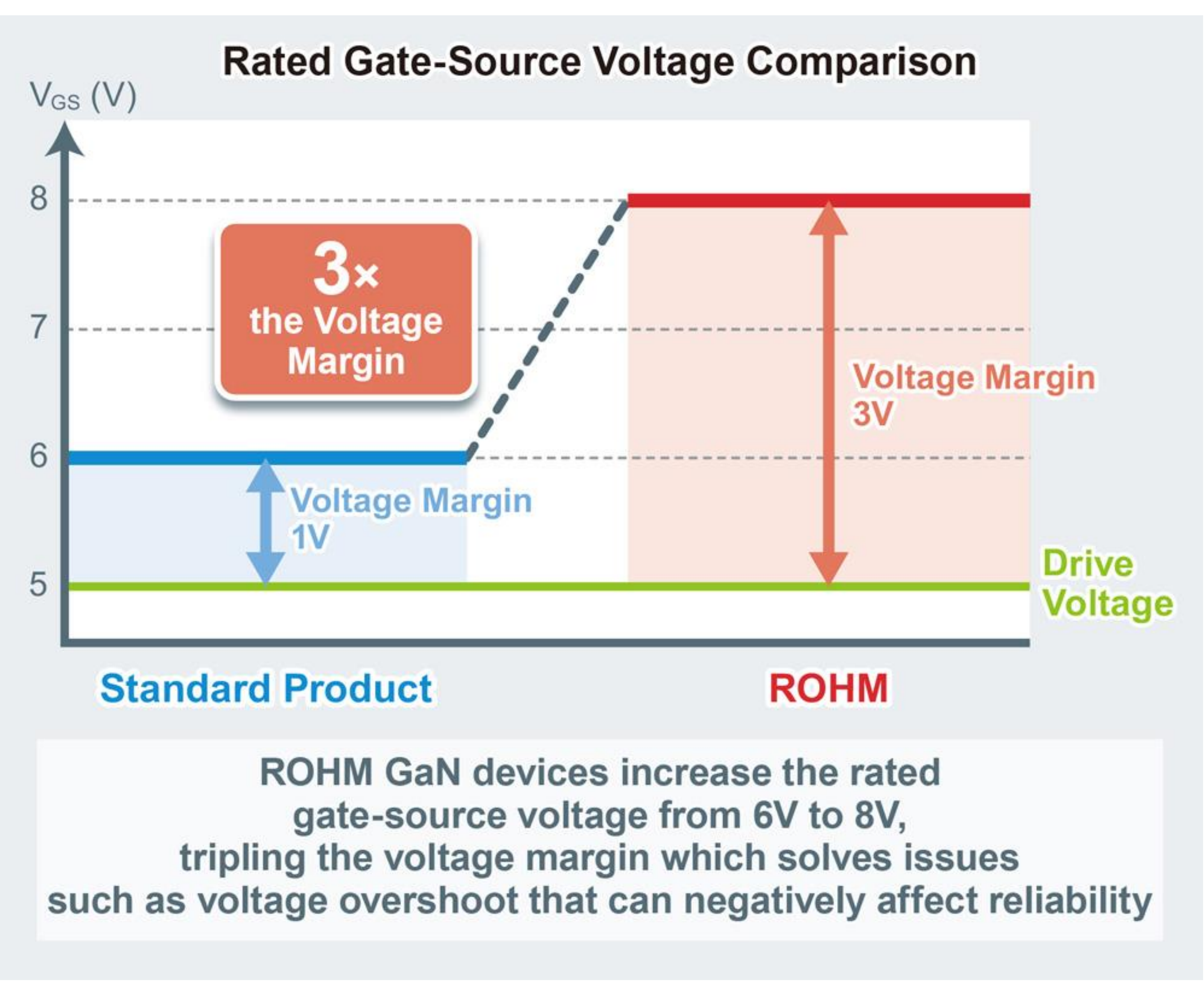
SemiconductorToday

Power semiconductor maker ROHM says that it has developed the industry’s highest (8V) gate breakdown voltage (rated gate-source voltage) technology for 150V gallium nitride (GaN) high-electron-mobility transistor (HEMT) devices – optimized for power supply circuits in industrial and communication equipment.

Along with mass-producing silicon carbide (SiC) devices and a variety of feature-rich silicon devices, ROHM has developed GaN devices for high-frequency operation in the medium-voltage range. Cultivating technology that increases the rated gate-source voltage has allowed ROHM to propose a wider range of power solutions for a variety of applications.

As GaN devices provide improved switching characteristics and lower ON-resistance than silicon devices, they are expected to contribute to lower power consumption and greater miniaturization of switching power supplies used in base stations and data centers. However, drawbacks that include low rated gate-source voltage and overshoot voltage exceeding the maximum rating during switching pose major challenges to device reliability.

In response, ROHM has succeeded in raising the rated gate-source voltage from the typical 6V to 8V by using an original structure. This makes it possible to both improve the design margin and increase the reliability of power supply circuits using GaN devices that require high efficiency.



ROHM says that, in addition to maximizing device performance with low parasitic inductance, it is also developing a dedicated package that facilitates mounting and delivers excellent heat dissipation, enabling easy replacement of existing silicon devices while simplifying handling during the mounting process.

Application examples are cited as: 48V input buck converter circuits for data centers and base stations; boost converter circuits for the power amplifier block of base stations; Class D audio amplifiers; and light detection & ranging (LiDAR) drive circuits and wireless charging circuits for portable devices.

Going forward, ROHM aims to accelerate the development of GaN devices based on this technology, with sample shipment planned for September.

LG InnoTek to sell LED patents and equipment to Chinese firm

LedInside

LG InnoTek will sell its patents and equipment related to its LED business to a Chinese LED company, TheElec has learned.

The South Korean component maker will clean out equipment related to LED at its Paju plant within the month, people familiar with the matter said.

LG InnoTek will handover some 10,000 patents related to LED to its Chinese counterpart.

Besides the payment, this will allow the Korean firm to save around 1 billion won in maintaining those patents.

Last year, LG began talks to sell its LED patents and equipment for 100 billion won in turn-key fashion.

The Chinese company will be able to make a profit from the LED business, especially in areas related to lighting, by relying on subsidies given by the regional government.

It will also be able to offer more LED products in the market. The secured patents will also allow it to defend itself from potential lawsuits filed by rivals. LG InnoTek has invested largely in its LED business before selling it, especially in ultraviolet (UV) LED areas.

