GANEXT

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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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GANEXT

Cluster of Excellence (Labex, 2020-2024)

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

The end of **GaNeX** Cluster of Excellence program (Labex 2012-2019) was scheduled on December 2019. However, the French government decided **to expand the labex program for five additional years**, in order to further strengthen the synergy between French academic research organizations and industrial players in the field of GaN optoelectronics and electronics. Therefore, **GANEXT** Cluster of Excellence program **will replace and succeed GaNeX** for the next five years (2020-2024).
Accordingly, the **GANEXT newsletter** will follow and adapt to the new program, **focusing on scientific publications, patent applications and press releases related to optoelectronics** (LED, µ-LED, laser, photonics, etc.) **and electronics** (power, RF, advanced electronics, etc.), ruling out publications which are not related to one of these two families of applications. For instance, publications dealing with MEMS, sensors, photovoltaics, nanostructures, semi-polar and non-polar materials, fundamental physics, etc. that do not obviously relate to optoelectronic or electronic applications will not be included in the **GANEXT newsletter**.
Besides, a panel of **GANEXT** experts will continue to interact with Knowmade team in order to select the most relevant publications of the month, consistently with **GANEXT**'s ongoing projects.

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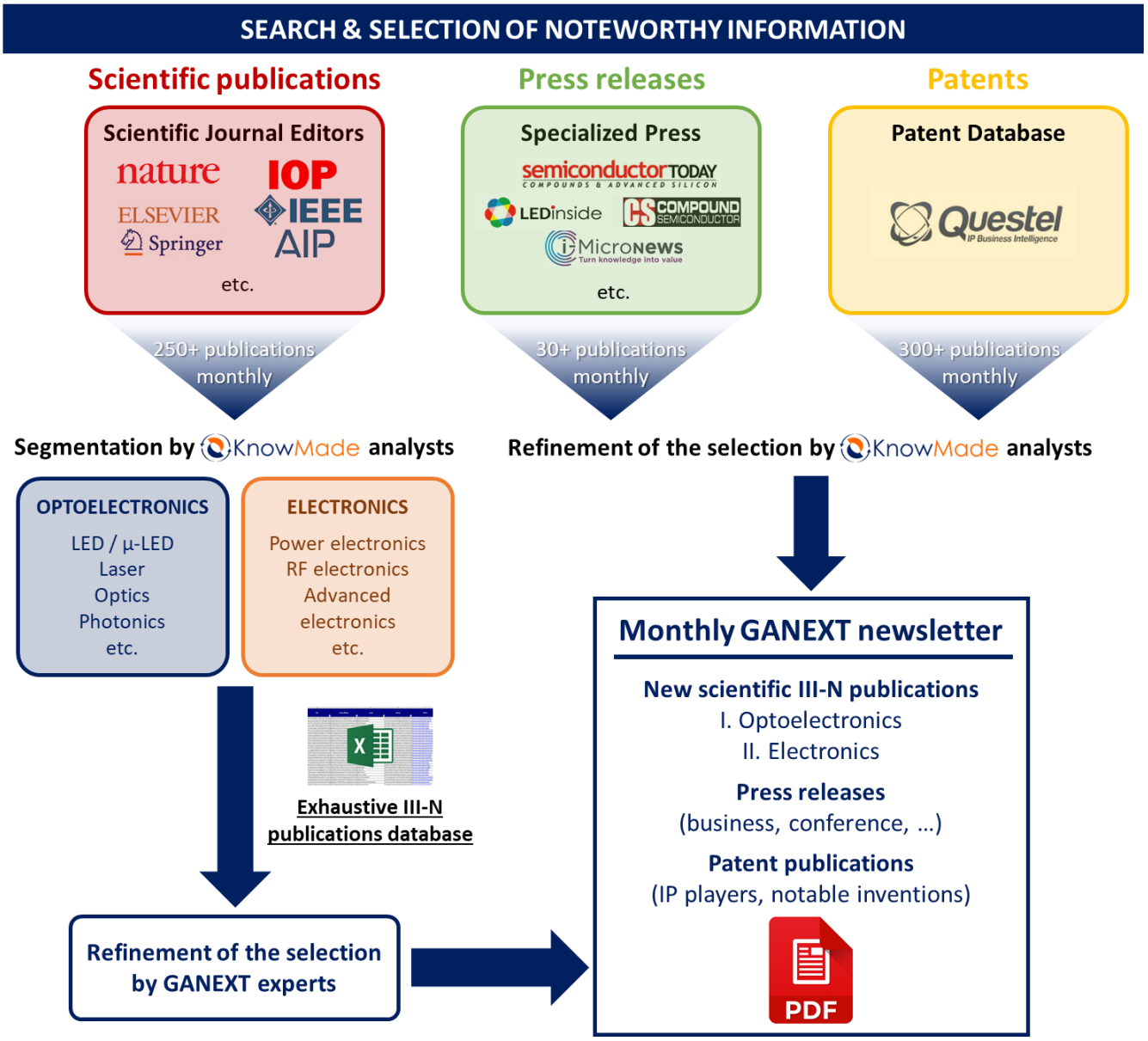
METHODOLOGY



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)

Polarization-enhanced AlGaN solar-blind ultraviolet detectors

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Photonics Research
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AlGaN solar-blind ultraviolet detectors have great potential in many fields, although their performance has not fully meet the requirements until now. Here, we proposed an approach to utilize the inherent polarization effect of AlGaN to improve the detector performance. AlGaN heterostructures were designed to enhance the polarization field in the absorption layer, and a high built-in field and a high electron mobility conduction channel were formed. As a result, a high-performance solar-blind ultraviolet detector with a peak responsivity of 1.42 A/W at 10 V was achieved, being 50 times higher than that of the nonpolarization-enhanced one. Moreover, an electron reservoir structure was proposed to further improve the performance. A higher peak responsivity of 3.1 A/W at 30 V was achieved because the electron reservoir structure could modulate the electron concentration in the conduction channel. The investigation presented here provided feasible approaches to improve the performance of the AlGaN detector by taking advantage of its inherent property.

Epitaxial superconducting tunnel diodes for light detection applications

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Optical Materials Express
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We demonstrate epitaxially integrated nanoscale superconductor tunnel diodes, realized using NbN on GaN thin films. Tuning the growth conditions leads to reduced interface defect density and to the emergence of the superconducting coherence peaks in the interface tunneling characteristics. The degree of disorder in the superconductor is correlated with the variance in the order parameter value of different domains. Epitaxial integration of the nanoscale layers allowed precise control on the quality of the superconductor at the interface, and, by extension, the variance in the order parameter value. The numerical calculations taking a normal distribution of superconducting order parameter at the interface with a fixed variance in its order parameter values closely match the measured interface transport characteristics at different temperatures. Strong sub-gap nonlinearity observed in the differential conductivity measurements were subsequently shown to be sensitive to photon incidence, thereby acting as a photodetector. Usage of superconducting interfaces with semiconducting layers such as GaN permit sensitivity tunability and enable large scale device fabrication and integration.

Light Extraction and Auger Recombination in AlGaN-Based Ultraviolet Light-Emitting Diodes

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IEEE Photonics Technology Letters
https://doi.org/10.1109/LPT.2020.3006863

AlGaN-based 300-nm ultraviolet (UV) light-emitting diodes (LEDs) with various p-n junction mesa perimeter-to-area (P/A) ratios and mesa depths were fabricated. As the mesa P/A ratio increases from 0.0133μm−1 to 0.157 μm−1 and the mesa depth increases from 550 nm to 1700 nm, the peak external quantum efficiency (EQE) increases from 2.93% to 4.89%. Fitting results from the ABC+f(n) model reveal that the light-extraction efficiency (LEE) is the major factor limiting the EQE, which can be enhanced by increasing the mesa P/A ratio and mesa depth. On the other hand, increasing the mesa P/A ratio and mesa depth also leads to increased Auger recombination coefficient from 1.11×10−31 cm 6s−1 to 2.11×10−30 cm 6s−1 , and the probable mechanism is defect-assisted Auger recombination at mesa sidewall by etching damage. In spite of the decreased internal quantum efficiency by Auger recombination, the improved LEE by increasing the mesa P/A ratio and mesa depth is still the major factor for the EQE at the current density below 150 A/cm 2 for UV LEDs.

Size dependence of quantum efficiency of red emission from GaN:Eu structures for application in micro-LEDs

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Optics Letters
https://doi.org/10.1364/OL.397848

GaN-based micro-LEDs typically suffer from a size-dependent efficiency due to the relatively long carrier lifetime and sidewall-related recombination effects. We demonstrate that for red-emitting Eu-doped GaN, sidewall-related recombination is hardly an issue for emission efficiency. We determine the photoluminescence quantum efficiency (PL QE) of Eu-related emission as a function of the size of square structures ranging from 3 to 192 μm. With the support of finite-difference time-domain simulations, we show that the light extraction efficiency and material losses are responsible for the decrease in PL QE for large sizes. For sizes smaller than 24 μm, there is an influence of the sidewall-related non-radiative recombination of carriers on the PL QE; however, it is only minor as a result of the limited carrier diffusion lengths in the Eu-doped material. These properties combined with the high efficiency of luminescence indicate the potential of this material for micro-LED applications.

Large-scale integration of artificial atoms in hybrid photonic circuits

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Nature
https://doi.org/10.1038/s41586-020-2441-3

A central challenge in developing quantum computers and long-range quantum networks is the distribution of entanglement across many individually controllable qubits1. Colour centres in diamond have emerged as leading solid-state ‘artificial atom’ qubits2,3 because they enable on-demand remote entanglement4, coherent control of over ten ancillae qubits with minute-long coherence times5 and memory-enhanced quantum communication6. A critical next step is to integrate large numbers of artificial atoms with photonic architectures to enable large-scale quantum information processing systems. So far, these efforts have been stymied by qubit inhomogeneities, low device yield and complex device requirements. Here we introduce a process for the high-yield heterogeneous integration of ‘quantum microchiplets’—diamond waveguide arrays containing highly coherent colour centres—on a photonic integrated circuit (PIC). We use this process to realize a 128-channel, defect-free array of germanium-vacancy and silicon-vacancy colour centres in an aluminium nitride PIC. Photoluminescence spectroscopy reveals long-term, stable and narrow average optical linewidths of 54 megahertz (146 megahertz) for germanium-vacancy

(silicon-vacancy) emitters, close to the lifetime-limited linewidth of 32 megahertz (93 megahertz). We show that inhomogeneities of individual colour centre optical transitions can be compensated in situ by integrated tuning over 50 gigahertz without linewidth degradation. The ability to assemble large numbers of nearly indistinguishable and tunable artificial atoms into phase-stable PICs marks a key step towards multiplexed quantum repeaters7,8 and general-purpose quantum processors.

High quality AlN film grown on a nano-concave-circle patterned Si substrate with an AlN seed layer

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Applied Physics Letters
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We have investigated the growth of AlN films on hexagonal nano-concave-circle patterned Si substrates using metal–organic chemical vapor deposition. By depositing a thin AlN seed layer on the Si substrate before the pattern process, a high quality AlN film with a thickness of 2 μm has been obtained. The full width at half maximum values of X-ray diffraction rocking curves are as low as 409 and 677 arc sec for AlN (002) and (102) planes, respectively. Further experimental results indicate that the AlN seed layer can suppress the misorientation of the adjacent grains, as revealed by the lower twist and tilt angles of the mosaic structure, and thus only a few dislocations generated during the grain coalescence. In addition, the migration of Al adatoms is enhanced on the Al terminated surface of the AlN seed layer, which accelerates the coalescence process. All these improvements are attributed to the lower binding energy and diffusion barrier for Al adatoms on the Al terminated surface than that on the Si surface. Our results demonstrate an effective approach to obtain high quality AlN films for high performance ultraviolet light-emitting diodes on the Si substrate.

Above 25 nm emission wavelength shift in blue-violet InGaN quantum wells induced by GaN substrate misorientation profiling: towards broad-band superluminescent diodes

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Optics Express
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We report a thorough study of InGaN quantum wells spatially modified by varying the local misorientation of the GaN substrate prior to the epitaxial growth of the structure. More than 25 nm shift of emission wavelength was obtained, which is attributed to indium content changes in the quantum wells. Such an active region is promising for broadening of the emission spectrum of (In,Al,Ga)N superluminescent diodes. We observed that the light intensity changes with misorientation, being stable around 0.5° to 2° and decreasing above 2°. This relation can be used as a base for future device designing.

Lift-off of semipolar blue and green III-nitride LEDs grown on free-standing GaN

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Applied Physics Letters
https://doi.org/10.1063/5.0013453

Light emitting diodes (LEDs), with active blue and green emitting and sacrificial multi-quantum well layers, were epitaxially grown using metal organic chemical vapor deposition on free-standing semipolar (202—1) GaN substrates. NanoLEDs were then fabricated and released into solution using an approach based on forming a mm-scale mesa, Au–Au thermocompression bonding to a submount, large-area photoelectrochemical etching, and colloidal

lithography. Photo- and cathodoluminescence (CL) measurements demonstrated that nanoLEDs were optically active after fabrication and released into the solution. Monte Carlo simulations of the electron trajectory through GaN/InGaN were performed to understand the patterns shown in CL images. The fabrication process developed herein could provide a viable route to highly efficient, nanoscale blue and green light emitters for applications in next-generation display technologies.

Photoassisted chemical smoothing of AlGaN surface after laser lift-off

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Journal of Vacuum Science & Technology B
https://doi.org/10.1116/6.0000192

To fabricate AlGaN-based ultraviolet (UV) vertical cavity surface-emitting laser diodes, a pair of distributed Bragg reflectors (DBRs) having a smooth surface is desired to have a high quality factor (Q). In this work, photoassisted chemical etching (PCE) was attempted to smoothen the -c(000-2) AlN surface after removing the sapphire substrate by means of the laser lift-off process. First, the conditions for PCE were optimized using an Xe lamp and KOH solution. The root-mean-square roughness of the -c(000-2) AlN surface was reduced from 30.5 to 5.6 nm, which enables us to fabricate an improved HfO2/SiO2 DBR on the AlN surface. Then, using the optimized PCE technique, improved UV (Al,Ga)N planar microcavities were fabricated and distinct cavity-mode-related emissions were observed using the photoluminescence (PL) technique. By comparing the PL spectra between the samples with and without PCE treatment, the Q value at 303 nm for the case of the improved DBR was determined to increase from 174 to 270. The increase in the Q value is mainly attributed to the reduction of scattering losses in optical cavities. Furthermore, the discussion on the mechanism of improved surface during the PCE treatment is given. Consequently, PCE is demonstrated to be a feasible approach to refine the quality of ultraviolet nitride microcavities.

Micrometer scale InGaN green light emitting diodes with ultra-stable operation

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Applied Physics Letters
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We report on the demonstration of InGaN photonic nanocrystal light emitting diodes (LEDs), which operate in the green wavelength (~548 nm). The devices are designed to operate at the Γ point of the photonic band structure and exhibit a spectral linewidth ~4 nm, which is nearly five to ten times narrower than that of conventional InGaN quantum well LEDs in this wavelength range. Significantly, the device performance, in terms of the emission peak and spectral linewidth, is nearly invariant with injection current, suggesting the insusceptibility to quantum-confined Stark effect commonly seen in InGaN quantum wells. The external quantum efficiency is characterized by a sharp rise with increasing current and reaches a maximum at ~5 A/cm2, which is comparable to conventional blue quantum well LEDs. A relatively small (~30%) efficiency droop was measured at an injection current density over 200 A/cm2 at room temperature without any active cooling.

Room-temperature operation of c-plane GaN vertical cavity surface emitting laser on conductive nanoporous distributed Bragg reflector

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Applied Physics Letters
https://doi.org/10.1063/5.0012281

Technological feasibility of III-nitride vertical cavity surface emitting laser (VCSEL) has been hindered by the lack of an electrically conductive, easily manufacturable, wide reflection stop band distributed

Bragg reflector (DBR). Here, we present the first electrically injected III-nitride VCSEL on an electrically conductive DBR using nanoporous (NP) GaN. The measured threshold current density and the maximum light output power were 42 kA/cm2 and 0.17 mW, respectively, at 434 nm. Vertical injection was demonstrated and showed no deterioration in the threshold current density or slope efficiency, demonstrating the feasibility of vertical injection in NP GaN VCSELs. Filamentary lasing was observed, and its effect on the slope efficiency and the lasing linewidth is studied. Initial measurements showing the correlation between the measured high threshold current density and surface undulations are presented and discussed.

Degradation study of InGaN-based laser diodes grown on Si

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Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/ab985f

The degradation characteristics of InGaN-based laser diodes (LDs) grown on Si substrate have been studied under an electrical stress with a pulsed current of 180 mA. After the electrical stress, the light output power, leakage current and capacitance of the LD decreased, while the operation voltage and threshold current increased, and the slope efficiency remained nearly unchanged after the pulsed electrical stress for 620 h. Further analysis shows that the degradation was probably due to the newly generated group-III vacancies and/or related defects, which can not only act as acceptor-like defects to compensate the n-type donors, leading to the reduction of conductance and capacitance, but also work as non-radiative recombination centers affecting the internal quantum efficiency and emission intensity of the active region.