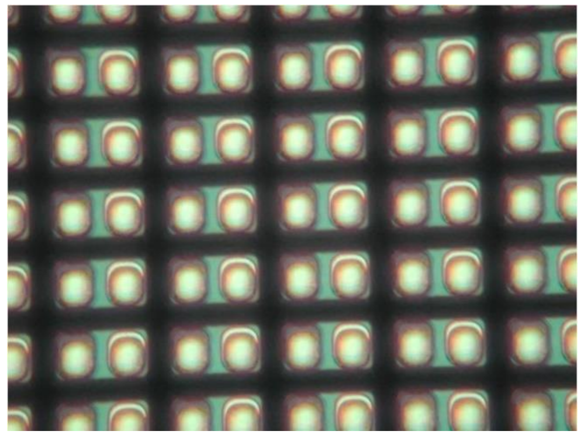
The deal to sell the business likely went through because of the high-value patents related to UV LED.

Some have voiced concern over the selling of UV LED patents as they believed LG InnoTek could license them instead.

The South Korea component maker decided to exit the LED business in October, 2019. In the second quarter of 2020, it attempted to sell its LED facilities in China and South Korea, but these talks were delayed due to the COVID-19 pandemic.

Nitride Semi Makes Micro UV-LED Breakthrough

LedInside



Nitride Semiconductors has succeeded in miniaturising the micro UV-LED chip for micro LED displays, the technology expected to be used for next-generation AR glasses and smart glasses. The company is now developing mass production technology.

Micro LED displays are the next-generation displays for liquid crystal and organic LED displays, and are being developed by Apple Inc and many other companies across the world. The red, blue, and green micro LED chips that these companies are working on are under development. But it is proving difficult to miniaturise the red LED chip to 50 µm or less.

Nitride Semiconductors' group is taking another approach by developing displays using micro-ultraviolet (hereinafter UV) LEDs to excite red, blue, and green phosphors. In this way, the cost of micro UV-LED chips can be reduced, says Nitride.

Nitride as been working on the development of chips with a wavelength of 385 nm ahead of other companies. The chip size of the conventional micro UV-LED is 16 µm x 48 µm, the chip spacing is as wide as 10 µm in the horizontal direction and 30 µm in the vertical direction, and the quantity that can be obtained from the wafer is about 3.4 million chips from the 4-inch wafer.

The newly developed micro UV-LED chip has a chip size of only 12 µm x 24 µm, the chip spacing is 5 µm in both the vertical and horizontal directions, and the number of chips that can be obtained from a 4-inch wafer is about 14 million chips, which is about four times as many.

The cost per chip is one- fourth that of the conventional chip. In terms of electrical characteristics, we have confirmed good electrical characteristics and have made great strides toward practical application in the near future.

When making a 25 mm square size display, 300,000 micro LED chips are required, but 11 micro LED displays can be made from one wafer. (All chips are controlled by an IC driver to display a full-colour screen).

Nitride Semiconductor comments that since the particle size of edible wheat flour is 10 µm to 100 µm, the size of these tiny chips is close to the size of fine flour!

Ushio's Spectro Broadband LED Breaks Own Output Power World Recor

LedInside

USHIO

Oude Meer, the Netherlands – Upon its 2019 release, Ushio's Spectro series of broadband LEDs caught the attention of machine vision manufacturers by setting a new broadband LED optical output power record of 160 mW. Not content to accept the record as the limit of its broadband achievements, Ushio has broken the record once again. In 2021, the new and improved Spectro LED series has been unveiled with an extra 20 mW of power added to the existing package. The updated indium gallium nitride (InGaN) chip achieves a new record output power of 180 mW, at 500 nm – 1,000 nm.

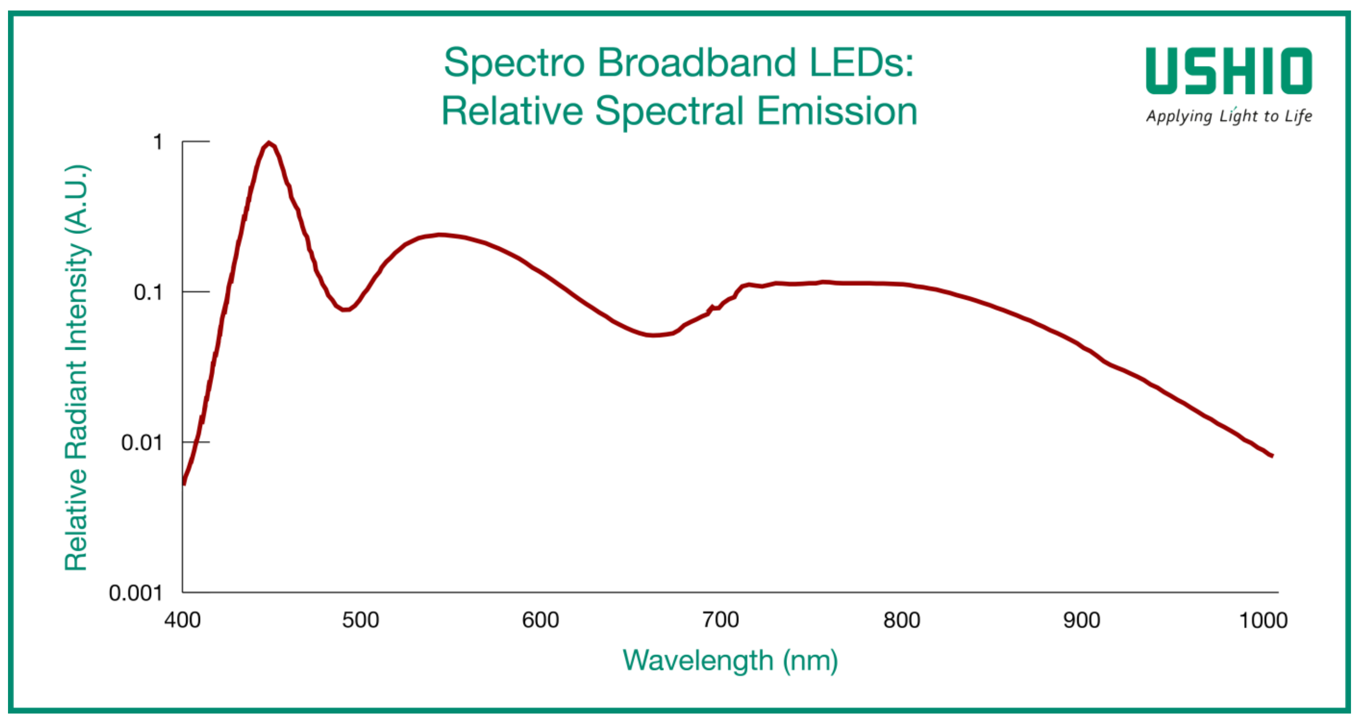
The 1 mm2 chip simultaneously emits a total broadband visible and near infrared (NIR) spectrum, from 400 nm to 1,000 nm. The SMBB package also features excellent heat dissipation abilities and a choice of lens options.

Ushio's Spectro LEDs are ideally paired with photodetector sensors and spectral imaging cameras. Capturing the spectral absorption properties of common materials allows automated systems perform categorization, quality assurance, and other sorting tasks. Potential applications include detecting moisture content within an object, such as in optical food sortingapplications, or monitoring the fill level of a medicine bottle.

Technical Specifications of Ushio Spectro Broadband LEDs

- World's highest optical output power for a broadband LED
- Hyperspectral wavelength emission
- Emission spectrum stable against temperature and forward current
- Compact SMBB package for tiny footprint
- Easy installation for simple integration into OEM devices
- High standard of heat dissipation

- Long-life compared to conventional halogen alternatives
- Lens selection allows different viewing angles
- Multiple chips can be implemented depending on the required output power
- Customized requests can be discussed and fulfilled to customer requirements



What makes Ushio's broadband LEDs special?

Developed in Kyoto, Japan, the Spectro Serieshas proven popular in the food and medicine production industries. The absorption characteristics of near infrared (NIR) light differ from one substance to another, so these LEDs lend themselves well to applications such as determining the type and quantity of a substance.

Simultaneously identifying multiple materials, each with a different peak light absorbency, is possible by deploying separate LED and sensor packages to illuminate and detect each respective material independently. A popular solution for this is Ushio's multi-chip SWIR packages, such as the Epitex D series. The D series can house up to three narrowband chips, each emitting a different wavelength.

So why would you need a broadband LED? One reason to choose a broadband LED light source is the wider range of wavelengths simultaneous emission. By using complimentary metal-oxide semiconductor (CMOS) sensors to detect how much of the broadband emissions are absorbed, it is possible to identify multiple materials within a substance while only using one broadband light source. Not only can does this technique make it possible to recognize multiple contents within an object, the data gleaned from the analysis can provide accurate quantitative measurement.

Potential applications for Ushio's Spectro broadband LEDs

There are many potential applications for Spectro broadband LEDs, such as checking the sugar content of a soft drink or monitoring blood oxygen saturation. Since the broadband output includes wavelengths in the visible spectrum, more applications are able to utilize broadband

LEDs. The spectral emission of Spectro is roughly in-line with the spectral sensitivity of the CMOS photodetector typically employed in common sensory devices. This offers incredible possibilities for implementation such as the sorting of items by material, colour, or the detection and removal of foreign matter from a production process.

Ushio's LED experts can guide you to the right broadband solution. Contact Ushio todayif you are interested in the following applications:

- Substance / matter analysis
- Machine vision
- Optical sorting (by raw material, by colour, etc.)
- Detection of foreign matter
- Blood oxygen saturation analysis
- Endoscopic procedures
- Hyperspectral imaging
- Photodynamic therapy
- Instrument diagnostics and research execution
- Spectroscopy

Miniaturization continues to progress while high expectations of portable devices have become an outright demand by consumers and industry bodies alike. Until fairly recently, many LEDson the market were able to eliminate the bulky size and excessive heat issues synonymous with halogen lamp solutions; but only offered a relatively weak output in comparison.

The broadband LED Spectro seriesoffers a higher power, and consequently, measurement applications can become even more accurate. The construction of the SMBB package means that there is no need for a heat-dissipation jig to accompany it. Multiple LEDsare also no longer necessary to cover a hyperspectral wavelength band, thanks to the implementation of a phosphor that features a continuous spectrum extending from violet-visible to NIR.

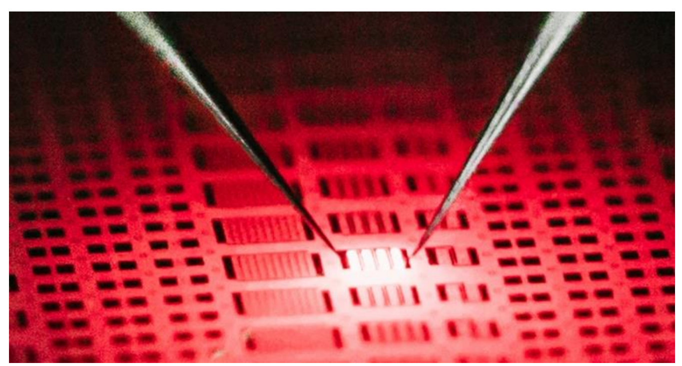
KAUST fabricates red InGaN-based micro-LEDs

[SemiconductorToday]

Saudi Arabia's King Abdullah University of Science and Technology (KAUST) has reported indium gallium nitride (InGaN)-based red micro-LEDs that they plan to integrate with green and blue micro-LEDs to create full-color micro-displays (Zhuang Z, Iida D and Ohkawa K, 'Investigation of InGaN-based red/green micro-light-emitting diodes', Optics Letters 46, 1912-1915 (2021)).

Nitride semiconductors can be used to make blue and green micro-LEDs, whereas phosphide semiconductors are currently used for red light. But combining different semiconductors in this way makes construction of RGB micro-LEDs more difficult and expensive. Also, the efficiency of phosphide micro-LEDs falls significantly with shrinking chip size.

Red-light-emitting InGaN can be created by increasing the materials' indium content. But this tends to lower the efficiency of the resulting LED because there is a mismatch between the separation of atoms in the GaN and InGaN crystal lattices, which causes atomic-level imperfections. Moreover, damage to the sidewalls of an InGaN micro-LED induced during the fabrication process makes the new device less efficient. "But we have a chemical treatment to remove the damage and retain the high crystal quality of the InGaN and GaN sidewall interface," says Zhuang.



The 47µm-long red-emitting nitride-based micro-LEDs fabricated by KAUST. © 2021 KAUST; Anastasia Serin.

Zhang's team created and characterized a series of square devices with a side length of 98µm or 47µm. Their 47µm-long devices emitting light at a peak wavelength of 626nm were shown to have an external quantum efficiency (the number of photons emitted from the LED per electron injected into the device) of up to 0.87%. Also, the color purity of the red micro-LED is optimum because it is very close to the primary red color defined by the industrial standard known as Rec. 2020.

"The next step is to increase the efficiency of the red micro-LED with even smaller chip sizes, maybe below 20µm," says Zhuang. "Then we hope to integrate RGB nitride-based LEDs for full-color displays."

BluGlass to begin reliability testing of packaged lasers in next two months

[SemiconductorToday]

BluGlass Ltd of Silverwater, Australia – which develops low-temperature, low-hydrogen remote-plasma chemical vapor deposition (RPCVD) technology for manufacturing devices such as laser diodes, next-generation LEDs and micro-LEDs – has provided an update for March-quarter 2021 on its laser product development.

Laser diode development progress

BluGlass continues to advance commercialization of its laser diode product suite, with multiple products (405nm, 420nm, 450nm and others) progressing through the final stages in the manufacturing supply chain.

The first products for launch have completed multiple design iterations and processing steps ahead of packaging. These products continue to demonstrate good performance and meet internal specifications as unpackaged devices, says the firm.