Nanolayered Graphene/Hexagonal Boron Nitride/n-AlGaN Heterostructures as Solar-Blind Deep-Ultraviolet Photodetectors

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ACS Appl. Nano Mater.
https://doi.org/10.1021/acsanm.0c01219

The spectral specificity of deep-ultraviolet photodetectors makes them useful in the development of many fields, spanning from disinfection of various surfaces, water purification to optical communication. Since silicon-based devices show obvious disadvantages in ultraviolet devices due to its low band gap, the semiconductor materials with wide band gap exceeding 4 eV provide excellent alternatives. In this paper, by the integration of the unique properties of each constituent material, we design a nanolayered graphene/hBN/n-AlGaN GIS deep-ultraviolet photodetector with high performance. The wide-bandgap AlGaN semiconductor enables to detect deep-ultraviolet signals without the requirement of ultraviolet-pass filter and thus achieve true solar-blind photodetectors. In addition, the several nanolayered graphene-hBN heterostructure is utilized to enhance the performance of photodetectors, which successfully solves the strain issue between the graphene and conventional bulk insulators. Besides, the high transparency of graphene can lead incident light to directly excite active layer with negligible optical loss, and the two-dimensional hBN insulator is beneficial to reduce dark current and assist quantum tunneling of photogenerated carriers. Interestingly, the photodetectors demonstrated in this work show the highest responsivity and detectivity compared with previously reported AlGaN-based deep-ultraviolet photodetectors.

AlGaN Deep Ultraviolet Light-Emitting Diodes with Localized Surface Plasmon Resonance by high-density array of 40 nm Al Nanoparticles

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ACS Appl. Mater. Interfaces
https://doi.org/10.1021/acsami.0c08916

We present a remarkable improvement in the efficiency of AlGaN deep ultraviolet light-emitting diodes (LEDs) enabled by the coupling of localized surface plasmon resonance (LSPR) mediated by a high-density array of Al nanoparticles (NPs). The Al NPs with the average diameter of ~ 40 nm were uniformly distributed near the Al0.43Ga0.57N/Al0.50Ga0.50N multiple quantum well active region for coupling 285 nm emission by block copolymer lithography. The internal quantum efficiency is enhanced by 57.7% due to the decreased radiative recombination lifetime by the LSPR. As a consequence, the AlGaN LEDs with the array of Al NPs show 33.3% enhanced electroluminescence with comparable electrical properties to the reference LEDs without Al NPs.

High Modulation Bandwidth of Semi-polar (11-22) InGaN/GaN LEDs with Long Wavelength Emission

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ACS Appl. Electron. Mater.
https://doi.org/10.1021/acsaelm.0c00399

Visible light communication requires III-nitride LEDs with a high modulation bandwidth but has c-plane limitations. General illumination requires green/yellow III-nitride LEDs with high optical efficiency that are difficult to achieve on c-plane substrates. Micro-LEDs with a low efficiency are used to obtain a high modulation bandwidth. This paper demonstrates a record modulation bandwidth of 540 MHz for our semi-polar green LEDs with a broad area. Semi-polar yellow and amber LEDs with a modulation bandwidth of 350 MHz and 140 MHz respectively have also been reported, and are the longest wavelength III-nitride LEDs. These results agree with differential carrier lifetime measurements.

Enhanced UV Emission of GaN Nanowires Functionalized by Wider Band Gap Solution-Processed p-MnO Quantum Dots

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ACS Appl. Mater. Interfaces
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GaN-based UV light-emitting devices suffer from low efficiency. To mitigate this issue, we hybridized GaN nanowires (NWs) grown on Si substrates by plasma-assisted molecular beam epitaxy with solution-processed p-type MnO quantum dots (QDs) characterized by a wider band gap (~5 eV) than that of GaN. Further investigations reveal that the photoluminescence intensity of the GaN NWs increases up to ~3.9-fold (~290%) after functionalizing them with p-MnO QDs, while the internal quantum efficiency is improved by ~1.7-fold. Electron energy loss spectroscopy (EELS) incorporated into transmission electron microscopy reveals an increase in the density of states in QD-decorated NWs compared to the bare ones. The advanced optical and EELS analyses indicate that the energy transfer from the wider band gap p-MnO QDs to n-GaN NW can lead to substantial emission enhancement and greater radiative recombination contribution because of the good band alignment between MnO QDs and GaN NWs. This work provides valuable insights into an environmentally friendly strategy for improving UV device performance.

Photoluminescence efficiency of Al-rich AlGaN heterostructures in a wide range of photoexcitation densities over temperatures up to 550 K

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PHYSICAL REVIEW B
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Time-resolved photoluminescence and light-induced transient grating techniques were applied for the comparative investigation of the evolution of the internal quantum efficiency and of the carrier diffusion in an AlxGa1−xN silicon-doped epilayer and AlxGa1−xN MQWs (x>0.6). The experiments were performed between 80 and 550 K under various densities of excitation from 1μJcm−2 to 1mJcm−2. The decrease of the photoluminescence efficiency measured at high excitations is quantitatively correlated to the increase of the diffusion coefficients of carriers and to the increase of their nonradiative recombination rate. We evidence the reduction of the density of localized excitons with increasing both excitation density and temperature. The decrease of the excitation-dependent lifetime is less pronounced than the corresponding drop of the time-integrated photoluminescence efficiency. This is dominated by the thermal dissociation of excitons. At the lowest excitation densities, the excitons are captured to vacancy complexes. When increasing the excitation density, the ionization of excitons is produced, which leads to enhancing the nonradiative recombination of holes to aluminum vacancies and this simultaneously quenches the PL efficiency, due to the saturation of the bimolecular free-carrier–plasma recombination. At the initial recombination stages and under high excitation conditions we reveal diffusive recombination on dislocations. After a careful and sophisticated modeling, we establish relevant numbers for the following: (i) the free exciton binding energies, with values of 104 and 140 meV in the MQWs and in the layer respectively; (ii) the exciton localization energies, which are framed in the 12–35-meV range; (iii) the lifetimes of the localized excitons, which sit in the 2–4-ns range; (iv) the free exciton and carrier radiative recombination rate coefficients that are rex=(0.6±0.2)×(T/300)−1×109s−1 and Brad=(7±1)×(T/300)−3/2×10−10cm3s−1, respectively; (v) the capture cross section for excitons to the vacancy complex σ=(2±1)×(300/T)2×10−16cm2. Regarding the electron and hole capture cross sections to aluminum vacancy we found values of (1.5±1)×10−13cm2 and (7±1)×10−13cm2, respectively. The value of the Coulomb dislocation radius for the free-carrier recombination is established to be 12–15 nm.

High-Bandwidth Green Semipolar (20–21) InGaN/GaN Micro Light-Emitting Diodes for Visible Light Communication

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ACS Photonics
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The light-emitting diode (LED) is among promising candidates of light sources in visible light communication (VLC); however, strong internal polarization fields in common c-plane LEDs, especially green LEDs, result in low frequency and limited transmission performance. This study aims to overcome the limited 3-dB bandwidth of long-wavelength InGaN/GaN LEDs. Thus, semipolar (20–21) micro-LEDs (μLEDs) were fabricated through several improved approaches on epitaxy and chip processes. The μLED exhibits a 525 nm peak wavelength and good polarization performance. The highest 3-dB bandwidth up to 756 MHz and 1.5 Gbit/s data rate was achieved under a current density of 2.0 kA/cm2. These results suggest a good transmission capacity of green semipolar (20–21) μLEDs in VLC applications.

Efficiency improvement of AlGaN-based deep ultraviolet LEDs with gradual Al-composition AlGaN conduction layer

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Optoelectronics Letters
https://doi.org/10.1007/s11801-020-0072-4

The low internal quantum efficiency (IQE) of AlGaN-based deep ultraviolet light emitting diode (DUV-LED) limits its wider application. The main reasons for low IQE include low carrier concentration, poor carrier location and large defects. The bending of energy band between AlGaN electron blocking layer and conduction layer obstructs transport of holes to multiple quantum wells. In this paper, we propose a gradual Al-composition p-type AlGaN (p-AlGaN) conduction layer to improve the light emitting properties of AlGaN-based DUV-LED. Increased carrier concentration in the active region enhances the effective radiative recombination rate of the LED. Consequently, the IQE of our optimazited DUV-LED is increased by 162% in comparison with conventional DUV-LEDs.

Advantage of SiO_2 Intermediate Layer on the Electron Injection for Ti/n-Al0.60Ga0.40N Structure

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IEEE Transactions on Electron Devices
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In this work, and experimentally propose inserting an SiO_2 intermediate layer between the Ti and n-AlGaN layer to improve the electron injection efficiency. When the SiO_2 intermediate layer is adopted, the SiO_2 layer can share a part of the applied voltage and then weakens the surface depletion effect, which is confirmed by the capacitance-voltage measurement. Furthermore, the energy bending of the SiO_2 layer pushes the affinity of Ti to be even higher than the conduction band of the Al0.60Ga0.40N layer, which then screens the Schottky barrier and favors the election injection. The influence of the thickness of the SiO_2 intermediate layer is also investigated in this work. When the SiO_2 layer becomes thick, the tunneling capability of the electrons will be significantly limited due to the increased tunnel region width, leading to increased forward voltage.

Improved carrier confinement and stimulated recombination rate in GaN-based vertical-cavity surface-emitting lasers with buried p-AlGaN inversion layer

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Superlattices and Microstructures
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A GaN-based vertical cavity surface emitting laser (VCSEL) featuring a buried ring-shape p-Al0.10Ga0.90N inside n-GaN contact layer for lateral electron confinement is proposed. The p-AlGaN layer inserted in n-GaN forms an n-p-n structure, acting as a potential barrier to prevent vertical electron migration outside the aperture of the VCSEL, where optical gain is accumulated. By adjusting the thickness and position of the p-AlGaN layer, electron concentration and stimulated recombination rate in the aperture of the VCSEL increased significantly. Consequently, the output power of VCSEL with buried p-AlGaN layer increases by 57% compared to the conventional VCSEL at an injection current of 10 mA. The detailed mechanism responsible for this enhancement is further explored. This work suggests that the introduction of the buried p-AlGaN layer in VCSEL can provide new line of thought in achieving effective current confinement in the development of high-efficient, low-threshold solid-state lasers.

Carrier Dynamics in Al-Rich AlGaN/AlN Quantum Well Structures Governed by Carrier Localization

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physica status solidi b
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The carrier dynamics of Al-rich AlGaN/AlN quantum well (QW) structures in the presence of strong carrier localization is reported. Excitation density-dependent photoluminescence (PL) measurements at low temperatures reveal a clear correlation between the onset of efficiency droop and the broadening of the time-integrated PL spectra. While the droop onset is heavily impacted by the localization strength, the PL emission broadening is observed almost exclusively on the high energy side of the emission spectrum. Spectrally resolved PL decay transient measurements reveal a strong dependency of the carrier lifetimes on the emission photon energy across the spectrum, consistent with a distribution of localized states, as well as on the temperature, depending on the localization strength of the investigated structure. The characteristic “S”-shaped temperature dependence of the PL emission energy is shown to be directly correlated to the thermal redistribution of carriers between localized states. Based on these findings, the role of carrier localization in the recombination processes in AlGaN QW structures is underlined and its implications for efficiency droop are discussed.

Room temperature electroluminescence from Laser MBE grown Gallium nitride LEDs

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Materials Science and Engineering: B
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Gallium Nitride (GaN) based inverted p-i-n junction and InGaN/GaN quantum well LEDs have been demonstrated using Laser Molecular Beam Epitaxy technique. The fabricated p-i-n junction and QW LEDs exhibited rectifying I-V characteristics with a forward threshold voltage of about 3.4 V and 4.5 V, respectively. The electrically injected LEDs showed room temperature electroluminescence, wherein inverted p-i-n junction LED exhibited single peaked UV emission around 365 nm wavelength and the InGaN/GaN QW LED demonstrated both UV (368 nm) and visible (430 nm) spectral components. The emission in QW LED was found to exhibit a spectral blue shift with increasing injection current.

Ultraviolet optoelectronic devices based on AlGaN-SiC platform: Towards monolithic photonics integration system

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Nano Energy
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Rapid advancement of wide-bandgap AlGaN semiconductor materials offers tremendous opportunities in the field of ultraviolet (UV) optoelectronics for a wide range of advanced applications. Additionally, SiC has large bandgap and excellent material properties, also making itself a suitable material for UV photodetection. More importantly, high-quality AlGaN alloys can be epitaxially grown on SiC substrates because of the very small lattice mismatch between them (less than 1%), which enables a possible monolithic integration of those two materials and allows us to take advantage of their material and physical properties to realize high-performance UV optoelectronics and eventually the integrated UV photonics systems. Herein, we review the recent progress in the development of UV optoelectronics based on AlGaN-SiC platform, mainly focusing on: (1) the growth strategies and material characterizations of AlGaN epilayers on SiC; (2) the fabrication and performance evaluation of UV optoelectronic devices built on the platform, including UV LEDs/lasers and UV photodetectors. Thereafter, we briefly discuss the initial efforts in the pursuit of monolithic integration of those UV optoelectronic devices. Finally, the challenges and potential advances associated with individual UV optoelectronic components as well as UV integrated photonics system on the prosperous AlGaN-SiC platform are outlined, providing insights and perspectives for possible device- and system-level innovation in future.

Point Defect-Induced UV-C Absorption in Aluminum Nitride Epitaxial Layers Grown on Sapphire Substrates by Metal-Organic Chemical Vapor Deposition

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physica status solidi b
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We report on the optical properties of aluminum nitride (AlN) epitaxial layers grown on sapphire substrates by metal-organic chemical vapor deposition (MOCVD). The structures investigated in this study have been grown at highly different degrees of supersaturation in the MOCVD process. In addition, both pulsed and continuous growth conditions were employed and AlN is deposited on nucleation layers favoring different polarities. The samples are investigated by photoluminescence (PL), photoluminescence excitation (PLE) and absorption spectroscopy and found to vary significantly in absorption and emission characteristics. Two distinct absorption bands in the UV-C spectral range are observed and examined in greater detail, with either giving rise to a significant absorption coefficient of around 1000 cm−1. The corresponding defect transitions are identified by PL spectroscopy. Combined with secondary-ion mass spectrometry (SIMS) measurements, these absorption bands are allocated to the incorporation of carbon and oxygen impurities, depending on the applied growth conditions. Furthermore, similarities with other epitaxial growth techniques serving as basis for UV-C applications are highlighted. These results are highly relevant for a better understanding of absorption issues in AlN templates grown by various deposition techniques. In addition, consequences for the growth of efficient UV-C devices by MOCVD on sapphire substrates are outlined.

Electrical properties and microstructure formation of V/Al-based n-contacts on high Al mole fraction n-AlGaN layers

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Photonics Research
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The electrical and structural properties of V/Al-based n-contacts on n-AlxGa1−xN with an Al mole fraction x ranging from x=0.75 to x=0.95 are investigated. Ohmic n-contacts are obtained up to x=0.75 with a contact resistivity of 5.7×10−4 Ω·cm2 whereas for higher Al mole fraction the IV characteristics are rectifying. Transmission electron microscopy reveals a thin crystalline AlN layer formed at the metal/semiconductor interface upon thermal annealing. Compositional analysis confirmed an Al enrichment at the interface. The interfacial nitride-based layer in n-contacts on n-Al0.9Ga0.1N is partly amorphous and heavily contaminated by oxygen. The role and resulting limitations of Al in the metal stack for n-contacts on n-AlGaN with very high Al mole fraction are discussed. Finally, ultraviolet C (UVC) LEDs grown on n-Al0.87Ga0.13N and emitting at 232 nm are fabricated with an operating voltage of 7.3 V and an emission power of 120 µW at 20 mA in cw operation.

InGaN blue light emitting micro-diodes with current path defined by tunnel junction

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Optics Letters
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We have fabricated tunnel-junction InGaN micro-LEDs using plasma-assisted molecular beam epitaxy technology, with top-down processing on GaN substrates. Devices have diameters between 5 µm and 100 µm. All of the devices emit light at 450 nm at a driving current density of about 10Acm−2. We demonstrate that within micro-LEDs ranging in size from 100 µm down to 5 µm, the properties of these

devices, both electrical and optical, are fully scalable. That means we can reproduce all electro-optical characteristics using a single set of parameters. Most notably, we do not observe any enhancement of non-radiative recombination for the smallest devices. We assign this result to a modification of the fabrication process, i.e., replacement of deep dry etching by a tunnel junction for the current confinement. These devices show excellent thermal stability of their light emission characteristics, enabling operation at current densities up to 1kAcm−2.

Color-tunable <10 µm square InGaN micro-LEDs on compliant GaN-on-porous-GaN pseudo-substrates

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Applied Physics Letters
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In this study, two methods to tune the emission wavelength of micro-LEDs fabricated on tile patterned compliant GaN-on-porous-GaN pseudo-substrates (PSs) are presented. The mechanical flexibility of porous GaN was utilized to relax the strain induced during the growth of light-emitting diode (LED) structures with n- and p-InGaN layers and enhance the indium incorporation via the composition pulling effect. The first approach involved only varying the size of the PS square tiles used for LED structure regrowth, from 20 × 20 µm2 to 8 × 8 µm2. Higher n-InGaN base layer relaxation with decreasing tile size resulted in a red shift of emission from 525 nm to 561 nm with no change in the growth conditions. The second method involved changing the mole fraction, x, of the n-InxGa1−xN base layer of the LED structure from 0.04 to 0.09 by reducing growth temperature, while maintaining the high temperature growth conditions of the multi-quantum well (MQW) and p-InGaN targeting 530 nm emission. The resulting wavelength shift was a remarkable 536–616 nm due to the stronger composition pulling effect, providing a pathway to enable high indium content MQW active regions to be grown at high temperature.