Once complete, packaged devices will commence accelerated reliability testing at BluGlass' US facility ahead of product launches. The firm expects these tests to be underway within the next two months.

BluGlass is refining multiple packaging solutions, both internally at its US facility and supported by the firm's recent appointment of specialist laser packaging and integration expert Dr Arkadi Goulakov, and with several expert packaging vendors at their facilities.

BluGlass expects to deliver packaged products to its customers in the coming months. Following the launch of initial products, BluGlass and its suppliers will qualify the manufacturing process for commercial production and the delivery of further product designs and applications later in the year.

Laser industry veteran joins US operations
In March, BluGlass appointed laser diode expert Dr Arkadi Goulakov as a senior laser scientist in its US operations. He brings deep fabrication, packaging and product integration expertise to the development and operations team and is currently assisting in the final steps of the pre-launch and delivery of BluGlass' proprietary GaN-based laser technology for the industrial, automotive, lighting and biotech markets.

Goulakov has more than 30 years' experience developing and commercializing optoelectronics, including over 17 years managing dynamic laser innovation projects. He has held technical leadership positions at leading US laser organizations including II-VI Optoelectronic Devices, Western Digital and Seagate Technologies, and has held technical roles at Microsemi, AlfaLight Inc and Corning Applied Technology.

BluGlass says that the appointment provides enhanced depth to its laser diode business development, bringing extensive fabrication and back-end processing expertise to complement the firm's existing design and epitaxial capabilities.

Goulakov completed his PhD in Physics at the Ioffe Institute in Saint Petersburg, one of Russia's largest research centres specializing in physics and technology. He is the principal inventor of four issued US patents, the author of multiple trade secrets, and a recipient of numerous patent and invention disclosure awards, says BluGlass.

Product development and paper presented at Photonics West
During first-quarter 2021, BluGlass showcased its laser diode product development at SPIE Photonics West. At the conference it also presented a paper outlining recent developments utilizing hybrid MOCVD and RPCVD techniques ('InAlGaN-based ridge-guide laser diodes using remote plasma chemical vapour deposition for enhanced performance'). The paper highlighted the latest results and confirmation of the benefits of low-temperature RPCVD for the manufacture of both traditional and novel laser diode structures.

Innovate UK grant for LUSS consortium to develop LED-based UV exposure for safe surfaces

SemiconductorToday
MicroLink Devices UK Ltd says that the consortium for the project LUSS (LED based Ultra-Violet exposure for Safe Surfaces) has been awarded a grant by UK Government agency Innovate UK (which provides funding and support for business innovation as part of UK Research and Innovation) to develop an economical solution to combat COVID-19 infection in public spaces, with the added ability to also disinfect surfaces of other viruses and bacteria.

With support from product design specialist WideBlue Ltd (in Glasgow's West of Scotland Science Park) and the UK's Compound Semiconductor Applications (CSA) Catapult (based in South Wales), lead industrial partner MicroLink Devices will develop an automatically self-cleaning door panel, exploiting specific UV light, that will kill

viruses/bacteria and prevent the spread of infection. The door panel will be disinfected automatically between uses, reducing the need for frequent manual cleaning and reducing the transmission of viruses/bacteria.

"As a not-for-profit RTO [research and technology organization], the CSA Catapult's mission is to accelerate the development and commercialization of novel applications using compound semiconductors," notes CSA Catapult's chief commercial officer Amar Abid-Ali.

"The consortium is excited to develop a novel COVID-19 system which will aid in the reduction of transmission in public spaces through this innovative technology," says Microlink's director Steve Whitby. "The consortium is well placed to developed and rapidly take the technology towards commercial exploitation and deployment," he concludes.

LED market to grow 8.1% to $16.53bn in 2021

SemiconductorToday

Due to the impact of the COVID-19 pandemic in 2020, not only did LED revenue experience a downward trajectory but this decline also reached a magnitude rarely seen in recent years, according to market research firm TrendForce. However, as vaccinations begin taking place in first-half 2021, the LED market's long-stifled demand is expected to rebound from rock bottom. Hence, global LED market revenue (i.e. revenue from packaged LEDs, plus revenue from mini/micro-LED chips directly used in backlighting and other self-emitting products) will likely undergo a corresponding recovery this year as well, growing by 8.1% to a forecasted $16.53bn in 2021. Most of this increase can be attributed to four major categories, including automotive LEDs, mini/micro-LEDs, video wall LEDs, and ultraviolet/infrared (UV/IR) LEDs.

TrendForce expects the soaring growth of NEV (new energy vehicle) sales and the accelerated adoption of LED lighting solutions in new models of conventional fossil-fuel vehicles this year to result in a persistent rise in the penetration rate of automotive LED solutions from 2020. Automotive LED revenue will likely grow by 13.7% to $2.93bn in 2021, making it the fastest-growing sector among all LED applications.

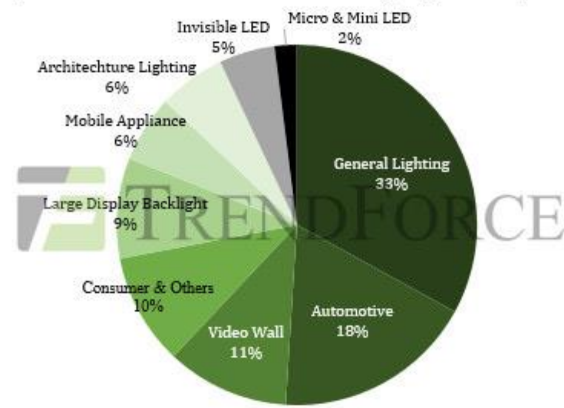
Demand for emerging mini/micro-LED technologies in display applications, on the other hand, has been skyrocketing this year. In particular, the latest 12.9-inch iPad Pro and Samsung TVs both feature mini-LED

backlighting technology, and these products will propel mini/micro-LED revenue up by 265% to $380m in 2021, in turn giving the mini/micro-LED sector the second-largest growth among the four categories.

Third largest is the video-wall market. Emerging solutions, such as all-in-one LED displays for meetings and conferences, 5G 8K ultra-high-resolution video walls, home theaters and virtual production, have placed the video-wall market in the spotlight in recent years. Video-wall LED revenue is expected to grow at 12% to $1.78bn in 2021, making it the third-largest growing sector in the LED industry.

Among all segments of the UV/IR LED market, the UV-C LED segment has garnered significant attention due to the onset of the pandemic. Not only have various brands been gaining major awareness of the importance of disinfection and sterilization but UV-C LED products have also been improving in terms of radiant power (optical power). Notably, home-appliance brand manufacturers from China, Europe, Korea and Japan are all planning to integrate UV-C LED technologies into their products, and over 35 manufacturers are introducing or planning to introduce UV-C LED in their products. All in all, various applications are expected to drive UV/IR LED revenue up by 27% to $830m in 2021.

Figure 2: LED Market Revenue Share by Application, 2021



Source: TrendForce, May 2021

On the whole, the gradual recovery and rebound of demand for traditional LED applications, as well as the upcoming ramp-up of niche LED technologies, will be the main drivers of LED market revenue. At the same time, both demand and revenue in the LED industry are expected to enter an upward trajectory accordingly due to two factors. First, the improvement in supply and demand in the LED industry has allowed prices of most LED products to stabilize, with some products even seeing a price hike. Second, emerging LED applications command higher average selling prices (ASPs) and gross margins. TrendForce thus believes that LED makers will no longer have to reduce price by increasing order quantity. Companies in the LED industry are therefore expected to post improved earnings as a result.

Nanosys Acquires Leading MicroLED Company glō

Businesswire

SILICON VALLEY, Calif.--(BUSINESS WIRE)--Nanosys, the industry pioneer and leading supplier of quantum dot light emitting materials and technology, today announced the acquisition of glō, the leading technology company for microLED displays. The transaction significantly expands Nanosys' capabilities and technology offerings, accelerating the company's development and progress toward the widespread adoption of microLED and nanoLED display technology for future displays.

"Nanosys created a vibrant, growing marketplace for our proprietary quantum dot technology over the past two decades"

Founded in 2003, glō developed highly efficient xGaN microLEDs based on unique methods and processes. The acquisition fills a key role in Nanosys' technology roadmap, uniquely positioning Nanosys to lead the future of display across all technologies from miniLED to OLED and MicroLED to NanoLED. Prior to the acquisition, glō had invested over $200 million in its technology, which funded development of best-in-class microLED epitaxy, device and transfer technology, resulting in leading microLED performance at the smallest dimensions.

According to Eric Virey, of Yole Développement1, this acquisition positions Nanosys with a unique and broad technology portfolio to address all future display applications. “MicroLED is one of the greatest potential display technologies but there is one problem: cost. To deliver on this potential, microLED pixels must be ultra small, bright and cost effective. The market currently lacks a cost effective microLED solution with ultra small and bright pixels. Bringing microLED together with Quantum Dot is an exciting opportunity to unlock the growth potential in this market.”

“Nanosys created a vibrant, growing marketplace for our proprietary quantum dot technology over the past two decades,” said Jason Hartlove, Nanosys President & CEO. “Combining the best Quantum Dot and microLED technologies allows Nanosys to unlock the disruptive potential of microLED by lowering production cost and maximizing performance. Together, we can create the smallest, brightest, lowest cost pixels that will enable microLED to penetrate the mainstream TV market and open the doors for new applications in AR, automotive and beyond.”

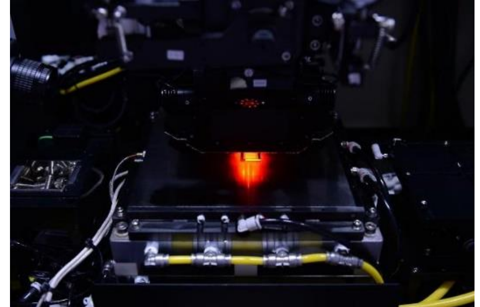
The acquisition of glō significantly expands Nanosys intellectual property portfolio enabling the company to continue to provide margin rich disruptive solutions to the massive $200 billion display market.

Jefferies acted as financial advisor for the transaction and Latham and Watkins served as legal counsel to Nanosys in connection with the transaction.

Researchers Develop Cheaper Production Technique For Micro LEDs

LedInside

Through a 16-year development project, South Korea's state research institute has discovered a way for the cheaper production of micro light-emitting diodes (microLEDs) by combining two separate manufacturing processes into a single one. The new technique using laser melding will save time and costs to eventually lower the price of microLED products.



A microLED is a microscopic LED that is ideal for the production of high-performance flat-panel displays. Compared to conventional liquid crystal display (LCD) and organic light-emitting diode (OLED) display technologies, the microLED technology offers better contrast, response times, and energy efficiency. As it has a higher density than normal LED TVs, microLED TVs are suitable for displaying ultra-high-resolution video contents.

Despite the superior characteristics of microLED, the complex manufacturing process makes it extremely expensive. Samsung's 110-inch microLED TV released in early 2021 came with a price tag of $156,000. Samsung's 85-inch LCD TV is priced at about $1,999.

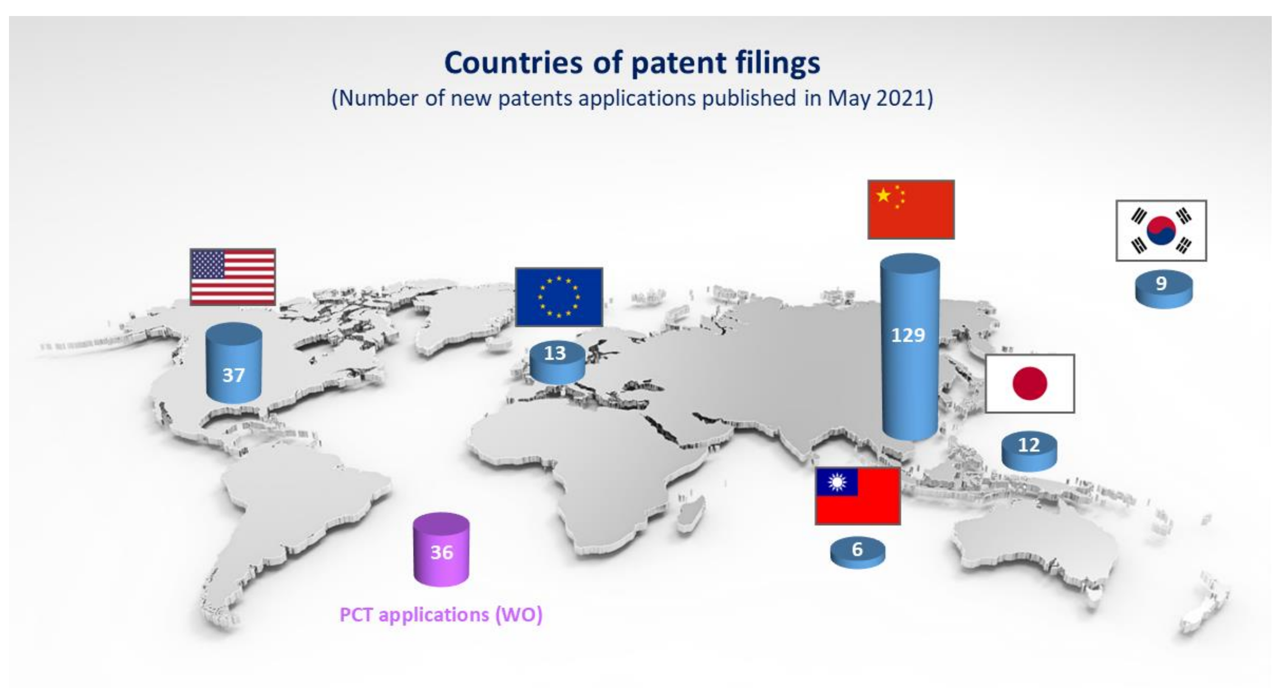
The state-funded Electronics and Telecommunications Research Institute (ETRI) said in a statement on May 25 that its research team simplified the process of manufacturing microLEDs using a laser and a film-like novel material called SITRAB. Researchers were able to create a flat-panel display prototype with 1,225 microLEDs. The Institute aims to commercialize its technology in two years.