Enhanced hole transport in AlGaN deep ultraviolet light-emitting diodes using a double-sided step graded superlattice electron blocking layer

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Journal of the Optical Society of America B
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In this paper, deep ultraviolet AlGaN light-emitting diodes (LEDs) with a novel double-sided step graded superlattice (DSGS) electron blocking layer (EBL) instead of a conventional EBL have been proposed for ∼254nm wavelength emission. The enhanced carrier transport in the DSGS structure results in reduced electron leakage into the p-region, improved hole activation and hole injection, and enhanced output power and external quantum efficiency. The calculations show that output power of the DSGS structure is ∼3.56 times higher and electron leakage is ∼12 times lower, compared to the conventional structure. Moreover, the efficiency droop at 60 mA in the DSGS LED was found to be ∼9.1%, which is ∼4.5 times lower than the regular LED structure.

Optical Quality and Stimulated Emission of Molecular Beam Epitaxy Grown AlGaN in the Deep Ultraviolet

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physica status solidi b
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In this work, the optical quality and stimulated emission of aluminum gallium nitride (AlGaN)/AlN double heterostructure grown by molecular beam epitaxy in the deep ultraviolet (UV) are reported. The room temperature internal quantum efficiency at a carrier density of 1 × 1018 cm−3 is around 12%, mainly limited by dislocations. For such as-grown wafers,

spectral narrowing and nonlinearity of the light output are measured from the wafer edge, with the transverse-electric (TE)-polarized component becoming dominant as the excitation increases. With cleaving, edge-emitting lasing at 298 nm is measured, with an estimated threshold of 0.95 MW cm−2.

Light-emitting diodes with AlN polarization-induced buried tunnel junctions: A second look

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Applied Physics Letters
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Interband Zener tunneling of electrons has been recently used in III-nitride semiconductor based light emitters to efficiently inject holes into p-cladding layers. Zener tunneling probabilities can be significantly enhanced if crystal symmetry-induced internal polarization fields assist the dopant-induced built-in electric fields of tunnel junctions because of the large reduction of the tunneling distance. In a metal-polar buried tunnel junction geometry, such electric field alignment needs an AlN interlayer at the tunnel junction. Because AlN is a larger bandgap semiconductor than GaN, it is not clear a priori if the net tunneling probability is reduced or enhanced compared to a homojunction. By combining theoretical modeling with experimental blue light emitting diodes, we find that the large tunneling enhancement due to the polarization field and band realignment overcome the reduction in tunneling due to the larger bandgap of AlN. Compared to a homojunction tunnel-junction, the inclusion of AlN in the tunnel junction is found to lower the turn-on and operating voltages and increase the wall-plug efficiency. This proves that polarization-induced AlN tunnel junctions are superior to homojunctions at low injection currents, resulting in higher optical emission intensity and superior uniformity.

Monolithic integration of ultraviolet microdisk lasers into photonic circuits in a III-nitride-on-silicon platform

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Optics Letters
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Ultraviolet microdisk lasers are integrated monolithically into photonic circuits using a III-nitride-on-silicon platform with gallium nitride (GaN) as the main waveguide layer. The photonic circuits consist of a microdisk and a pulley waveguide, terminated by out-coupling gratings. In this Letter, we measure quality factors up to 3500 under continuous-wave excitation. Lasing is observed from 374 to 399 nm under pulsed excitation, achieving low-threshold energies of 0.14mJ/cm2 per pulse (threshold peak powers of 35kW/cm2). A large peak-to-background dynamic of around 200 is observed at the out-coupling grating for small gaps of 50 nm between the disk and the waveguide. These devices operate at the limit of what can be achieved with GaN in terms of operation wavelength.

Quantum random number generator based on single-photon emitter in gallium nitride

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Optics Letters
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We experimentally demonstrate a real-time quantum random number generator by using a room-temperature single-photon emitter from the defect in a commercial gallium nitride wafer. Due to the brightness of our single-photon emitter, the raw bit

generation rate is about 1.8 MHz, and the unbiased bit generation rate is about 420 kHz after the von Neumann's randomness extraction procedure. Our results show that the commercial gallium nitride wafer has great potential for the development of integrated high-speed quantum random number generator devices.

Large-area far ultraviolet-C emission of Al0.73Ga0.27N/AlN multiple quantum wells using carbon nanotube based cold cathode electron-beam pumping

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Thin Solid Films
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In this study, we demonstrated a far ultraviolet-C (far-UVC) emitter using Al0.73Ga0.27N/AlN multiple quantum wells (MQWs) by carbon nanotube based cold cathode electron-beam (C-beam) excitation. The Al0.73Ga0.27N/AlN MQW structure was grown on AlN/sapphire by high-temperature metal-organic chemical vapor deposition. The large-area far-UVC emission (276 mm2) was investigated using C-beam, as a function of anode voltage (VA) and anode current (IA), and the near-band-edge emission of Al0.73Ga0.27N/AlN MQWs was observed at a peak wavelength of 233 nm, with a VA of 4 kV, an IA of 0.5 mA. The results suggest that the large-area C-beam pumped far-UVC emitter could be a promising sterilization light source.

High-brightness InGaN/GaN Micro-LEDs with Secondary Peak Effect for Displays

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IEEE Electron Device Letters
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The green InGaN/GaN micro light-emitting diode (Micro-LED) is a significant component in micro-display whereas lack of size dependence and high injectedcurrent analysis. In this paper, different size Micro-LDs were fabricated and the electro-optical characteristics were measured. The size-dependence phenomenon for EQE "efficiency droop", luminous flux and brightness were observed and discussed. All sizes Micro-LEDs exhibited an extremely high brightness as 37.5k and 67.6k nits at 1 A/cm2, 2.89M and 3.81M nits at 300 A/cm2 for 25 and 200 µm respectively. In addition, the elevating current densities from 160 to 6400 A/cm2 were injected into 25 µm Micro-LED and the electroluminescence (EL) spectra transformation of different current densities were depicted. The green to blue shift and secondary peak effect, which promise an opportunity to modulate the emission wavelength for higher quality and lower the barrier of mass transfer technology, were observed and analyzed through the spectra.

Performance improvement of GaN-based blue and ultraviolet double quantum well laser diodes by using stepped-doped lower waveguide

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Materials Science in Semiconductor Processing
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We have proposed a new stepped-doped lower waveguide (LWG) and systematically investigated its effect on GaN-based blue and ultraviolet laser diodes (LDs) through the simulation software LASTIP. It is found that increasing doping concentration of the LWG is beneficial to decrease the threshold current and raise the output power. Furthermore, when a suitably designed stepped-doped LWG layer replaces the homogeneously heavily doped LWG layer, the performance of the blue and ultraviolet LDs is further improved. It is mainly attributed to the decrease of electron leakage current and the increase of hole injection current. In addition, the stepped-doped LWG improves ultraviolet LDs characteristics more

significantly than the blue LDs, which is due to the reduction of the total optical loss.

Superlattice hole injection layers for UV LEDs grown on SiC

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AlGaN-based germicidal UV LEDs show promise in fighting the COVID-19 pandemic through disinfection of air, water, and surfaces. We report UV LEDs grown by MOCVD on SiC substrates, fabricated into thin-film flip chip devices. Replacing the uniform p-AlxGa1-xN layer (x = 0.2) with a short-period-superlattice of alternaying (x = 0.1 and 0.8) Al-composition improved EQE frm 1.3% to 2.7% (3.2% with encapsulation) at 20 A/cm2. Peak EQE and WPE values of 4.8% and 2.8% (287 nm) were measured at current densities below 2 A/cm2, and maximum output power of 7.4 mW (76 mW/mm2) was achieved at 284 nm. Further WPE improvements are expected with both superlattice and uniform layer optimization, improved p-contact metallization, and active region optimization.

Ultraviolet to mid-infrared supercontinuum generation in single-crystalline aluminum nitride waveguides

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Optics Letters
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We demonstrate ultrabroadband supercontinuum generation from ultraviolet to mid-infrared wavelengths in single-crystalline aluminum nitride waveguides. Tunable dispersive waves are observed at the mid-infrared regime by precisely controlling the waveguide widths. In addition, ultraviolet light is generated through cascaded second-harmonic generation in the modal phase-matched waveguides. Numerical simulation indicates a high degree of coherence of the generated spectrum at around the telecom pump and two dispersive waves. Our results establish a reliable path for multiple octave supercontinuum comb generation in single-crystalline aluminum nitride to enable applications including precision frequency metrology and spectroscopy.

Device quality templates of InxGa1−xN (x < 0.1) with defect densities comparable to GaN

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Applied Physics Letters
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InGaN/GaN multiple quantum well (MQW) structures currently used in optical devices are based on highly strained InGaN films. The presence of strain reduces quantum efficiency and indium incorporation, two critical parameters in addressing the green gap. We report on the growth of InGaN-relaxed templates on GaN as substrates to reduce the strain in the MQW structures. Relaxation in the InGaN templates, due to the lattice mismatch, is accommodated by the generation of V-pits rather than the formation of misfit dislocations. InxGa1−xN templates (x ∼ 0.1) are grown via a modified semibulk (SB) approach, with a gradually increasing GaN interlayer thickness to provide a mechanism for backfilling of V-pits. We used high-resolution x-ray diffraction rocking curves to quantify the edge-type and screw-type dislocation density present in the SB and compared the results with the etch pit density obtained via atomic force microscopy after treating the SB with a silane etch. Device-quality InGaN templates with defect density in the mid 108 cm−2 were investigated using the above two approaches, with a quality comparable to state-of-the-art GaN.

Bandwidth enhancement in an InGaN/GaN three-section superluminescent diode for optical coherence tomography

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Applied Physics Letters
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In this paper, the optoelectronic properties of InGaN-based blue (430 nm) superluminescent light-emitting diodes with a multi-section, three contact design are reported. The bias conditions of the rear absorber section and gain sections are explored in terms of enhancing and maximizing spectral bandwidth. We demonstrate that broader emission can be obtained with a short circuit, rather than an open circuit absorber section, and with two active regions at different current densities as opposed to a single active contact. Under optimal drive conditions, a −3 dB linewidth of 20 nm is obtained at 430 nm. Analysis of the device emission spectrum indicates that an axial resolution of ∼3.4 μm may be obtained in an optical coherence tomography system.

High gain and high ultraviolet/visible rejection ratio photodetectors using p-GaN/AlGaN/GaN heterostructures grown on Si

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Applied Physics Letters
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We report high performance ultraviolet (UV) photodetectors (PDs) based on p-GaN-gated AlGaN/GaN heterostructures grown on silicon substrates. Benefitting from the high electrical gain resulting from the transistor-like operation of the device, a photocurrent as high as 4.8 mA/mm was achieved with UV illumination. Due to the effective depletion of the two-dimensional electron gas at the AlGaN/GaN heterointerface via a p-GaN optical gate, the dark current was suppressed to below $3 \times 10{-}8$ mA/mm. A high photo-to-dark current ratio over 108 and a high responsivity of 2×104 A/W were demonstrated in the device. Moreover, with a cutoff wavelength of 395 nm, the PDs exhibited an ultrahigh UV-to-visible rejection ratio of over 107. Limited by a persistent photoconductivity effect, the rise time and fall time of the device frequency response were measured to be 12.2 ms and 8.9 ms, respectively. The results suggest the potential of the proposed PDs for high-sensitivity UV detection.

Fully transparent GaN homojunction tunnel junction-enabled cascaded blue LEDs

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Applied Physics Letters
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A sidewall activation process was optimized for buried magnesium-doped p-GaN layers yielding a significant reduction in tunnel junction-enabled light emitting diode (LED) forward voltage. This buried activation enabled the realization of cascaded blue LEDs with fully transparent GaN homojunction tunnel junctions. The initial optimization of buried p-GaN activation was performed on PN junctions grown by metal organic chemical vapor deposition (MOCVD) buried under hybrid tunnel junctions grown by MOCVD and molecular beam epitaxy. Next the activation process was implemented in cascaded blue LEDs emitting at 450 nm, which were enabled by fully transparent GaN homojunction tunnel junctions. The tunnel junction-enabled multi-active region blue LEDs were grown monolithically by MOCVD. This work demonstrates a state-of-the-art tunnel junction-enabled cascaded LED utilizing homojunction tunnel junctions which do not contain any heterojunction interface.

Simulating random alloy effects in III-nitride light emitting diodes featured

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Statistical fluctuations in the alloy composition on the atomic scale can have important effects on electronic and optical properties of bulk materials and devices. In particular, carrier localization induced by alloy disorder has been a much discussed topic during the last decade with regard to III-nitride light emitting diodes (LEDs). Much experimental and theoretical work has been dedicated to the study of the effects of alloy disorder on carrier localization and finally on the efficiency and transport properties in such devices. Modeling approaches range from empirical analytical models down to atomistic ab initio ones, each with its advantages and disadvantages. In this tutorial, we discuss the simulation of alloy fluctuations in nitride quantum well LEDs by combining continuum device models and an atomistic empirical tight binding model, which provides a suitable compromise between atomic precision and computational effort.

Different I-V behaviors and leakage current Mechanisms in AlGaN Solar-Blind Ultraviolet Avalanche Photodiodes

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The different current-voltage (I-V) behaviors and leakage current mechanisms of AlGaN solar-blind ultraviolet avalanche photodiodes (APDs) have been investigated to better understand the relationships between multiplication gain and threading dislocations (TDs) in wide band-gap AlGaN materials. The cross-sectional transmission electron microscopy (TEM) and first-principles calculations were used to study the types, location, density and electronic structures of threading dislocations. The I-V behaviors of APDs for different types of dislocations were simulated based on nonlocal band to band tunneling model, we found that 4-core-edge TDs in the avalanche region can give rise to electron tunneling from the valence band of p-AlGaN to the conduction band of i-AlGaN and results in a premature breakdown, and the multiplication gain were significantly reduced under high electric field. The dark current of avalanche devices with high gain were dominated by open core and full core screw TDs.

Effects of 5 MeV electron irradiation on deep traps and electroluminescence from near-UV InGaN/GaN single quantum well light-emitting diodes with and without InAlN superlattice underlayer

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The electrical properties, electroluminescence (EL) power output and deep trap spectra were studied before and after 5 MeV electron irradiation of near-UV single-quantum-well (SQW) light-emitting diodes (LED) structures differing by the presence or absence of InAlN superlattice underlayers (InAlN SL UL). The presence of the underlayer is found to remarkably increase the EL output power and the radiation tolerance of LEDs, which correlates with a much lower and more slowly changing density of deep traps in the QW region with radiation dose, and the higher lifetime of charge carriers, manifested by higher short-circuit current and open-circuit voltage in current–voltage characteristics under illumination. The observed phenomena are explained by the capture of native defects segregated at the growing surface by In atoms

in the underlayer which traps them in the underlayer and prevents their penetration into the QW region.

Internal loss of AlGaN-based ultraviolet-B band laser diodes with p-type AlGaN cladding layer using polarization doping

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Applied Physics Express
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Aluminum gallium nitride (AlGaN)-based ultraviolet-B band laser diodes (LDs) with a p-type AlGaN cladding layer using polarization doping were fabricated on lattice-relaxed Al0.6Ga0.4N/AlN/sapphire. The threshold current density J th and lasing wavelength of this LD were 25 kA cm−2 and 298 nm, respectively. The internal loss (α i) was estimated by means of a variable stripe length method using optical excitation. The α i value of this LD was relatively low (i.e. <10 cm−1), thus suggesting that the device is characterized by both, proper light confinement and low internal loss.

High-performance nanowire ultraviolet light-emitting diodes with potassium hydroxide and ammonium sulfide surface passivation

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Applied Optics
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Potassium hydroxide (KOH) and ammonium sulfide (NH4)2Sx have been used as a surface passivation treatment to improve the electrical and optical performance of AlGaN nanowire ultraviolet (UV) light-emitting diodes (LEDs). Enhancements in photoluminescence at 335 nm (49%), optical output power (65%), and electroluminescence (83%), with respect to the as-grown nanowire LED are recorded for the AlGaN nanowire UV LEDs with surface passivation. These enhancements are attributed to the reduced nonradiative recombination on the nanowire surfaces. This study provides a potential surface passivation approach to produce high-power AlGaN nanowire LEDs operating in the UV spectrum.

V-Pits-Induced Photoresponse Enhancement in AlGaN UV-B Photodetectors on Si (111)

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IEEE Transactions on Electron Devices
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We demonstrate the influence of surface terminated V-pits in tuning dark current and spectral responsivity of Al0.25Ga0.75N-based UV-B photodetectors with metal-semiconductor-metal geometry on Si (111) substrate. We show that the V-pit morphological defects contribute to a large internal gain in these photodetectors, thereby leading to a substantial enhancement in external quantum efficiency (EQE) at relatively low applied biases. For photodetectors fabricated on metal organic chemical vapor deposition grown Al0.25Ga0.75N epilayers with a surface pit density of 2 x 10^8 $cm^{-}{}_2$, an EQE of 100% was measured at a meager bias of 1.7 V, which increased significantly with bias. The EQE, photo-to-dark current ratio, and UV-to-visible rejection ratio measured 5 x 10^4%, 1.2 x10^4, and 2 x 10_3, respectively, at 5 V. The evidence of localized enhancement of photoresponse at the surface terminations of V-pits is exemplified by UV-assisted conductive atomic force microscopy. Temperature-dependent carrier transport analysis under dark and UV illumination revealed cumulative contributions of pit-induced thermionic field emission and hole-trapping-induced gain to the observed large EQE. This work presents the highest value of responsivity for III-nitride UV-B detectors at a given bias.

Overcoming the excessive compressive strain in AlGaN epitaxy by introducing high Si-doping in AlN templates

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The influence of compressive strain in high-quality AlN templates on the subsequent growth of AlGaN-based device layers was investigated. The AlN templates showed compressive strain of ~−0.29% and threading dislocation densities (TDDs) below 6.5 × 108 cm−2. By introducing high Si-doping in MOVPE-grown AlN, the compressive strain was relaxed while preserving the low TDD. By this method, the low TDD was transferred from the AlN template to the micron-thick n-Al0.63Ga0.37N. A 275 nm LED was demonstrated with a ~2.5 times power enhancement than the same LED on conventional MOVPE-grown AlN template under low current injection. The maximum external quantum efficiency (EQE) was enhanced from 1.6% to 2.2% with an improved n-AlGaN.