"In a sector where global display makers and related organizations are locked in a fierce competition, ETRI played a pioneering role by overcoming the limits of conventional display-making techniques," ETRI's microLED development division head Choi Gwang-seong was quoted as saying. When commercialized, ETRI said it can lower manufacturing costs and time down to 10 percent of the current method.

Conventional microLED manufacturing includes a transferring process in which microscopic LEDs are moved onto a chip, and a bonding process that fuses diodes and the chip together. ETRI's new method uses a laser to heat microLEDs adhered onto a SITRAB film to bond them onto a chip. ETRI said that its manufacturing technique can selectively meld LEDs without having to move diodes from a manufacturing palette to a preferred position before fusing. ETRI's laser-melding technique can also be used for other types of LEDs such as mini LEDs.

PATENT APPLICATIONS

More than **200 new patent families** related to GaN technology were published in **May 2021**.



Main patent applicants
(Number of new patent applications published in May 2021)

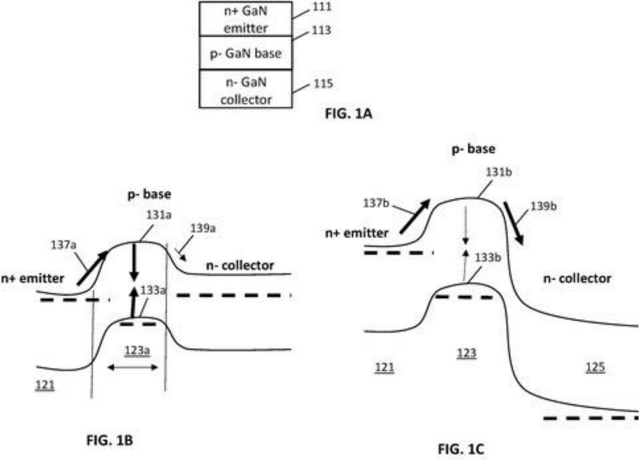
Applicant	Number
XIDIAN UNIVERSITY	11
HC SEMITEK	9
MITSUBISHI ELECTRIC	6
GALLIUM SEMICONDUCTOR TECHNOLOGY	5
HATCHIP	5
INNOSECO SUZHOU TECHNOLOGY	5
UNITED MICROELECTRONICS	5
CHANGCHUN INSTITUTE OF OPTICS FINE…	4
YANGZHOU YANGJIE ELECTRONIC	4
INNOSECO SEMICONDUCTOR	3
KOREA PHOTONICS TECHNOLOGY INSTITUTE	3
SEMICONDUCTOR ENERGY LABORATORY	3
SHENZHEN SITAN TECHNOLOGY	3
SUMITOMO CHEMICAL	3
BOWEI INTEGRATED CIRCUITS	2
CEA - COMMISSARIAT A L ENERGIE…	2
DISCO	2
ENAM OPTOELECTRONIC MATERIAL	2
FACEBOOK TECHNOLOGIES	2
GLOBALWAFERS	2

Other patent applicants: Hunan University, Institute of Semiconductors, Mitsubishi Chemical, Nanjing University of Science & Technology, Nikkiso, Ningbo Anxinmei Semiconductor, Osram Opto Semiconductors, Qianhai Shenzhen Yun Fu Technology, Sai Auk Faith, Samsung Electronics, Shaanxi Junpu Xinhang Technology, Shanxi Zhongke Luan Ultraviolet Photoelectric Technology, Sony Semiconductor Solutions, South China University of Technology, Sumitomo Electric Device Innovations, Sumitomo Electric Industries, Tsinghua University, Ushio Electric, Xiamen San An Optoelectronics, Zhejiang Jinzhou Electronic Technology, 38th Research Institute China Electronics Technology, Actron Technology, Ames Micron, Ampleon Netherlands, AOTI Photoelectric Technology Hangzhou, Avicenatech, Axign, Beijing Institute of Radio Measurement, Beijing Zhongke Youwill Technology, Black Peak, Chonnam National University, Datang Semiconductor Design, Delta Electronic Enterprise Management, Differential Power, Dongguan RDK Electronic Technology, Dongguan Sino Crystal Semiconductor, Edgeless Semiconductor, Electrolux Appliances, ETH Zurich, Fuji Electric, Fujian Prima Optoelectronics, Fuyang Electronic Information Research Institute, GaN Power Technology, GM Global Technology Operations, Gree Electric Appliances, Guangdong APT Electronics, Guangdong OML Technology, Hangzhou Dianzi University, Heyuan Tianhe Third Generation Semiconductor Industry Technology Research Institute, Hon Hai Precision Industry, Huizhou Wenda Precision Electronic Technology, Ibeam Materials, Idemitsu Kosan, Infineon Technologies, Innoscience Technology, Institute of Microelectronics Chinese Academy of Sciences, Institute of Physics Chinese Academy of Sciences, Institute of Semiconductors Guangdong Academy of Sciences, Jenoptik Optical Systems, Ji You Technology, Jiangsu Electric Power Company, Jusung Engineering, King Abdullah University of Science & Technology, Korea Electronics & Telecommunications Research Institute, Kyocera, Leoni Bordnetz Systeme, Lumileds, Macom Technology, Mingzhilan Jiangsu Electronic Technology, Myongji University Industry & Academia Cooperation, Nanjing University, Nanjing Youtian Metal Technology, National Chiao Tung University, National Institute For Materials Science, National University Corporation Tokai National Higher Education & Research System, NGK Insulators, Nichia Chemical Industries, Ningbo Glauber Intelligent Industry, Northeastern University, Northwestern University.