The optimization of surface plasmon coupling efficiency in InGaN/GaN nanowire based nanolasers

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Applied Physics Express
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In this study, surface plasmon-enhanced nanolasers beyond the optical diffraction limit with different structural parameters have been designed and analyzed to optimize the surface plasmon coupling efficiency. Electric field energy can be highly confined in the ultrathin insulating region, as revealed via simulated distribution of the electric field using COMSOL Multiphysics software, resulting in an enhanced stimulated emission of radiation. Additionally, through optimizing the structural parameters, the optical performance of plasmon-enhanced nanolasers was significantly improved, with a threshold as low as ~4 W cm−2 and a Quality (Q) factor of up to 196 under optical pumping.

Multi-microscopy nanoscale characterization of the doping profile in a hybrid Mg/Ge-doped tunnel junction

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Nanotechnology
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A multi-microscopy investigation of a GaN tunnel junction (TJ) grown on an InGaN-based light emitting diode (LED) has been performed. The TJ consists of a heavily Ge-doped n-type GaN layer grown by ammonia-based molecular-beam epitaxy on a heavily Mg-doped p-type GaN thin layer, grown by metalorganic vapor phase epitaxy. A correlation of atom probe tomography, electron holography and secondary ion mass spectrometry has been performed in order to investigate the nm-scale distribution of both Mg and Ge at the TJ. Experimental results reveal that Mg segregates at the TJ interface, and diffuses into the Ge-doped layer. As a result, the dopant concentration and distribution differ significantly from the nominal values. Despite this, electron holography reveals a TJ depletion width of ~7 nm, in agreement with band diagram simulations using the experimentally determined dopant distribution.

Improvement of Light Extraction in Deep Ultraviolet GaN Light Emitting Diodes with Mesh P-Contacts

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Appl. Sci.
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One of the main reasons that the emission efficiency of GaN-based light-emitting diodes (LEDs) decreases significantly as the emission wavelength shorter than 300 nm is the low light extraction efficiency (LEE). Especially in deep ultra-violet (DUV) LEDs, light propagating outside the escape cone and being reflected back to the semiconductor or substrate layer is absorbed not only by active layers but also by p-type layers with narrower bandgaps and electrodes that are neither transparent nor reflective of the DUV wavelength. In this report, we propose a DUV LED structure with mesh p-GaN/indium-tin-oxide (ITO) contacts and a Ti/Al/Ni/Au layer as a reflective layer to improve LEE. The mesh p-GaN/ITO DUV LED showed an output power of 12% higher than that from the conventional DUV LED due to the lower light absorption at 280 nm.

Performance improvement of ultraviolet-A multiple quantum wells using a vertical oriented nanoporous GaN underlayer

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Well-aligned, lateral and vertical oriented nanoporous GaN was fabricated using the electrochemical etching procedure and its influence on the optical characteristics of ultraviolet-A multiple quantum well (MQW) structure was investigated. We used a MQW structure with a V-defect and n-Al0.1Ga0.9 N layer, which greatly improved the uniformity of vertical electrochemical etching. Compared to the as-grown MQW structure, the lateral and vertical oriented nanoporous MQW structures have 3.8-fold and 8.1-fold photoluminescence intensity enhancement and the full width at half maximum has been narrowed from 18.4 nm to 7.9 nm and 2.8 nm, respectively. The vertical oriented nanoporous MQW structure has a rectangular far-field emission pattern with uniform forward light distribution and the view angle of 85% intensity is 50°. This study provides an effective method for improving the light output and controlling the emission angle of GaN based light emitting devices, as well as a method for preparing well-aligned nanopores in semiconductors.

Optimized design of narrow spectral linewidth nonpolar m-plane InGaN/GaN micro-scale light-emitting diode

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Journal of Optics
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In this paper, a non-polar InGaN/GaN LED, which is oriented in the direction of the m-plane, is simulated through the TCAD tool. The In-GaN/GaN LED device reported in this paper is designed and optimized to modify its characteristic parameters to achieve narrow linewidth. Device simulation of LED is carried out in an LED simulator and extracted data is represented in the form of graphs. This paper has a prime focus on the linewidth of LEDs. After optimization of design, the linewidth of LED is reduced from 32 nm (calculated graphically by measuring − 3 db linewidth) to 5 nm. In addition to linewidth optimization, the impact of the device dimension and InxGa1−xN mole fraction, on peak wavelength and maximum amplitude is reported. The significance of reducing the linewidth is that it reduces the material dispersion in optical fiber communication systems operated with LEDs. Material dispersion is a mechanism which limits the capacity of optical fibers. Hence, it improves the performance of the optical fiber and reduces the power consumption and hence it improve the overall performance and efficiency of the communication systems.

Comparative analysis of light trapping GaN nanohole and nanorod arrays for UV detectors

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Journal of Nanoparticle Research
https://doi.org/10.1007/s11051-020-04972-x

In this paper, based on the excellent light trapping performance of the nanostructure, the structure of the electron emission layer of the ultraviolet detector is optimized. In this paper, simulation models of gallium nitride (GaN) nanohole arrays and nanorod arrays are designed by COMSOL Multiphysics software, which is based on the finite element method (FEM). In order to optimize the geometric parameters of GaN nanohole and nanorod arrays, and understand the influence of polarized light on them, the light absorption performance in the ultraviolet (UV) band has been fully analyzed. We found that when the lattice constant ranges from 200 to 500 nm, the GaN nanohole array and the GaN nanorod array have extreme absorptivity. And when the incident light has an inclination of 20°, the light trapping performance of the nanohole array can be further improved. GaN nanostructures with high light trapping capabilities will help improve the photoelectric emission efficiency of GaN photocathode and provide design reference for UV detectors with excellent performance.

Enlightening gallium nitride-based UV photodetectors

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Journal of Materials Chemistry C
https://doi.org/10.1039/D0TC03219K

This article highlights the emerging demand for gallium nitride (GaN) semiconductor technology that offers superior optoelectronic properties making it suitable for highly efficient ultraviolet (UV) photodetection devices. An overview of the required physical mechanisms and a background review of the latest approaches for highly responsive GaN-based UV photodetectors are compiled and the future perspective for optoelectronic devices is discussed. It was proposed that the GaN subfield is directed towards integration with two-dimensional materials for futuristic applications. Finally, this article provides open questions for future researchers and suggests a direction for possible solutions to the problems faced during the development of highly efficient optoelectronic devices.

Alternative Strategy to Reduce Surface Recombination for InGaN/GaN Micro-light-Emitting Diodes—Thinning the Quantum Barriers to Manage the Current Spreading

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Nanoscale Research Letters
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Owing to high surface-to-volume ratio, InGaN-based micro-light-emitting diodes (μLEDs) strongly suffer from surface recombination that is induced by sidewall defects. Moreover, as the chip size decreases, the current spreading will be correspondingly enhanced, which therefore further limits the carrier injection and the external quantum efficiency (EQE). In this work, we suggest reducing the nonradiative recombination rate at sidewall defects by managing the current spreading effect. For that purpose, we properly reduce the vertical resistivity by decreasing the quantum barrier thickness so that the current is less horizontally spreaded to sidewall defects. As a result, much fewer carriers are consumed in the way of surface nonradiative recombination. Our calculated results demonstrate that the suppressed surface nonradiative recombination can better favor the hole injection efficiency. We also fabricate the μLEDs that are grown on Si substrates, and the measured results are consistent with the numerical calculations, such that the EQE for the proposed μLEDs with properly thin quantum barriers can be enhanced, thanks to the

less current spreading effect and the decreased surface nonradiative recombination.

Increasing the Luminescence Efficiency of Long-Wavelength InGaN Quantum Well Structures by Electric Field Engineering Using an AlGaN Capping Layer

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Despite the very high efficiency at blue wavelengths, nitride-based light-emitting diodes suffer from low efficiencies in the green and red spectral ranges. Different solutions have been proposed to mitigate the “green gap,” including the addition of an AlGaN capping layer to the quantum well structure. In this work, we show how the increased polarization field due to such an AlGaN capping layer has profound effects on carrier location and recombination probabilities. The proper choice of AlGaN composition leads to an increased electron-hole overlap as well as an enhanced confinement in the quantum well region. Therefore, the combination of band structure and electric field engineering can be a promising approach to mitigate the green gap problem.

ELECTRONICS

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Investigation on harmonic spur characteristics of hybrid integrated LDMOS and AlGaN /GaN power amplifiers at different temperatures

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The harmonic spur characteristics of a hybrid integrated S-band power amplifier (PA), consisting of both stages of LDMOSFET and AlGaN/GaN HEMT, are studied at different temperatures. The PA offers a peak output power of 50 dBm (100 W) with power added efficiency higher than 50%, and adjacent channel power ratio performance is less than −30 dBc. A temperature test chamber is employed for measuring the harmonic spur of PA from 233 to 393 K, and its linear response to temperature is captured at high output power level.

Time Dependent Shift in SOA boundary and Early Breakdown of Epi-Stack in AlGaN/ GaN HEMTs Under Fast Cyclic Transient Stress

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IEEE Transactions on Device and Materials Reliability
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This experimental study reports first observations of (i) SOA boundary shift in AlGaN/GaN HEMTs and (ii) early time-to-fail of vertical AlGaN/GaN epi-stack under fast changing (sub-10ns rise time) cyclic pulse transient stress, which otherwise qualified for 600 V DC stress. It is shown that a epi stack qualified for 10 years lifetime under DC stress, fails faster under cyclic transient stress. The drain-to-substrate leakage exhibits different trends under DC and pulse stress. Integrated electrical and mechanical stress characterization routine involving Raman/ PL mapping, PFM and CL spectroscopy along with atomistic simulations reveals material limited unique failure physics under transient stress condition. Failure analysis using cross-sectional SEM and TEM investigations reveal signature of different degradation and failure mechanism under transient and DC stress conditions. A failure model is proposed for rapid breakdown of AlGaN/GaN epi-stack under cyclic transient stress and it is experimentally validated.

Modeling Bias Dependence of Self-Heating in GaN HEMTs Using Two Heat Sources

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IEEE Transactions on Electron Devices
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This article proposes a new approach for modeling self-heating in gallium nitride (GaN) high-electron-mobility transistors (HEMTs). The proposed approach utilizes two heat sources to model the effects of the

relatively uniform heat generation when the device is in the linear regime and the concentrated heat generation in the high-field area after the device pinches off. Compared to traditional single heat source modeling approaches, the proposed approach yields a model that can accurately capture the bias dependence of the heat and temperature distribution in the GaN HEMT channel without resorting to the more resource-intensive electrothermal simulations. It also leads to a simple yet accurate analytical expression for the maximum channel temperature using thermal resistances that have clear geometric dependence.

Improving the Current Spreading Effect for GaN-Based Quasi-Vertical PIN Diode by Using an Embedded PN Junction

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physica status solidi
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GaN-based quasi-vertical PIN diodes are grown on insulating sapphire substrates, and thus both the n-electrodes and the p-electrode are made on the same side, which causes lateral current injection scheme. Therefore, one of the challenges for this design lies in the serious current crowding at the mesa edges, which leads to the local hole accumulation, and thus the Auger recombination will significantly give rise to the poor conductivity modulation in the drift region when the devices are forwardly biased. In this work, we propose utilizing an embedded PN-GaN junction, such that the embedded PN-GaN junction will be reversely biased when the PIN diode is in the on-state condition. The built-in electric field in the reversely biased PN-GaN junction will deplete holes at the mesa edges, and correspondingly the Auger recombination can be decreased. Our results also show that the proposed structures do not affect the breakdown voltage for PIN diodes.

A 3-to-40-V Automotive-Use GaN Driver With Active Bootstrap Balancing and VSW Dual-Edge Dead-Time Modulation Techniques

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This article presents a GaN driver operating at a switching frequency variable from 10 to 30 MHz to achieve reliable and efficient power conversion for automotive electronics applications. An active bootstrap (BST) balancing (ABB) technique is presented to stabilize the BST rail voltage by sensing VSW and controlling BST rail charging. Meanwhile, a VSW dual-edge dead-time (tdead) modulation senses instant VIN and IO and generates optimal tdead for VSW trailing and leading edges, achieving zero-voltage switching (ZVS) turn-on for GaN power switches. To operate at high frequency and retain high efficiency, pulse-based dynamic up- and down-level shifters are developed to achieve sub-nanosecond propagation delay with a quiescent current of 0.5 µA. To validate this work, a switching power converter prototype is implemented using a 0.35-µm high-voltage (HV) BCD process. It maintains a constant 5.1-V BST rail voltage to prevent GaN FET from destructive breakdown and accomplishes 0.9-to-3.7-ns tdead and 3.7-to-10.4-ns tdead for VSW trailing and leading edge, respectively, in response to load current IO change from 0.01 to 1.2 A. The proposed techniques jointly improve the efficiency by 8.3%, which peaks at 90.7% for 12-to-5-V conversion and 88% for 40-to-5-V conversion.

Characterization, Modeling, and Compensation of the Dynamic Self-Biasing Behavior of GaN HEMT-Based Power Amplifiers

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Charge-trapping phenomena in radio-frequency (RF) power amplifiers (PAs) based on GaN high-electron-mobility transistor (HEMT) technology are understood to be responsible for the dynamic self-biasing behavior

that leads to a seemingly intractable slow dynamic residual nonlinearity in communications applications. For this reason, and based on recent developments in the characterization and modeling of charge-trapping phenomena, in this article we demonstrate how the dynamic self-biasing behavior of GaN HEMT-based PAs can be characterized, modeled, and compensated. First, we describe a method for the accurate characterization of the capture and emission dynamics of charge-trapping phenomena using transient two-tone large-signal RF measurements. Then, we demonstrate that the accurate modeling of these phenomena is contingent on the capture process being described by a state-variable time constant, rather than a fixed near-instantaneous time constant as is typically assumed. Finally, we propose a fully analog electronic circuit that implements an approximation of the Shockley-Read-Hall (SRH) statistics-based physical model of charge trapping to compensate the dynamic self-biasing behavior of a 15 W GaN HEMT-based PA.

Ultra-compact, high-frequency power integrated circuits based on GaN-on-Si Schottky Barrier Diodes

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IEEE Transactions on Power Electronics
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GaN transistors are being employed in an increasing number of applications thanks to their excellent performance and competitive price. Yet, GaN diodes are not commercially available and little is known about their performance and potential impact on power circuit design. In this work, we demonstrate scaled-up GaN-on-Si Tri-Anode Schottky Barrier Diodes (SBDs), whose excellent DC and switching performance are compared to commercial Si fast recovery diodes and SiC SBDs. Moreover, the advantageous lateral GaN-on-Si architecture enables to integrate several devices on the same chip, paving the way to power integrated circuit. This is demonstrated by realizing a diode-multiplier Integrated Circuit (IC), which includes up to 8 monolithically-integrated SBDs on the same chip. The IC was integrated on a DC-DC magnetic-less boost converter able to operate at a frequency of 1 MHz. The IC performance and footprint are compared to the same circuit realized with discrete Si and SiC vertical devices, showing the potential of GaN power ICs for efficient and compact power converters.

Homo-epitaxial growth of n-GaN layers free from carbon-induced mobility collapse and off-angle-dependent doping variation by quartz-free hydride vapor phase epitaxy

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Applied Physics Letters
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Certain undesired phenomena are observed in n-GaN layers grown by metal–organic chemical vapor deposition (MOCVD) due to the unavoidable C-induced carrier compensation. They are a drastic reduction in carrier mobility, called mobility collapse, and significant non-uniformity in the carrier concentration due to the off-angle dependence of the C-incorporation efficiency of the process. These phenomena are particularly severe for low doping levels between 1015 and 1016/cm3, which are suitable for fabricating drift layers used in vertical-type GaN power devices that operate in the range of a few kilovolts to tens of kilovolts. However, the C-related undesired characteristics are absent in homo-epitaxial n-GaN layers grown by quartz-free hydride vapor phase epitaxy (QF-HVPE), recently developed by us. The utilization of C-free raw materials alongside quartz-free parts enables the growth of highly pure GaN crystals with negligible Si, C, and O incorporations. These crystals exhibited an electron concentration in the low-1015/cm3 range with the highest reported room temperature electron mobility, μ, of 1470 cm2/V s among GaN crystals, whereas n-GaN layers with similar carrier concentrations but containing C-compensation, as in the case of those grown by MOCVD, exhibited a severe mobility collapse (μ = 288 cm2/V s). High uniformity in the carrier concentration with a small standard deviation of 4.0% was observed in a 2-in. n-GaN wafer grown by QF-HVPE on a GaN substrate with an off-angle variation of 0.3°. On the other hand, the standard deviation of the carrier concentration in wafers grown by MOCVD was

approximately 17% because of the off-angle-dependent C-incorporation.

Early stage degradation related to dislocation evolution in neutron irradiated AlGaN/GaN HEMTs

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Applied Physics Letters
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The early stage degradation of electrical properties in AlGaN/GaN high electron mobility transistors (HEMTs) under fast neutron irradiation is studied. After the 1 MeV neutron irradiation at a low fluence of 1 × 1014 neutrons/cm2, the reverse leakage current decreases while the output and transfer characteristics remain unchanged, which cannot be explained by the previously reported high-fluence degradation model. By employing temperature-dependent gate leakage current measurements, we show that the dislocation related Poole–Frenkel (PF) emission dominates the gate leakage mechanism before and after irradiation whereas the barrier height for electron emission to conductive dislocation increases after the neutron irradiation. A model with the evolution of dislocation from the VGa-decorated configuration to the pure configuration is proposed to describe the degradation of AlGaN/GaN HEMTs at the low-fluence early stage neutron irradiation. This model enriches the understanding of the degradation mechanism of neutron irradiated AlGaN/GaN HEMTs.