High speed and multi-contact leds for data communication

Publication Number: US20210152244, US20210151623, WO2021/102013, WO2021/102034
Patent Applicant: Avicena Tech

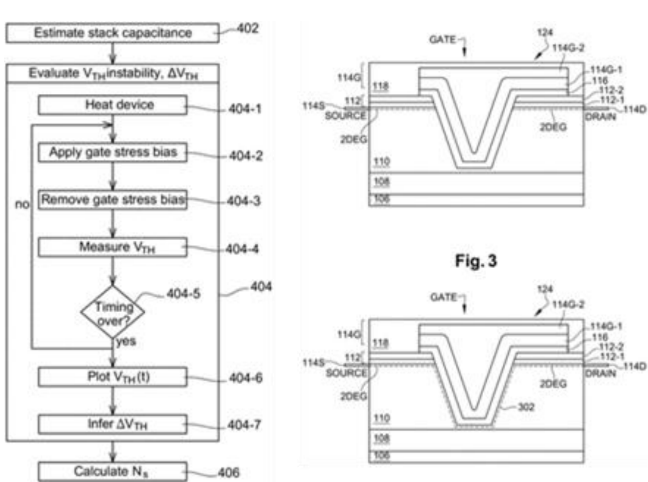
An LED may have structures optimized for speed of operation of the LED. The LED may be a microLED. The LED may have a p-doped region with one or more quantum wells instead of an intrinsic region. The LED may have etched vias therethrough. An optical communication system for communicating information provided by a processor to another area of the processor or another chip in a multi-chip module, comprising: an LED associated with the processor; an LED driver to modulate optical output power of the LED, such that the LED will generate light based on data provided to the LED driver from the processor; a detector for performing optical-electrical conversion using the light; and an optical waveguide optically coupling light from the LED to the detector; wherein the LED comprises: a p type layer; an n type layer; a lightly doped recombination layer, the recombination layer including at least one quantum well between the p type layer and the n type layer.



A method of estimating a carbon concentration in a GaN epitaxial layer

Publication Number: US20210156812
Patent Applicant: Cea

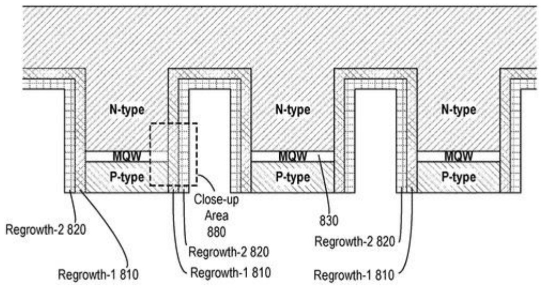
A method of estimating a nitrogen site carbon concentration, in a first epitaxial layer made of carbon-doped gallium nitride of an electronic component, including steps of: estimating an electric capacitance of a stack interposed between the first layer and a first electrode of the component; heating the component; measuring an offset of a threshold voltage of the component; and deducing therefrom a nitrogen site carbon surface concentration in the first layer.



In situ selective etching and selective regrowth of epitaxial layer for surface recombination velocity reduction in light emitting diodes

Publication Number: US20210151498, WO2021/097201
Patent Applicant: Facebook

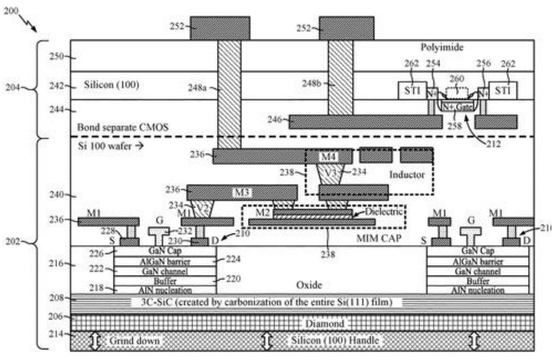
LED apparatuses featuring etched mesas and techniques for manufacturing LED apparatuses are described, including techniques for reducing surface recombination and techniques for charge carrier confinement. Etched facets of an LED mesa can be passivated using epitaxial regrowth of one or more semiconductor regrowth layers. The one or more semiconductor regrowth layers can include a transition layer. The transition layer can be configured with a bandgap energy between that of layers that are on opposite sides of the transition layer. A transition layer can separate an etched facet and another regrowth layer or separate two regrowth layers. In some instances, selective etching can be performed to preferentially etch a quantum well layer relative to a barrier layer. The selective etching removes surface imperfections, which contribute to surface recombination and which tend to be more prevalent in etched facets of the quantum well layer than etched facets of the barrier layer.



Integration of heterogeneous transistors on diamond substrate by layer transfer

Publication Number: US20210151428
Patent Applicant: Qualcomm

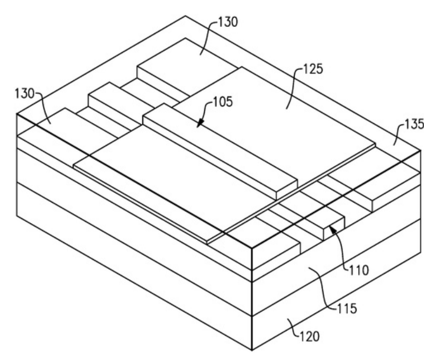
A semiconductor device having heterogeneous transistors integrated on a diamond substrate with a carbonized layer. An example semiconductor device generally includes a first semiconductor die and a second semiconductor die. The first semiconductor die includes a diamond substrate, a carbonized layer disposed above the diamond substrate, and a first transistor disposed above the carbonized layer, the first transistor comprising gallium nitride. The second semiconductor die is disposed above the first semiconductor die, where the second semiconductor die includes a second transistor comprising a different semiconductor material than the first transistor.



Heterogenous integration and electro-optic modulation of III-nitride photonics on a silicon photonic platform

Publication Number: US20210157178, WO2021/102224
Patent Applicant: Raytheon BBN Technologies

A photonic integrated circuit comprises a silicon nitride waveguide (110), an electro-optic modulator formed of a III-nitride waveguide structure (105) disposed on the silicon nitride waveguide (110), a dielectric cladding (135) covering the silicon nitride waveguide(110) and electro-optic modulator, and electrical contacts (140) disposed on the dielectric cladding (135) and arranged to apply an electric field to the electro-optic modulator.



Reconfigurable transistor device

Publication Number: WO2021/097374
Patent Applicant: Qorvo

Disclosed is a reconfigurable transistor device having a substrate, a plurality of first transistor fingers disposed in a first region over the substrate, and a phase change switch (PCS) having a patch of a phase change material (PCM) disposed over the substrate in a second region to selectively couple a first set of the plurality of first transistor fingers to a bus, wherein the patch of the PCM is electrically insulating in an amorphous state and electrically conductive in a crystalline state. The PCS further includes a thermal element disposed adjacent to the patch of PCM, wherein the first thermal element is configured to maintain the patch of the PCM to within a first temperature range until the patch of the PCM converts to the amorphous state and maintain the patch of the PCM within a second temperature range until the first patch of PCM converts to the crystalline state.

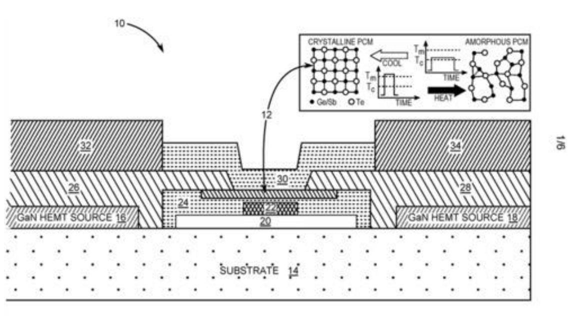
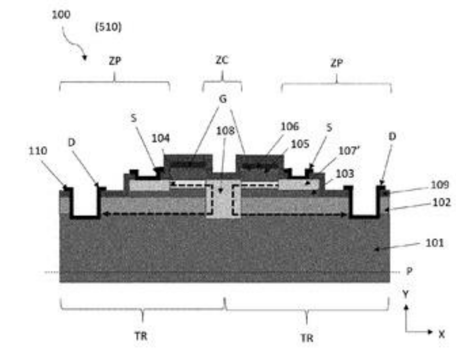


FIG. 1

Transistor with electron gas, single-piece device comprising at least two cascading transistors and associated manufacturing methods

Publication Number: EP3826072, FR3103321
Patent Applicant: Cea

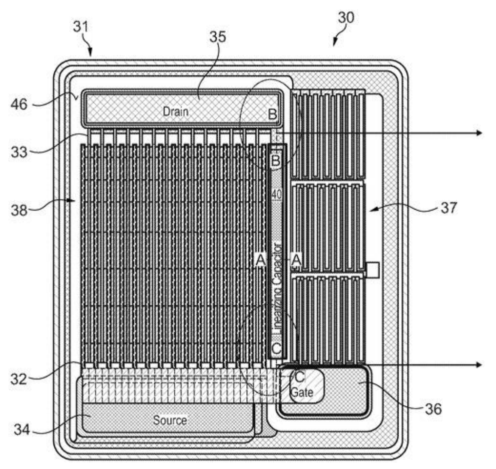
One aspect of the invention relates to a transistor (TR), comprising: - first (101) and second (102) semiconductor layers; - a third p-type doped semiconductor layer (103) with at least one first n-type doped zone (107); - at least one second zone (108) with N-type or metallic doping; - a source electrode (S) formed on the first zone (107); - a drain electrode (D) formed on the first semiconductor layer (101); - a gate (G) situated between the source electrode (S) and the second zone (108).



Semiconductor device and inverter

Publication Number: US20210134968, EP3817045, CN112750814
Patent Applicant: Infineon

In an embodiment, a semiconductor device is provided that comprises a lateral transistor device having a source, a drain and a gate, and a monolithically integrated capacitor coupled between the gate and the drain. A semiconductor device (30, 60, 100), comprising: a lateral transistor device (31, 61) having a source, a drain and a gate; a monolithically integrated capacitor (40, 62) coupled between the gate and the drain, wherein the semiconductor device (30, 60) comprises a reverse transfer capacitance Crss, wherein Crss (Vds = 0V) /Crss(Vds = 400V) < 50.



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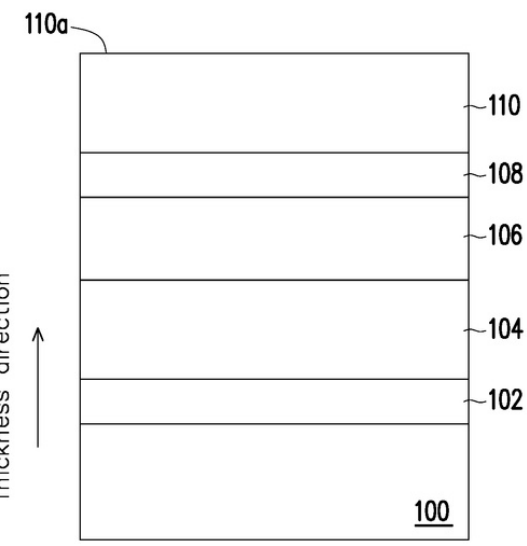
Epitaxial structure

Publication Number: US20210148007
Patent Applicant: GlobalWafers

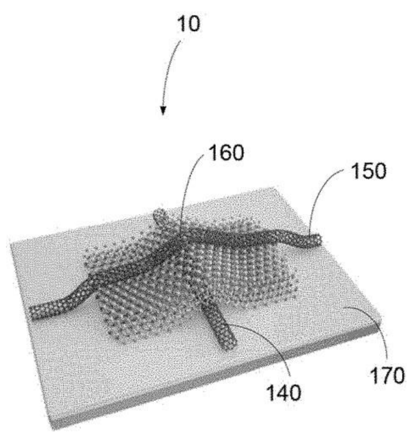
An epitaxial structure including at least a substrate, a nucleation layer, a buffer layer, a channel layer, a barrier layer, and a P-type aluminum indium gallium nitride layer is provided. The nucleation layer is formed on the substrate; the buffer layer is formed on the nucleation layer; the channel layer is formed on the buffer layer; the barrier layer is formed on the channel layer; and the P-type aluminum indium gallium nitride layer is formed on the barrier layer. The material of the P-type aluminum indium gallium nitride layer is AlInGaN with a P-type dopant, in which the contents of Al, In and Ga all change stepped-periodically or stepped-periodical-gradually in the thickness direction, and the doping concentration of the P-type dopant changes stepped-periodically or stepped-periodical-gradually in the thickness direction.



Light emitting diode

Publication Number: US20210143301, JP2021077847, CN112786755
Patent Applicant: Foxconn Technology (Hon hai Precision Industry), Tsinghua University

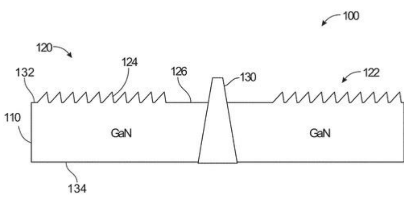
The present disclosure relates to a light emitting diode. The light emitting diode comprises a first semiconductor layer, a second semiconductor layer, an active layer, a first electrode, and a second electrode. The active layer is located between the first semiconductor layer and the second semiconductor layer. The first electrode is a first carbon nanotube, the second electrode is a second carbon nanotube. A first extending direction of the first carbon nanotube and a second extending direction of the second carbon nanotube are crossed with each other. A vertical p-n junction or a vertical p-i-n junction is formed by the first semiconductor layer and the second semiconductor layer in a direction perpendicular to the first semiconductor layer.



Pixelated light-emitting diode for self-aligned photoresist patterning

Publication Number: WO2021/101765, US20210151626
Patent Applicant: Lumileds

The present disclosure relates generally to micro-light emitting diode (LED) lighting systems. In certain embodiments, self-aligned photoresist patterning is used to create features that reduce optical crosstalk between LED pixels. A light source includes an array of light emitters, with at least some light emitters having a central patterned surface and an unpatterned border; a light blocking metal layer positioned between each of the array of light emitters; and down-converter material positioned on each of the array of light emitters.



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