A Fully Integrated GaN Dual-Channel Power Amplifier With Crosstalk Suppression for 5G Massive MIMO Transmitters

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We present a broadband dual-channel power amplifier (PA) with crosstalk suppression for multi-input multi-output (MIMO) communications. Operation of MIMO system with crosstalk is theoretically evaluated for two popular coding schemes including the space-time coding and linear precoding. Design challenges of a multi-channel PA on a single chip are investigated and circuit techniques, including second-harmonic trapping integrated into the output matching network and the use of back-via lines to isolate the channels, are proposed to mitigate the inter-channel crosstalk. A fully integrated dual-channel PA prototype, implemented using a 250-nm GaN-on-SiC process, provides 34.9–36.3 dBm output power, 44–49% power-added efficiency (PAE), 11.3–12.3 dB power gain, 31.0–34.2 dB second-harmonic rejection, and –28.1 dB to –25.7 dB inter-channel crosstalk across 4.5–6.5 GHz. For a 100-MHz 256-QAM signal with 7.2 dB peak-to-average power ratio (PAPR), the PA achieves 29.9 dBm average output power, 30% average PAE–, 38.2/–39.1 dBc adjacent channel leakage ratio (ACLR), and –28.2 dB (3.9%) rms error vector magnitude (EVM), without using digital predistortion (DPD). Effect of crosstalk on linearity of the dual-channel PA is also measured and it is shown that for a 256-QAM signal EVM can increase by 3–8 dB, depending on relative power levels of the two channels.

Effects of the Growth Temperature on Structural and Electrical Properties of AlN/GaN Heterostructures Grown by Metal Organic Chemical Vapor Deposition

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Thin Solid Films
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In this paper, we present the dependence of structural and electrical properties of AlN/GaN heterostructure on the growth temperature on sapphire substrates by metal organic chemical vapor deposition. The results revealed that higher Ga incorporation (~47%) and higher trench density on the surface of AlN barrier

layer when grown at 1125 °C. However, further decreasing the AlN growth temperature to 500 °C results in the lower Ga incorporation (~5%), higher dislocation density, 3D island growth and larger tensile strain of AlN barrier layer. Degradation of structural properties and surface morphologies AlN barrier layer results in the higher resistivity of 2-dimensional electron gas transport properties. Low sheet resistance (255.45 Ω/sq), high free carrier electron density (2.86 × 1013 cm−2), simultaneously maintaining low surface roughness and high crystal quality of AlN barrier were achieved at optimized growth temperature around 800 °C.

Al0.3Ga0.7N/GaN heterostructure transistors with a regrown p-GaN gate formed with selective-area Si implantation as the regrowth mask

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This study demonstrates an Al0.3Ga0.7N/GaN heterostructure field-effect transistor (HFET), which features a regrown p-GaN gate layer formed by selective-area regrowth using Si ion implantation at the drain and source area as a mask layer. The surface of the Si-implanted area has distorted lattices compared with the implantation-free area. As such, selective-area growth (SAG) can be achieved when the regrowth process is performed using the Al0.3Ga0.7N/GaN heterostructure with selective-area Si implantation as growth templates. The Ti/Al/Ti/Au metal scheme is then deposited on the surface of the Si-implanted Al0.3Ga0.7N layer after the regrowth of the p-GaN gate layer. The Ti/Al/Ti/Au contacts without subsequent thermal alloying on the Si-implanted Al0.3Ga0.7N layers exhibit a typical specific contact resistance of approximately 4.5 × 10−4 Ω cm2. However, the Ti/Al/Ti/Au contacts deposited on the undoped Al0.3Ga0.7N layer exhibit Schottky I–V characteristics even the samples are alloyed at high temperatures. According to the results described above, an Al0.3Ga0.7N/GaN HFET with a p-GaN gate layer formed by SAG on the Si-implanted Al0.3Ga0.7N layer is also demonstrated in this study.

Modeling of Short-Channel Effects in GaN HEMTs

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IEEE Transactions on Electron Devices
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In this article, we propose an explicit and analytic charge-based model for estimating short-channel effects (SCEs) in GaN high-electron-mobility transistor (HEMT) devices. The proposed model is derived from the physical charge-based core of the École Polytechnique Fédérale de Lausanne (EPFL) HEMT model, which treats HEMT as a generalized MOSFET. The main emphasis of this article is to estimate SCEs by effectively capturing 2-D channel potential distribution to calculate the reduced barrier height, drain-induced barrier lowering (DIBL), velocity saturation, and channel length modulation (CLM). The model is validated with TCAD simulation results and agreed with measurement data in all regions of operation. This represents the main step toward the design of high-frequency and ultralow-noise HEMT devices using AlGaN/GaN heterostructures.

Demonstration of Wide Bandgap AlGaN/GaN Negative-Capacitance High-Electron-Mobility Transistors (NC-HEMTs) Using Barium Titanate Ferroelectric Gates

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Advanced Electronic Materials
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A negative-capacitance high electron mobility transistor (NC-HEMT) with low hysteresis in the subthreshold region is demonstrated in the wide bandgap AlGaN/GaN material system using sputtered BaTiO3 as a “weak” ferroelectric gate in conjunction with a conventional SiNx dielectric. An enhancement in the capacitance for BaTiO3/SiNx gate stacks is

observed in comparison to control structures with SiNx gate dielectrics directly indicating the negative capacitance contribution of the ferroelectric BaTiO3 layer. A significant reduction in the minimum subthreshold slope for the NC-HEMTs is obtained in contrast to standard metal-insulator-semiconductor HEMTs with SiNx gate dielectrics—97.1 mV dec−1 versus 145.6 mV dec−1—with almost no hysteresis in the I D–V G transfer curves. These results are promising for the integration of ferroelectric perovskite oxides with III-Nitride devices toward NC-field-effect transistor switches with reduced power consumption.

Screw dislocation that converts p-type GaN to n-type: Microscopic study on Mg condensation and leakage current in p–n diodes

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Applied Physics Letters
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Recent experiments suggest that Mg condensation at threading dislocations induces current leakage, leading to degradation of GaN-based power devices. To investigate this, we perform first-principles total-energy electronic-structure calculations for various Mg and dislocation complexes. We find that threading screw dislocations (TSDs) indeed attract Mg impurities, and that the electronic levels in the energy gap induced by the dislocations are elevated toward the conduction band as the Mg impurity approaches the dislocation line, indicating that the Mg-TSD complex is a donor. The formation of the Mg-TSD complex is unequivocally evidenced by atom probe tomography in which Mg condensation around the [0001] screw dislocation is observed in a p–n diode. These findings provide a picture in which the Mg, being a p-type impurity in GaN, diffuses toward the TSD and then locally forms an n-type region. The appearance of this region along the TSD results in local formation of an n–n junction and leads to an increase in the reverse leakage current.

SiNx/(Al,Ga)N interface barrier in N-polar III-nitride transistor structures studied by modulation spectroscopy

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Scientific Reports
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Contactless electroreflectance studies coupled with numerical calculations are performed on in-situ SiNx capped N-polar III-nitride high electron mobility transistor (HEMT) structures with a scaled channel thickness in order to analyse the built-in electric field in the GaN channel layer. The experimentally obtained field values are compared with the calculated field versus channel thickness curves. Furthermore, the experimental and theoretical sheet carrier densities, ns, are evaluated. While a gradual decrease in carrier concentration with decreasing channel thickness is expected for N-polar structures, experimentally a sudden drop in the ns values is observed for samples with very thin channels. The additional loss in charge was associated with a change in the SiNx/AlGaN interface Fermi level at very thin channel thicknesses.

Trap-related frequency dispersion of zero-bias microwave responsivity at low temperature in GaN-based self-switching diodes

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Nanotechnology
https://doi.org/10.1088/1361-6528/ab9d44

The zero-bias microwave detection capability of self-switching diodes (SSDs) based on AlGaN/GaN is analyzed in a wide temperature range, from 10 K to 300 K. The measured responsivity shows an

anomalous enhancement at low temperature, while the detected voltage exhibits a roll-off in frequency, which can be attributed to the presence of surface and bulk traps. To gain a deep insight into this behavior, a systematic DC and AC characterization of the diodes has been carried out in the mentioned temperature range. DC results confirm the existence of traps and AC measurements allow us to identify their properties. In particular, impedance studies enable to distinguish two types of traps: at the lateral surfaces of the channel, with a wide spread of relaxation times, and in the bulk.

Electron transport properties of Al0.3Ga0.7 N/GaN high electron mobility transistor (HEMT)

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Applied Physics A
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In this study, a Al 0.3 Ga 0.7 N/GaN high electron mobility transistor (HEMT) structure is grown on a c-oriented sapphire substrate using a metal organic chemical vapor deposition (MOCVD) system. Resistivity (ρ), Hall mobility (μ) and carrier density (n) are measured in 0.01–0.14 T magnetic field range and 25–340 K temperature range. Also, scattering mechanisms effecting electron mobility are discussed. Resistivity analyses are presented by depending on resistivity measurements.

Trapping Effects on Leakage and Current Collapse in AlGaN/GaN HEMTs

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Journal of Electronic Materials
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In this paper, we showcase our investigation regarding the effect of acceptor traps in GaN buffer and AlGaN barrier layers on the leakage current and current collapse in GaN high-electron-mobility transistors. The dependence of current collapse and leakage current on the density and energy level of traps is carefully considered. With an increase in trapping density from 1015 cm−3 to 1018 cm−3, the leakage current was significantly reduced from 80.2% to 1.76% in the buffer layer and 95% to 12.6% in the barrier layer, while the current collapse increased from 6% to 89.8% in the buffer layer and 0.3% to 17.5% in the barrier layer. The effects of current collapse and leakage were more noticeable in the buffer layer than in the barrier layer. Different energy levels (0.75 eV, 1.8 eV, and 2.85 eV) of acceptor traps were likewise studied. It was demonstrated that high-energy traps induced a lower amount of leakage, while the current collapse was greater. Based on these results, a balanced trade-off between the current collapse and the leakage current is proposed.

Trap-Mediated Avalanche in Large-Area 1.2 kV Vertical GaN p-n Diodes

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IEEE Electron Device Letters
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This work studies the avalanche characteristics of the 1.2 kV vertical GaN p-n diodes with implanted edge termination, based on quasi-static current-voltage (I-V) sweeps and unclamped inductive switching (UIS) tests. The UIS tests reveal a ∼1.7 kV avalanche breakdown voltage (BVAVA), 51 A maximum avalanche current (IAVA), and 63 mJ maximum avalanche energy (EAVA). The IAVA and EAVA are the highest reported in high-voltage GaN power devices. A lower BVAVA is observed in the I-V curves and a trap mediated avalanche model is proposed to explain it. The BVAVA in I-V curves is believed to be induced by avalanche-assisted trapfilling in the edge termination region, while the BVAVA in the UIS test reflects the robust avalanche at the main p-n junction. These results provide important new insights on the avalanche breakdown in GaN devices and address some seemingly contrary observations of vertical GaN p-n diodes published recently.

Modeling and Analysis of Normally-OFF p-GaN Gate AlGaN/GaN HEMT as an ON-Chip Capacitor

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IEEE Transactions on Electron Devices
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An accurate physics-based analytical model for the gate capacitance of p-GaN gate AlGaN/GaN high electron mobility transistor (HEMT) is presented. The Poisson's equation is formulated considering the incomplete ionization of acceptors in the p-GaN cap layer and the out-diffusion of Mg acceptors into the AlGaN barrier layer, which is solved in conjunction with the charge equation in the AlGaN/GaN quantum well. The model is validated across a wide bias range and shows a good agreement with the experimental results. The effect of individual device parameters on the capacitance-voltage (C-V) characteristics is also analyzed using this model. A simplified equivalent circuit model is also presented to intuitively explain the C-V characteristics of these normally-off devices.

Short Circuit Capability Characterization and Analysis of p-GaN Gate HEMTs under Single and Repetitive Tests

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IEEE Transactions on Industrial Electronics
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Short circuit (SC) capability of 650-V Schottky-type p-GaN gate high-electron-mobility transistors (HEMTs) under single and repetitive tests is characterized. The investigated devices exhibit strong capability under a single SC test, but weak capability under repetitive SC tests with a bus voltage of 400 V and a gate drive voltage of 6 V. The failure mechanism under repetitive SC tests is revealed through electrothermal simulation and micro-scale failure spot analysis. Thermal fatigue cracks are formed due to the high temperature spike and local temperature fluctuations in the narrow GaN channel and buffer layers, leading to weak repetitive SC capability. The unique heat confinement effect in the GaN layer plays an important role in the formation of high temperature spike and fatigue cracks. The withstand time in a single SC test is several hundred microseconds due to fast drain current drop that results from high temperature and, to a lesser degree, the dynamic threshold voltage shift during the SC transient. The device failure in a single-event SC test is related to heat diffusion to a wider region. Some guidelines are proposed for handling and improving the repetitive SC capability.

Analysis of Surface Charge Effects and Edge Fringing Capacitance in Planar GaAs and GaN Schottky Barrier Diodes

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IEEE Transactions on Electron Devices
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In this article, by means of a 2-D ensemble Monte Carlo simulator, the Schottky barrier diodes (SBDs) with realistic geometries based on GaAs and GaN are studied as promising devices for increasing the high-frequency performance- and power-handling capability of frequency mixers and multipliers. The nonlinearity of the capacitance-voltage (CV) characteristic is the most important parameter for optimizing the performance of SBDs as frequency multipliers. The small size of the diodes used for ultrahigh-frequency applications makes the value of its intrinsic capacitance to deviate from the ideal one due to fringing effects. We have observed that the value of the edge capacitance well into reverse bias does not depend on the applied voltage. We define an edge-effect parameter β, which, interestingly, is affected by the presence or absence of surface charges at the semiconductor-dielectric interface σ. Two physical models have been considered: a fixed σ related to a surface potential V_s constant surface-charge model (CCM) and a self-consistent model in which the local value of σ is dynamically evaluated depending on the surrounding electron density self-consistent surface-charge model (SCCM). Using the CCM, we obtain that β depends on the depth of the depletion region W_s created by the surface charges, nearly irrespectively of the epilayer doping or semiconductor type. The more realistic SCCM indicates that, at low frequencies, when the surface

charges are able to follow the variations of the applied voltage, the value of β approaches the one obtained without surface charges, while the high-frequency value (the significant one) is smaller.

GaN HEMT with Convergent Channel for Low Intrinsic Knee Voltage

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IEEE Electron Device Letters
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When the gated channel region of a GaN highelectron-mobility transistor (HEMT) is configured into multiple sub-channels in parallel and separated by embedded isolating patterns, the effective resistance of the access regions could be reduced, and consequently, the knee voltage (VK) of the transistor could be lowered. In this work, each sub-channel is defined as a convergent funnellike shape, with its width gradually shrunk from the source side to the drain side. Different from conventional channels with uniform width under the entire gate, the funnel-shaped channel could converge electrons as they transport from source side to drain side, which facilitates electrons' acceleration toward saturation velocity under a smaller drain-to-source bias, leading to a reduced intrinsic VK in the gated channel. Thus, more desirable I-V characteristics and more balanced performance enhancement in RF linearity and power added efficiency are achieved at a low supply voltage, making the convergent-channel HEMT attractive for power amplifiers in mobile terminals.

GaN Vertical p–i–n Diodes in Avalanche Regime: Time-Dependent Behavior and Degradation

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IEEE Electron Device Letters
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This paper shows that vertical GaN-on-GaN p–i–n diodes are able to withstand long-term operation in moderate avalanche conduction regime, thus proving the excellent stability of the gallium nitride material system. Under constant stress in stronger avalanche regime, the devices show a significant increase in the series resistance, a slight increase in forward voltage and a measurable increase in avalanche voltage. Degradation is ascribed to the generation of defects, a process which is likely occurring in the intrinsic region. The timedependence of the performance loss is explained by considering the simultaneous presence of field-assisted trapping in the avalanche region and of charge de-trapping in the medium-field region of the devices. An interpretative model based on these assumptions is proposed to explain the full set of the experimental data.

OFF-state Drain-voltage-stress-induced VTH Instability in Schottky-type p-GaN Gate HEMTs

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IEEE Journal of Emerging and Selected Topics in Power Electronics
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In this paper, we systematically investigate the OFF-state drain-voltage-stress-induced threshold voltage (VTH) instability in Schottky-type p-GaN gate high electron mobility transistors (HEMTs). OFF-state drain-voltage stress and recovery tests were conducted under various temperatures and different drain biases. A sharp increase in VTH was observed at the beginning of the stress, and VTH kept shifting positively during the stress until it reached saturation. Further experiments showed that two different mechanisms dominated the VTH shift, which were distinguished by the temperature dependence, degradation/ recovery process and affected locations in the gate region. The hole deficiency caused by hole emission from the p-GaN layer is suggested to be the dominant reason for the VTH instability at the beginning of the stress, while with increasing stress time, electron trapping in the barrier and buffer layers gradually dominates the VTH shift. Based on the identified mechanisms, physics-based analytical calculations and empirical fitting are conducted to describe the VTH behavior during the OFF-state drain-voltage stress. The fundamental mechanisms can

provide a guide to develop corresponding methods to address the drain-induced VTH instability issue.

Fully Integrated Digital GaN-based LSK Demodulator for High-Temperature Applications

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IEEE Transactions on Circuits and Systems II: Express Briefs
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We present the first Gallium Nitride (GaN)-based demodulator system dedicated to demodulating Load-Shift Keying (LSK) modulated signals that can operate at high temperature (HT). GaN500 technology is adopted to implement the proposed demodulator. Stable DC output characteristics of epitaxial AlGaN/GaN Heterojunction Field Effect Transistors (HFETs) operating at up to 500oC enable designing HT ICs. Conventional digital gates such as inverters, NAND2, NAND3, delay elements and a D Flip-Flop are employed to implement the proposed demodulator. The demodulation system is fabricated on a 2.67 mm2 silicon carbide (SiC) substrate and experimentally validated at 160oC, whereas the building blocks (inverters and NANDs) show a stable operation at HT up to 400oC. A minimum of 1 V amplitude difference can be detected between the high voltage level (HVL = ± 5 V) and low voltage level (LVL = ± 4 V) of an applied LSK modulated signal to recover transmitted digital data. Two high-voltage supply levels (±14 V) are required to operate the system. Its total power consumption is 3.4 W.

Design and Fabrication of Vertical GaN p-n Diode With Step-Etched Triple-Zone Junction Termination Extension

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IEEE Transactions on Electron Devices
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We demonstrate edge termination for vertical GaN p-n diodes using step-etched triple-zone junction termination extension (JTE). The technique was found to yield high breakdown efficiency without degradation of forward characteristics. The electric field distribution at various JTE thicknesses was simulated, and the experimental results were well matched to the simulation results. The fabricated GaN p-n diode with step-etched triple-zone JTE shows a breakdown voltage of 550 V corresponding to a junction termination efficiency of 75%, with a turn-on voltage of 3.1 V, a specific on-resistance of 1.3 mΩ · cm², and leakage current at -200 V of 80 nA/cm². The multistep JTE strategy demonstration could be important for future applications for multikilovolt-class GaN vertical power devices.

Improvement of Electron Transport Property and on-Resistance in Normally-off Al_2O_3/AlGaN/GaN MOS-HEMTs Using Post-Etch Surface Treatment

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Post-etch surface treatment technique was developed for normally-off recess-gate Al_2O_3/AlGaN/GaN metal-oxide-semiconductor high-electron-mobility transistors (MOS-HEMTs). By removing the residues and smoothing surface morphology after plasma etch, the diffusion-controlled interface oxidation (DCIO) and wet etch in MOS-HEMTs lead to a decrease in interface traps from 1.04 x 10^{12} to 6.3 x 10^{11} cm^{-2} with a filling voltage of 12 V. Field-effect mobility extracted in the linear region is 48 cm²/V·s for MOS-HEMTs with an optimized post-etch surface treatment process, 33% larger than the case with the conventional chemical clean process. Due to the increased electron mobility and decreased sheet resistance beneath the gate by over 30%, normally-off MOS-HEMTs with DCIO and wet etch exhibit a remarkable increase in output current by about 29% and an increase in peak transconductance from 35 to 41 mS/mm. The optimized post-etch surface treatment method also enhances blocking voltage from 120 to 230 V by suppressing the leakage current resulting from gate soft breakdown. Dynamic characterization shows that

the normalized on-resistance is increased by double with drain stress up to 80 V, and various post-etch surface treatment processes have little effect on current collapse. Two types of threshold voltage shifts caused by interface trapping and border trapping are observed in the normally-off MOS-HEMTs, which keeps stable with an increase in temperature up to 125 °C.

Effect of fluorinated graphene insulator on AlGaN/GaN MIS-HEMTs as gate dielectric

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We investigate the performance of AlGaN/GaN metal-insulator-semiconductor high electron mobility transistors (MIS-HEMTs) by inserting a fluorinated graphene insulator. It is found that the interface-state density of the sample with fluorinated graphene (5.8 × 1013–8.7 × 1011 eV−1·cm−2) was lower than that without fluorinated graphene (1.1 × 1014–8.1 × 1012 eV−1·cm−2) and exhibits better properties, including higher saturation drain current (Isat), lower on-resistance (Ron), smaller hysteresis of threshold voltage (ΔVth), and better current collapse suppression. Furthermore, the inserted fluorinated graphene could increase the activation energy of surface leakage current, which is verified by the analysis of leakage current. Our results suggest that the fluorinated graphene insulator can lessen interface-state density at the shallow energy levels by the interface-state density decrement and the activation energy increment.

Fabrication of AlGaN/GaN Fin-Type HEMT Using a Novel T-gate Process for Improved Radio-Frequency Performance

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To increase the radio-frequency (RF) performance of AlGaN/GaN-based fin-type high electron mobility transistors (HEMTs), a novel T-gate process was developed and applied to fabricate a device with high RF performance. In a single lithography process, the applied T-gate process shows a technique for forming a T-gate using the reactivity difference of several photoresists. The fabricated device has a steep fin width (Wfin) of 130 nm, a fin height (Hfin) of 250 nm, and a gate length (LG) of 190 nm. The device exhibits a low leakage current (Ioff) of 6.6 × 10−10 A/mm and a high Ion/Ioff current ratio of 4.7 × 108. Moreover, the fabricated device achieved a high cut-off frequency (fT) of 9.7 GHz and a very high maximum oscillation frequency (fmax) of 27.8 GHz. The fmax value of the proposed device is 138% higher than that of GaN-based fin-type HEMTs without T-gate.

Metal Embedded Chiplet Assembly for Microwave Integrated Circuits

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IEEE Transactions on Components, Packaging and Manufacturing Technology
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This letter provides an overview of the Metal Embedded Chiplet Assembly for Microwave Integrated Circuits (MECAMIC) technology. MECAMIC is a 2.5D wafer-level packaging approach that provides seamless heterogeneous integration capabilities of compound semiconductor transistors (e.g., GaN HEMTs) with passive components and interconnects using a backside metal embedding process. The chiplets are embedded in through-interposer cavities and the backside metallization locks the chiplets into

position while providing DC and RF ground for the high-frequency circuits. With this hybrid manufacturing approach, high-performance RF ICs can 1) be designed using the best transistor technology for the function, 2) be fabricated in short cycle times through hybrid manufacturing, and 3) compete performance-wise with monolithic circuits. We demonstrated an X-band power amplifier circuit realized in MECAMIC with a saturated output power of 31 dB and a peak power added efficiency of 54%, which compared favorably to its monolithic GaN MMIC counterpart. The MECAMIC process cycle time was 4.5X faster than the monolithic process.

Engineering Efficient Acoustic Power Transfer in HBARs and Other Composite Resonators

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Journal of Microelectromechanical Systems
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We present analytic and experimental evidence highlighting the importance of acoustic impedance matching for efficient power transfer in RF-MEMS composite resonators such as high-overtone bulk acoustic mode resonators (HBARs) and thin-film piezoelectric on substrate (TPoS) resonators. We show that materials used for the piezoelectric film and the bottom metal electrode in a composite resonator can be chosen or tailored for specific low-loss substrates, resulting in efficient acoustic power transmission across the interfaces of the acoustic source (piezoelectric transducer), intermediate layers including the bottom electrode, and into the acoustic cavity (substrate). We find that a composite resonator with good interfacial acoustic matching exhibits characteristic free spectral range (FSR) variations that are not well modeled in the literature, clearly differentiating it from resonators with poor acoustic matching. We verify this model by comparing the FSR spectra of the first experimentally demonstrated epitaxially grown Sc0.18Al0.82N/AlN/TaN/SiC HBARs (with a mismatched TaN bottom electrode) with epitaxial GaN/AlN/NbN/SiC HBARs where all constituent layers are acoustically matched to the substrate. Historically, the choice and quality of materials used for composite resonators has been limited by process constraints, but advances in epitaxial growth and heterogeneous integration techniques allow us to integrate multiple high quality, acoustically matched layers to form multi-functional composite resonators. [2020-0247]

Factors and Considerations for Modeling Loss of a GaN-based Inverter

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The paper investigates the impacts of four often-neglected factors on the loss model of a GaN-based full-bridge inverter: parasitic capacitance of the devices, dynamics of junction temperature (Tj) under time-varying power dissipation (Ploss), case temperature estimation, and detailed considerations of the passive components. Procedures to calculate the converter loss considering the above factors are proposed and implemented. A 4.5 kW hard-switching inverter prototype using Gallium Nitrite (GaN) high-electron-mobility transistors (HEMTs) is used to experimentally demonstrate the impact of each factor on the converter loss model. It is found that the accuracy of converter loss model is mainly affected by the passive components at the light load condition, while the thermal and loss models of the active components become the major factors as the output power increases. The results show that after considering the above factors, the converter loss discrepancy between calculation and measurement can be reduced from 30.6 W (28%) to 2.5 W (less than 3 %) at heavy load (Po = 4.5 kW), while at the light load condition (Po = 500 W), it is reduced from 3.9 W (28%) to 2.6 W (16%). Furthermore, the difference between simulated and measured case temperature of the GaN devices is within 6 C.

GaN Nanotube FET With Embedded Gate for High Performance, Low Power Applications

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On the road of CMOS device continuously scaling, there are lots of challenges regarding the device structure and material engineering. GaN channel has recently been used in MOSFETs and achieved excellent performance. In this paper, we study a novel embedded gate GaN nanotube field effect transistor of 5 nm gate length with ION/IOFF as high as 106, and subthreshold swing (SS) as small as 64 mV/dec using Sentaurus TCAD simulation. The device can effectively improve subthreshold characteristics due to the GaN channel and embedded gate design. Compared with Si nanotube FET and GaN nanowire FET, GaN embedded nanotube FET exhibits low SS and high ION/IOFF at the same channel thickness. GaN embedded nanotube FET has also been determined to superior temperature adaptability and performs better in terms of threshold voltage and subthreshold characteristics compared to Si nanotube FET at the same temperature. In addition, we investigated the impact of different lengths and thicknesses of the embedded gate on the subthreshold characteristics. As the length and thickness of the embedded gate are increased, SS and ION/IOFF are improved. This excellent electrical performance demonstrates the possibility of GaN as a channel material in MOSFETs and embedded gate as an effective design to improve subthreshold characteristics, opening a new way for continued device scaling.

An Investigation of Frequency Dependent Reliability and Failure Mechanism of pGaN Gated GaN HEMTs

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This paper presents a frequency dependent reliability study of commercially available GaN HEMTs. Both circuit and device-level experiments were performed to better understand the device-level cause of degradation. It was determined through step-frequency analysis performed in a boost converter that there is a frequency-dependent device degradation for positive gate stress. The point of degradation and its primary effect on the converter before the circuit ultimately failed have been analyzed with converter efficiency, gate current, and gate voltage overshoot. The findings of this experiment clearly show a decline in efficiency and voltage overshoot and increment in gate current, which are linked to device degradation. Furthermore, the recovery behavior of degraded devices has been investigated. However, after initial degradation, devices did not show any signs of recovery over twenty-four-hour recovery periods. The causal origin of these phenomena associated with the gate structure of the device was established by gate step-stress testing as well as an examination and analysis of the possible conduction mechanisms through the gate structure.

Growth and Properties of N-Polar InN/InAlN Heterostructures

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physica status solidi a
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N-polar InN/InAlN heterostructure growth and performance are studied on- and off-axis sapphire substrates misoriented toward the m or a plane by 4°. A high In molar fraction (0.57) in the InAlN layer is chosen to reduce the lattice mismatch. InN growth on the on-axis InAlN/sapphire system is initiated with random island formation, which coalesce at ≈10 nm thickness smearing grain boundaries. In contrast, on off-axis sapphires, growth is defined by misorientation-induced steps and grains remain visible even after the layer coalesces. The best electron mobility of 720 cm2 V−1 s−1 and carrier density of ≈1.5 × 1019 cm−3 are demonstrated on the heterostructure grown on-axis sapphire, with InN as thin as 20 nm, even though the InN/InAlN interface root mean square roughness is ≈1.3 nm. The concentrations of screw and edge dislocations in the 20 nm thick InN grown on the on-axis system are extracted to be 4.7 × 109 and 3.5 × 1010 cm−2. In all cases, the InN lattice is still partially strained, performing only ≈85% relaxation. Further lowering of

the lattice mismatch, smoothing of the InAlN surface, and achieving semi-insulating InAlN will provide necessary development steps toward predicted InN-channel transistors with unprecedented performance.

Design of a High Temperature 2.37 GHz Voltage-Controlled Oscillator With GaN-on-SiC HEMTs

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IEEE Transactions on Circuits and Systems I: Regular Papers
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This paper presents a high temperature voltage-controlled oscillator (VCO) for downhole communications. The VCO with the center frequency of 2.37 GHz is prototyped with 0.25µm GaN-on-SiC technology high electron mobility transistors (HEMTs) and microstrip transmission lines on Rogers 4003C PCB. The measured operating temperature of the VCO ranges from 25 °C to 225 °C. A minimum tuning range of 66 MHz and less than 20% variation for the output power of 17 dBm are achieved at 225 °C. The frequency variation remains below 1.5% over the temperature range of 25 °C to 225 °C, and the harmonics power level is 20 dB lower than the fundamental. A phase noise of -131 dBc/Hz at 1 MHz offset frequency is achieved at 225 °C.

Ru/N-polar GaN Schottky diode with less than 2 µA/cm2 reverse current

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IEEE Electron Device Letters
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In this letter, we report the Schottky barrier diode investigation of ruthenium (Ru) deposited by atomic layer deposition on N-polar GaN. The Schottky diodes showed near-ideal thermionic current behavior under forward bias and reverse bias at various temperatures. The barrier height values extracted from both regions agreed well at each temperature and the barrier was extracted to be 0.77 eV at room temperature. The combination of the 0.77 eV barrier and thermionic current characteristic resulted in < 2 µA/cm2 reverse current at -5 V, which is a record-low value for N-polar GaN Schottky diodes. As a comparison, the Ru on Ga-polar GaN Schottky barrier diode, which has a barrier height of 1.0 eV, exhibited a ~ two-order of magnitude higher leakage than Ru on N-polar GaN at -5 V due to other parasitic leakage mechanisms.

Gate Reliability and its Degradation Mechanism in the Normally-off High Electron Mobility Transistors with Regrown p-GaN Gate

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Gate reliability and its degradation mechanism were studied for the normally-off high electron mobility transistors (HEMTs) with regrown p-GaN gate and AlN/SiNx stack passivation. Through comparing the forward leakage current in two designed structures, the conduction mechanism is determined to be Fowler-Nordheim tunneling whose current is independent with temperature when the Pd/p-GaN Schottky junction is under high electric field. Even for the regrown p-GaN gates, this Schottky junction fails at first, resulting in an abruptly increase of gate current. The maximum gate operation voltage with a failure rate of 1% for 10-year lifetime is estimated to be about 6.87 V and 6.07 V at room temperature by adopting power law and exponential law as extrapolation fitting, respectively. Degradation process monitoring reveals that the net acceptor concentration NA extracted through C-V fitting presents an apparent decreasing trend from 3.8 × 1019 to 1.1 × 1019 cm-3 with stress time increased from 30 to 2600 sec. This is assumed to be related with the defects generation in the Schottky depletion region under high tunneling current and high electric field. These analyses show the feasibility of the normally-off HEMTs with a regrown p-GaN gate and AlN/SiNx stack passivation for practical applications, giving directions for further improving the gate breakdown voltage and lifetime.

Comparative Study on Dynamic Characteristics of GaN HEMT at 300K and 150K

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Dynamic characteristics of GaN HEMT grown on a native substrate were systematically investigated at 300K and 150K. Transfer and output characteristics of the GaN HEMT were measured after various off-state stressing conditions and recovery durations. In addition, a high-speed scheme was employed to finish the measurement within 75 µs , and to ensure maximum preservation of stressing/recovery consequences. The threshold voltage instability and current collapse commonly observed at room temperature were mostly diminished at 150K, which was attributed to reduced number of electrons through the metal-semiconductor contact and insufficient number of carriers overcoming the capture potential barrier. Two pulsed I-V measurements, including evaluations with various off-state quiescent bias points and “on-the-fly” on-resistance sampling, confirmed an inefficient electron capture process at 150K, with a time constant larger than dozens of seconds. The output characteristic comparison between hard switch and soft switch at 150K provided direct experimental evidence for electron capture promotion by hot carriers.

Surface-Potential-Based Compact Model for the Gate Current of p-GaN Gate HEMTs

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The gate leakage current of p-GaN gate HEMTs is modeled based on surface potential calculations. The model accurately describes the bias and temperature dependence of the gate leakage. Thermionic emission is the main mechanism of the gate current in forward bias operation while hopping transport component is the main mechanism of gate current in reverse bias operation. This newly developed gate current model was implemented in Verilog-A. A good agreement between the simulations and experimental data demonstrates the accuracy of the model.

Forward Conduction Instability of Quasi-Vertical GaN p-i-n Diodes on Si Substrates

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This article reports trap-related forward conduction instability of GaN quasi-vertical p-i-n diodes grown on a Si substrate. Three hole traps with activation energies of 0.38, 0.60, and 0.70 eV together with one electron trap with an energy level of 0.26 eV under the conduction band were revealed by deep-level transient spectroscopy (DLTS). Pulsed I-V measurements were performed on a device whose traps were prefilled. The rest time durations and off-state bias levels and periods were varied to investigate the forward I-V recovery phenomenon, which was highly correlated with the carrier detrapping process inside the device. The detrapping process could be greatly accelerated by a reverse bias or a lifted temperature. An ``on-the-fly'' resistance characterization was carried out to study the time-dependent carrier release process using short positive voltage pulses. The device was further submitted to switch-on transient assessment to investigate the time-resolved dynamic Ron evolution. The initial dynamic Ron ratio was proportional to the reverse bias level and duration and was gradually decreased after continuous carrier injection until the trapping effects were overwhelmed. With a forward voltage slightly higher than the threshold voltage, it took dozens of milliseconds for the dynamic Ron to be equal to its static counterpart. It was found that at 350 K, the on-

resistance ratio could reach unit more rapidly than the room temperature case, indicating mitigation of current collapse of p-i-n diodes and their great potential for high-temperature switching applications.

A Fully Integrated Reconfigurable Multi-Mode Class-F2,3 GaN Power Amplifier

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IEEE Solid-State Circuits Letters
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In this paper, we propose a reconfigurable multi-mode fully integrated power amplifier (PA) in GaN technology. The PA is composed of one main transistor, biased in class-AB, and three auxiliary transistors which can be switched between class-AB and deep class-C, to improve efficiency and linearity of the PA. Furthermore, a harmonic termination network is proposed to enable operation of the PA in class-F2,3. A proof-of-concept PA, fabricated using a 250-nm GaN-on-SiC process, provides 33.8 dBm output power and 42% peak drain efficiency (DE) at 4.8 GHz. Modulated-signal measurements using a 200-MHz 256-QAM 7.2-dB peak-to-average power ratio (PAPR) signal indicate that rms error vector magnitude (EVMrms) < 5% (–26 dB) can be achieved with 27.7–28.5 dBm average output power, 26–30% average DE, and –38.1 to –33.5 dBc adjacent channel leakage ratio (ACLR), in the four operation modes. It is shown that ACLR can be improved by 6 dB at lower output power levels through reconfiguring the mode of PA operation.

Vertical GaN-on-GaN Schottky Barrier Diodes With Multi-Floating Metal Rings

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Vertical GaN Schottky barrier diodes (SBDs) with floating metal rings (FMRs) as edge termination structures have been fabricated on bulk GaN substrates. Devices with different FMR geometries were investigated including various numbers of rings and various spacings between rings. These devices have a low Ron of 1.16 ~ 1.59 mΩ· cm 2 , a turn-on voltage of 0.96 ~ 0.94 V, a high on-off ratio of 10 9 , a nearly ideal ideality factor of 1.03 ~ 1.09, and a Schottky barrier height of 1.11 ~ 1.18 eV at room temperature. These devices have similar forward electrical characteristics, indicating that FMRs don't degrade the device rectifying performance. The ideality factor decreased and the Schottky barrier height increased with increasing temperature from 300 K to 420 K, where the temperature dependencies of the two parameters indicate the inhomogeneity of the metal/semiconductor Schottky interface. In addition, FMRs can improve device breakdown voltages. As the number of FMRs increased from 0 to 20, the reverse breakdown voltage increased from 223 to 289 V. As the spacing between the FMRs increased from 1.5 to 3 µm , the reverse breakdown voltage increased from 233 to 290 V, respectively. These results indicate multiple FMRs with proper spacings can effectively improve breakdown performance without degrading the device forward characteristics. This work represents a useful reference for the FMR termination design for GaN power devices.

Broadband Doherty-Like Power Amplifier Using Paralleled Right- and Left-Handed Impedance Transformers

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IEEE Transactions on Microwave Theory and Techniques
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Previously, the bandwidth of conventional Doherty power amplifiers (DPAs) is limited by the phase dispersion of the microstrip impedance transformer (IT). To overcome this phase dispersion, minimization of the phase delay of the IT is required, however at the expense of load modulation bandwidth, which limits further bandwidth extension. In this article, we present a broadband Doherty-like PA topology that, for the first time, uses parallel right- and left-handed

ITs. This satisfies the minimal phase delay requirement while simultaneously maintaining wideband load modulation. Consequently, the frequency range for load modulation can be significantly extended. For demonstration purposes, a Doherty-like PA prototype is realized using two identical 10-W GaN HEMTs. Measurement results show that a drain efficiency of at least 40% is achieved at 5.2-6-dB back-off from 1.25 to 2.30 GHz, which corresponds to a very wide bandwidth of ~60%.

Accurate Temperature Estimation for Each Gate of GaN HEMT With n-Gate Fingers

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An analytical approach based on the thermoelectrical analogy to calculate the maximum channel temperature of multifinger AlGaN/GaN HEMT transistor is presented. The model is capable of predicting the maximum channel temperature, including the impact of the nonlinearity of thermal conductivity for every single gate with excellent accuracy. The model remains invariant under device scaling up and down and gives an accurate estimation for any number of gate fingers. Furthermore, the temperature field fluctuation due to the interaction between gates and variation in the number of gate fingers can be easily identified by the model. The validity of the proposed approach has been testified by comparing the results with those from infrared spectroscopy and numerical simulations for different AlGaN/GaN HEMT transistors with a different number of gates. The significance of models is justified by its ability to evaluate the temperature of any gate finger with high accuracy. Such an ability is particularly highly important while optimizing the structure layout and cooling system for high-power AlGaN/GaN HEMT transistors. The model can serve as a powerful tool for power devices and microwave IC designers and can be easily incorporated into SPICE empirical or physical-based models.

Study of tri-gate AlGaN/GaN MOS-HEMTs for power application

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Micro and Nano Engineering
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In this letter, we present high-performance AlGaN/GaN high electron mobility transistor (HEMT) by 3-dimensional (3D) tri-gate. Due to the excellent channel control of tri-gate structure, the tri-gate HEMT shows the low subthreshold swing (SS) of 6 mV/decade, low off-state drain leakage current (Ioff) of 7 nA/mm, and On/Off ratio up to 7.6×107. Furthermore, we combined the tri-gate structure and metal oxide semiconductor (MOS) structure. The tri-gate MOS-HEMT with high-k dielectric oxide HfO2 was fabricated. The good interface between HfO2 and AlGaN and strain-induce polarization increase the carrier concentration. Compared to the tri-gate HEMT, the increased maximum drain current, higher On/Off ratio and better breakdown voltage is demonstrated by implanted the high k dielectric HfO2. The improved electrical performance of tri-gate MOS-HEMT shows potential for next generation power application.

An 18-31-GHz GaN-Based LNA With 0.8-dB Minimum NF and High Robustness

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IEEE Microwave and Wireless Components Letters
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Benefited from the high breakdown voltage and low noise characteristics, GaN high-electron mobility transistors (HEMTs) can be used for manufacturing of robust low noise amplifiers (LNAs). Therefore, limiter circuits which protect the entire system are no longer necessary and systems with smaller volume can be realized. In this letter, a LNA with low noise figure (NF) and longtime survivability for high input power stress

is designed and fabricated in a 100-nm GaN process. The LNA achieves a minimum NF of 0.8 dB and a flat gain of 21 ± 0.5 dB from 18 to 31 GHz. The LNA can survive in a 28-30-dBm input stress for 60 min without significant performance degradation.

Record high electron mobility and low sheet resistance on scaled-channel N-polar GaN/AlN heterostructures grown on on-axis N-polar GaN substrates by plasma-assisted molecular beam epitaxy

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GaN-based high electron mobility transistors (HEMTs) have demonstrated high frequency power amplification with considerably larger output power densities than that available from amplifiers based on other material systems such as GaAs or InP. To further increase the operating frequency while maintaining the high output power in HEMTs, the gate-to-channel distance needs to be reduced significantly. This leads to a reduced two-dimensional electron gas (2DEG) density (ns) and mobility (μ) in Ga polar HEMT structures resulting in a larger sheet resistance. This work demonstrates that by proper design of the back-barrier in N-polar GaN-based scaled-channel HEMT structures, a high 2DEG density can be maintained while scaling the channel thickness. Scaled-channel GaN-based HEMT structures with an AlN/GaN (0.5 nm/1.5 nm) digital alloy as the back-barrier were grown on an on-axis N-polar GaN substrate via plasma-assisted molecular beam epitaxy. A record high electron mobility of 2050 cm2/vs was achieved on an N-polar HEMT structure with a 10 nm-thick channel, while maintaining 8 × 1012 cm−2 2DEG density. By modifying the barrier structure, we demonstrated a combination of 2DEG density and a mobility of 1.7 × 1013 cm−2 and 1420 cm2/V s, respectively, leading to a record low sheet resistance of ∼258 Ω/□ on 7 nm-thick channel N-polar HEMT structures.

A Fast Extraction Method of Energy Distribution of Border Traps in AlGaN/GaN MIS-HEMT

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MIS-HEMT is one of the most promising structures to prohibit the unfavorable gate leakage in conventional AlGaN/GaN HEMTs. However, the extra insulator layer introduces massive border traps at insulator/AlGaN interface and results in the poor reliability. In this brief the energy distribution of border traps in AlGaN/GaN MIS-HEMT gate stack is extracted and investigated through a discharging-based trap energy profile technique. The technique adopts spot-Id sense measurement with 1 millisecond measurement time to capture the "whole (both fast and slow)" border traps. The results are beneficial to improve the reliability of AlGaN/GaN MIS-HEMT.

Dv/Dt-control of 1200-V Normally-Off SiC-JFET/GaN-HEMT Cascode Device

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IEEE Transactions on Power Electronics
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A normally-off SiC-JFET/GaN-HEMT cascode device is recently proposed, featuring a cascode configuration that incorporates a high-voltage (i.e. 1200 V) SiC

junction field effect transistor (JFET) and a low-voltage GaN high electron mobility transistor (HEMT). This cascode device exhibits superior thermal stability and switching performance compared to the SiC MOSFETs, but also inevitably presents challenge in dv/dt-control as the input gate does not directly control the high-voltage JFET. Since dv/dt-control is of great importance to the management and suppression of electromagnetic interference (EMI) in power electronics systems, methods of controlling the dv/dt rates of SiC/GaN cascode devices need to be developed. In this work, we conduct systematic investigation on different dv/dt control schemes with theoretical analysis and experimental evaluation. A dv/dt-control method based on diode-clamped external JFET gate resistor is proposed and evaluated by comparing it with other more conventional methods. The proposed dv/dt-control method is verified to provide a balanced dv/dt-control on the device turn-on and turn-off.

Impact of AlInN Back-Barrier Over AlGaN/GaN MOS-HEMT With HfO_2 Dielectric Using Cubic Spline Interpolation Technique

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The dc characteristics of AlGaN/gallium nitride (GaN) metal-oxide-semiconductor-high electron mobility transistor (MOS-HEMT) with an AlInN back-barrier layer has been studied here. An analytical model is proposed for evaluating the charge density (σtot), carrier concentration (nS), drain current (ID), and transconductance (g_m) of the device by incorporating Hafnium oxide (HfO_2) as a high-k dielectric layer. The charges created between the oxide and the AlGaN barrier layer influence the enhancement of carrier concentration of up to $6.2x10^{13}$ cm^{-2}, at the two-dimensional electron gas (2DEG). The AlInN back-barrier increases the conduction band (CB) level of the GaN buffer and eliminates the confinement problems near the channel. By deriving the mathematical dependence of these parameters, this device demonstrated a positive threshold shift and a high current drive of 880 mA/mm. Cubic spline interpolation (CSI) technique is employed here to model the parameters in a more precise manner. The outcomes are evidence that the device could be a potential solution for high power switching as well as microwave applications.

Design and Simulation of High Performance Lattice Matched Double Barrier Normally Off AlInGaN/GaN HEMTs

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A novel lattice matched double barrier Al0.72In0.16Ga0.12N/Al0.18In0.04Ga0.78N/GaN normally-off high electron mobility transistor (HEMT) is designed and simulated by solving a set of thermodynamic transport equations. Using the experimentally calibrated physical models with bearing mobility degradation by surface roughness in account, the recess gate and double barrier of the proposed device achieves a maximum drain current density (IDS,max) of 1149 mA/mm and a maximum transconductance (gm,max) of 358 mS/mm with a positive threshold voltage (Vth) of 0.2 V. The small polarization charge of first barrier is responsible for positive Vth. IDS,max in the double barrier HEMT at high gate bias condition is due to injection of electrons from upper 2DEG which is almost impossible at lower gate voltage because of insufficient energy to cross the barrier. The injection of electrons is further supported by the second peak in the gm curve at low gate bias VG = 1V. The outcome of this study suggests that the proposed device will be beneficial for high-frequency and high-power electronic applications.

Prospects for Wide Bandgap and Ultrawide Bandgap CMOS Devices

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Power and RF electronics applications have spurred massive investment into a range of wide and ultrawide bandgap semiconductor devices which can switch large currents and voltages rapidly with low losses. However, the end systems using these devices are often limited by the parasitics of integrating and driving these chips from the silicon complementary metal-oxide-semiconductor-based design (CMOS) circuitry necessary for complex control logic. For that reason, implementation of CMOS logic directly in the wide bandgap platform has become a way for each maturing material to compete. This review examines potential CMOS monolithic and hybrid approaches in a variety of wide bandgap materials.

A DC-50-GHz Direct-Coupled Self-Biased 50-nm Quasi-E-Mode GaN MMIC Amplifier Based on a 237-GHz fT-Multiplier

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IEEE Microwave and Wireless Components Letters
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This work is believed to be the first report of a single-supply quasi-enhancement-mode GaN-based monolithic microwave integrated circuit (MMIC) amplifier that operates from dc to 50 GHz. The quasi-E-mode GaN high electron mobility transistors (HEMTs) have an fT of 120 GHz and a positive turn-on voltage, Vgs-on, that enables an all positive-supply, regulated self-bias over threshold variation, and two-stage direct-coupled frequency response down to dc. Core to the quasi-E-mode design topology is a 237-GHz fT-multiplier transconductance gain stage to enhance the broad bandwidth response. The quasi-E-GaN MMIC obtains a gain of 11.4 dB at dc, 7 dB at 40 GHz, and 5.5 dB at 50 GHz. The 3-dB bandwidth is 31 GHz with return-losses <-10 dB over the 50-GHz frequency band. The MMIC amplifier is realized in a compact 0.6 x 0.5 mm² area on a 4-mil SiC substrate. Quasi-E-mode GaN HEMT-based circuit architectures can enable high performance and functionality in a compact size, which has far-reaching implications for scalable broadband millimeter-wave radio applications.

A Film Bulk Acoustic Resonator Based on ferroelectric Aluminum Scandium Nitride Films

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Journal of Microelectromechanical Systems
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This work reports on the first demonstration of the frequency tuning and intrinsic polarization switching of film bulk acoustic resonators (FBARs), based on sputtered AlScN piezoelectric thin films with Sc/(Al + Sc) ratio of approx. 30%. A box-like ferroelectric hysteresis behavior of 900 nm-thick Al0.7Sc0.3N sputtered films is obtained, showing a coercive electric field at ~3 MV/cm. The fundamental thickness-mode resonance of the bulk acoustic wave (BAW) resonator is measured at 3.17 GHz frequency with an excellent electromechanical coupling coefficient (kt^2) of 18.1 %. The FBAR frequency response is studied, in both (i) the linear tuning regime, upon application of DC electric fields below the coercive field; as well as (ii) the polarization switching regime, upon application of electric fields above the coercive field. A large linear tuning range of 215 ppm x µm/V is obtained in case (i), resulting from the high scandium content. The series resonance frequency of the FBARs is switched ON and OFF in (ii) upon application of 350 V unipolar waveform across the Al0.7Sc0.3N thickness. This is the first demonstration of the intrinsically switchable AlN-based FBARs with a large tuning range; and record high kt^2 reported for AlN-based FBARs to date. Furthermore, this work paves the way for realization

of tunable and switchable wideband acoustic filters operating at super high frequency ranges (SHF).

Demonstration of GaN-based metal–insulator–semiconductor junction by hydrogen plasma treatment

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We demonstrate a nickel/insulating-GaN (i-GaN)/p-type GaN junction and investigate its electrical properties. The i-GaN is formed by exposure to a low-power hydrogen plasma to passivate the p-GaN layer. Cathodoluminescence spectroscopy of the i-GaN is used to understand the passivation effect of the hydrogen plasma on p-GaN. The junction shows very low leakage (<10−9 A at −50 V), excellent rectifying properties (~107), high temperature stability, and blue light electroluminescence at forward bias. A bandgap model is proposed to illustrate the electrical properties of hydrogenated p-GaN and to understand the device characteristics.

Integration of 650 V GaN Power ICs on 200 mm Engineered Substrates

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GaN power ICs on engineered substrates of Qromis substrate technology (QST) are promising for future power applications, thanks to the reduced parasitics, thermally matched substrate of poly-AlN, high thermal conductivity, high mechanical yield in combination with thick GaN buffer layers. In this work, we will elaborate in detail on epitaxy, integration, and trench isolation. Electrical characterizations show that the GaN buffer bears a breakdown voltage of > 650 V under the leakage criterion of 10 µA/mm2 at 150 ◦C. The fabricated 36 mm power HEMTs with LGD of 16 µm show a high threshold voltage of 3.1 V and a low OFF-state drain leakage of <1 µA/mm until 650 V. The horizontal trench isolation breakdown voltage exceeds 850 V. The device dispersion is well controlled within 20% over full temperature and bias range. Finally, GaN power ICs on this platform are demonstrated.

PECVD SiNx Passivation for AlGaN/GaN HFETs with Ultra-Thin AlGaN Barrier

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Solid-State Electronics
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We have investigated the effects of a silicon nitride (SiNx) passivation process using plasma-enhanced chemical vapor deposition (PECVD) on a ultra-thin-barrier AlGaN/GaN heterostructure field-effect transistors (HFETs). The bulk charge characteristics of the PECVD SiNx films were dependent on the film deposition conditions, which strongly influenced the sheet resistance (Rsh) and flat-band voltage characteristics of AlGaN/GaN HFETs. The reduction in Rsh is a strong function of the amount of positive bulk charges in the SiNx passivation film. An optimized PECVD SiNx process was used to drastically decrease the Rsh from 45,450 Ω/sq to 732 Ω/sq. A Mo/Au Schottky-gate device fabricated with PECVD SiNx passivation exhibited a maximum drain current density of 172 mA/mm, quasi-normally-off operation, and breakdown voltage of >1100 V.

GaN Vertical-Channel Junction Field-Effect Transistors With Regrown p-GaN by MOCVD

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IEEE Transactions on Electron Devices
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We report an experimental demonstration of GaN-based vertical-channel junction field-effect transistors (VC-JFETs). A p-GaN regrowth by metalorganic

chemical vapor deposition (MOCVD) and a subsequent self-planarization process were developed to fabricate the GaN VC-JFETs. Fin-like channel regions were patterned by electron beam lithography (EBL) and aligned to m-plane or a-plane. The electrical properties of lateral and vertical p-n junctions were characterized to verify the effectiveness of the p-GaN regrowth. Both VC-JFETs with m-plane and a-plane channels show decent gate modulation. We further discussed important factors that may affect the device performance including interfacial impurities and nonuniform acceptor distribution. This work highlights the successful demonstration of GaN VC-JFETs and lateral p-n junctions by an etch-then-regrow process, providing valuable information and reference for the further development of GaN power electronics.

Thermally enhanced hole injection and breakdown in a Schottky-metal/p-GaN/AlGaN/GaN device under forward bias

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Applied Physics Letters
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In this work, the breakdown characteristics and the electroluminescence (EL) spectra of a Schottky-metal/p-GaN/AlGaN/GaN device under forward bias were investigated at different temperatures. The failure of the metal/p-GaN junction, which was caused by electron transport in the p-type Schottky junction, was identified as the first step in the device breakdown process. The breakdown voltage increased with higher temperatures. Under a forward bias of 8 V, the intensity of the EL emission increased more than two orders of magnitude, while the current increased by a factor of 4 as the temperature increased from 0 °C to 200 °C. This unambiguously demonstrated thermally enhanced hole injection at the Schottky-metal/p-GaN interface. We proposed that more electrons were annihilated by the thermally enhanced hole injection, resulting in the positive temperature dependence of the device breakdown.

Characterization of Self-Heating Process in GaN-Based HEMTs

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Electronics
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Thermal characterization of modern microwave power transistors such as high electron-mobility transistors based on gallium nitride (GaN-based HEMTs) is a critical challenge for the development of high-performance new generation wireless communication systems (LTE-A, 5G) and advanced radars (active electronically scanned array (AESA)). This is especially true for systems operating with variable-envelope signals where accurate determination of self-heating effects resulting from strong- and fast-changing power dissipated inside transistor is crucial. In this work, we have developed an advanced measurement system based on DeltaVGS method with implemented software enabling accurate determination of device channel temperature and thermal resistance. The methodology accounts for MIL-STD-750-3 standard but takes into account appropriate specific bias and timing conditions. Three types of GaN-based HEMTs were taken into consideration, namely commercially available GaN-on-SiC (CGH27015F and TGF2023-2-01) and GaN-on-Si (NPT2022) devices, as well as model GaN-on-GaN HEMT (T8). Their characteristics of thermal impedance, thermal time constants and thermal equivalent circuits were presented. Knowledge of thermal equivalent circuits and electro–thermal models can lead to improved design of GaN HEMT high-power amplifiers with account of instantaneous temperature variations for systems using variable-envelope signals. It can also expand their range of application.

1.48 MV·cm-1/0.2 mΩ·cm2 GaN Quasi-Vertical Schottky Diode Via Oxygen Plasma Termination

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IEEE Electron Device Letters
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In this letter, a high-performance GaN quasi-vertical Schottky barrier diode (SBD) is demonstrated via oxygen plasma termination. A specific on-resistance of 0.2 mΩ·cm2, turn-on voltage of 0.71 V, and breakdown voltage of 193 V are achieved with a GaN SBD of 1.3 µm drift layer. The average breakdown electric field is calculated to be about 1.48 MV/cm, which is much higher than the state-of-art value for GaN vertical SBDs. The temperature-dependent forward and reverse I-V characteristics confirm the high-temperature stability of the oxygen plasma treated SBDs. X-ray spectroscopy and Kelvin Probe Force Microscopy reveal that the surface potential is increased after the oxygen plasma treatment, which results in the suppression of the leakage current and improvement of the breakdown electric field.

Measuring Thermal Resistance of GaN HEMTs Using Modulation Method

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2020.3013509

This article describes the thermal resistance ``junction-to-case'' measurement results for GaN high-electron mobility transistors (HEMTs). The measurements were taken by using the apparatus which includes two methods of thermal resistance measurements. For the first one that uses standard MIL-STD-750-3, a sequence of heating current pulses passes through the transistor channel and then the junction temperature is measured. The second method uses modulated heating power and measures the response which is a variable component of the junction temperature. To exclude the influence of the heating pulses duration, which is typical for the standard method, preliminary measurements of the transient response of thermal impedance were taken. The analysis of this characteristic allows determining the optimal values of the pulse duration. To reduce the influence of the delay time caused by transient electrical processes in the transistor when it switches from heating mode to the measurement of the thermal sensitive parameter (TSP) mode, the TSP signal was extrapolated to the end of the heating pulse. A comparative analysis shows that the measurement results obtained by the standard and modulation methods differ by less than 2%. The results of a study of the influence of the heating current pulses magnitude on the thermal resistance measurements results are presented. It was found that, as heating current increased, the thermal resistance measured values increased, which indicates the nonlinear nature of the dependence of the temperature in the transistor channel on the power dissipated in it.

Commercial GaN-Based Power Electronic Systems: A Review

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Journal of Electronic Materials
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Wide bandgap semiconductor technology is gaining widespread acceptance in the area of high-power and high-temperature power electronics. Gallium nitride (GaN) not only has a wide bandgap of 3.4 eV and all the associated superior electronic properties but also enables the development of high-mobility power devices which is critical in increasing the power density of a power electronics system. Since a commercial GaN power transistor has a lateral structure as opposed to the traditional vertical device structure, commercially available devices are rated below 1000 V breakdown voltage with a maximum value of 900 V and typical value around 650 V. The primary focus of this review will be to introduce readers to the commercially available power electronic systems developed by various

manufacturers which employ GaN-based power devices and highlight their remarkable performance which surpasses existing technology. This review also includes a brief introduction on GaN technology followed by current market study showing the roadmap of integration of GaN-based power electronics in the power industry.

The effect of kink and vertical leakage mechanisms in GaN-on-Si epitaxial layers

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Semiconductor Science and Technology
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The connection between the kink position and vertical leakage mechanisms in GaN-on-Si epitaxial layers has been investigated. Based on combined experimental data and TCAD simulation results, we demonstrate that band-to-band tunneling and Poole–Frenkel effect greatly affect the current-voltage behaviors of GaN-on-Si epitaxial layers. Band-to-band tunneling occurring in both GaN and AlGaN layers could change a kink position, and Poole–Frenkel effect happening at high biases increases the slope of J-V at the voltage region after the kink. On the other hand, we found that the kink position is related to the depletion region width at the AlN/Si interface by numerical simulation. When the connection between the kink and leakage mechanisms was considered, numerical simulation results are consistent well with the current-voltage-temperature experimental results in GaN-on-Si epitaxial layers.

Design considerations for normally-off operation in Schottky gate p-GaN/AlGaN/GaN HEMTs

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Design criteria for normally-off operation in Schottky gate p-GaN/AlGaN/GaN HEMTs have been investigated. The threshold voltage (V th) of this structure is determined by the following five parameters: (i) acceptor concentration of p-GaN layer (N a), (ii) thickness of p-GaN layer (d p-GaN), (iii) Al composition of AlGaN layer (Alx), (iv) thickness of AlGaN layer (d AlGaN), and (v) Schottky barrier height at gate metal/p-GaN interface (ΦB). Analytical equations are derived to obtain the quantitative relations of these parameters and dependences of normally-off condition on these parameters are discussed. To derive the analytical equation, two cases are considered in this study, i.e., case 1; thick d p-GaN case, and case 2; thin d p-GaN case. For case 1, the normally-off condition is determined by Alx and d AlGaN, and independent of N a, d p-GaN, and ΦB. While for case 2, it is strongly affected by N a, d p-GaN, and ΦB. It is found that a thicker d p-GaN is needed for a lower N a, and with the increase of d AlGaN at a certain Alx to achieve a normally-off operation. Also, it is found that Alx has to be kept less than 0.26 because higher Alx will cause the electric field across AlGaN layer to exceed 3 MV cm−1, which may lead to breakdown in the AlGaN layer.

Fast System to measure the dynamic on-resistance of on-wafer 600 V normally off GaN HEMTs in hard-switching application conditions

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IET Power Electronics
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This study presents a novel system to investigate the on-wafer level dynamic properties of GaN-based power transistors in hard-switching application conditions. The system is able to analyse devices with an on-resistance (R DSON) in the range from few ohms to hundreds of ohms, and can be effectively used to improve the development process of GaN high electron mobility transistors (HEMTs) power devices at the wafer level. Contrary to the conventional double-pulse setup, where a resistive load is usually used in combination with a very low duty cycle, the dynamic R DSON is acquired during realistic operating conditions, in a boost converter circuit. Consequently, the authors' system is able to study not only the field-

activated trapping processes, but also those induced by hard-switching conditions, i.e. promoted by hot electrons and self-heating. The maximum working voltage (600 V) and the minimum R DSON measurement time after turn-on (2 µs) allow evaluating the operation limit of the devices in a voltage/frequency range close to real switching conditions. Working on the wafer level allows a more realistic assessment of the dynamic R DSON behaviour before the packaging phase, which is very important to improve the production and development process of GaN-HEMT devices.

Storage and release of buffer charge in GaN-on-Si HEMTs investigated by transient measurements

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Applied Physics Express
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This letter investigates the kinetics of the non-monotonic trapping mechanisms responsible for dynamic on-resistance (R DS,ON) in GaN-on-Si enhancement-mode HEMTs. We describe the time-dependences of electron trapping at carbon on the nitrogen site (CN) acceptors and for the first time we investigate the kinetics of the build-up of positive charge at the buffer/strain-relief layer interface. Part of the analysis is carried out on two-terminal ohmic devices, by a novel setup capable of measuring current transients (from 10 µs to 10 s) after stressing with a negative substrate bias.

Anomalous interface fixed charge generated by forming gas annealing in SiO2/GaN MOS devices

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Applied Physics Express
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We investigated the effect of forming gas annealing (FGA) on the electrical properties of SiO2/GaN MOS devices. We conducted systematic capacitance–voltage measurements on metal-oxide-semiconductor structures and observed a significant amount of anomalous positive fixed charge (3 × 1012 cm−2) at the interface between SiO2 and GaN for FGA temperatures over 250 °C. The fixed charges generated by FGA may be attributed to oxygen vacancies formed in the gallium oxide (GaO x) interlayer by the reaction between GaO x and hydrogen.

Fast System to measure the dynamic on-resistance of on-wafer 600 V normally off GaN HEMTs in hard-switching application conditions

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IET Power Electronics
https://doi.org/10.1049/iet-pel.2019.1455

This study presents a novel system to investigate the on-wafer level dynamic properties of GaN-based power transistors in hard-switching application conditions. The system is able to analyse devices with an on-resistance (R DSON) in the range from few ohms to hundreds of ohms, and can be effectively used to improve the development process of GaN high electron mobility transistors (HEMTs) power devices at the wafer level. Contrary to the conventional double-pulse setup, where a resistive load is usually used in combination with a very low duty cycle, the dynamic R DSON is acquired during realistic operating conditions, in a boost converter circuit. Consequently, the authors' system is able to study not only the field-activated trapping processes, but also those induced by hard-switching conditions, i.e. promoted by hot electrons and self-heating. The maximum working voltage (600 V) and the minimum R DSON measurement time after turn-on (2 µs) allow evaluating the operation limit of the devices in a voltage/frequency range close to real switching conditions. Working on the wafer level allows a more realistic assessment of the dynamic R DSON behaviour before the packaging phase, which is very important to improve the production and development process of GaN-HEMT devices.

Extreme reduction of on-resistance in vertical GaN p–n diodes by low dislocation density and high carrier concentration GaN wafers fabricated using oxide vapor phase epitaxy method

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Applied Physics Express
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Low dislocation density and low-resistance GaN wafers are in high demand for improving the performance of vertical GaN power devices. Recently, GaN wafers with the dislocation density of 8.8 × 104 cm−2 and the resistivity of 7.8 × 10−4 Ω cm, were fabricated using oxide vapor phase epitaxy (OVPE). In this study, GaN p–n diodes on GaN wafers prepared by the OVPE method were evaluated for verifying their suitability as vertical GaN power devices. An extremely low-differential specific on-resistance of 0.08 mΩ cm2 and a high breakdown voltage of 1.8 kV were obtained from forward and reverse I–V measurements.

AlGaN/GaN Schottky-Gate HEMTs with UV/O3-treated Gate Interface

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IEEE Electron Device Letters
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The surface condition under gate of AlGaN/GaN heterostructure plays a critical role in high-electron mobility transistor (HEMT). In this study, the effects of ultraviolet/ozone (UV/O3) treatment applied to Al0.3Ga0.7N/GaN heterostructure on the electrical performance of AlGaN/GaN Schottky-gate HEMT were investigated. The reverse-bias leakage current of Schottky diode was reduced by three orders after the treatment. X-ray photoelectron spectroscopy confirms the formation of the Ga2Ox layer which serves as an interface passivation layer and thus suppresses trap-assisted electron tunneling. Capacitance-voltage measurements of AlGaN/GaN HEMT show shifts of threshold and on-set voltages, indicating decreased surface states as a result of the treatment. The electrical characteristics of AlGaN/GaN HEMT exhibit improved transconductance and subthreshold swing values after the treatment.

Electrical activity at the AlN/Si Interface: identifying the main origin of propagation losses in GaN-on-Si devices at microwave frequencies

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Scientific Reports
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AlN nucleation layers are the basement of GaN-on-Si structures grown for light-emitting diodes, high frequency telecommunication and power switching systems. In this context, our work aims to understand the origin of propagation losses in GaN-on-Si High Electron Mobility Transistors at microwaves frequencies, which are critical for efficient devices and circuits. AlN/Si structures are grown by Metalorganic Vapor Phase Epitaxy. Acceptor dopant in-diffusion (Al and Ga) into the Si substrate is studied by Secondary Ion Mass Spectroscopy and is mainly located in the first 200 nm beneath the interface. In this region, an acceptor concentration of a few 1018 cm-3 is estimated from Capacitance–Voltage (C–V) measurements while the volume hole concentration of several 1017 cm-3 is deduced from sheet resistance. Furthermore, the combination of scanning capacitance microscopy and scanning spreading resistance microscopy enables the 2D profiling of both the p-type conductive channel and the space charge region beneath the AlN/Si interface. We demonstrate that samples grown at lower temperature exhibit a p-doped conductive channel over a shallower depth which explains lower propagation losses in

comparison with those synthesized at higher temperature. Our work highlights that this p-type channel can increase the propagation losses in the high-frequency devices but also that a memory effect associated with the previous sample growths with GaN can noticeably affect the physical properties in absence of proper reactor preparation. Hence, monitoring the acceptor dopant in-diffusion beneath the AlN/Si interface is crucial for achieving efficient GaN-on-Si microwave power devices.

Elimination of the low resistivity of Si substrates in GaN HEMTs by introducing a SiC intermediate and a thick nitride layer

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IEEE Electron Device Letters
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We report the effect of a thick nitride layer on the high-frequency performance of AlGaN/GaN high-electronmobility transistors (HEMTs) grown by metal oxide chemical vapor deposition (MOCVD) on a 6-inch Czochralski (Cz)-Si substrate. The thick nitride layer was grown via a 3C-SiC intermediate layer. A significantly low parasitic pad capacitance and a comparable cutoff frequency of 4.5 GHz for 2-μ m gate length devices were achieved along with excellent electron transport characteristics, such as a mobility of ~ 2200 cm2/V-s and a drain current density of 520 mA/mm. The extracted small-signal equivalent circuit parameters also verified the accuracy of the measured cutoff frequency and parasitic capacitances.

GaN Single Crystalline Substrates by Ammonothermal and HVPE Methods for Electronic Devices

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Electronics
https://doi.org/10.3390/electronics9091342

Recent results of GaN bulk growth performed in Poland are presented. Two technologies are described in detail: halide vapor phase epitaxy and basic ammonothermal. The processes and their results (crystals and substrates) are demonstrated. Some information about wafering procedures, thus, the way from as-grown crystal to an epi-ready wafer, are shown. Results of other groups in the world are briefly presented as the background for our work.

Monitoring the Joule heating profile of GaN/SiC high electron mobility transistors via cross-sectional thermal imaging

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Journal of Applied Physics
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The development of high-quality gallium nitride (GaN) high electron mobility transistors (HEMTs) has provided opportunities for the next generation of high-performance radio frequency and power electronics. Operating devices with smaller length scales at higher voltages result in excessively high channel temperatures, which reduce performance and can have detrimental effects on the device's reliability. The thermal characterization of GaN HEMTs has traditionally been captured from either the top or bottom side of the device. Under this configuration, it has been possible to map the lateral temperature distribution across the device with optical methods such as infrared and Raman thermometry. Due to the presence of the gate metal, however, and often also the addition of a metal air bridge and/or field plate, the temperature of the GaN channel under the gate is typically inferred by numerical simulations. Furthermore, measuring the vertical temperature gradient across multiple epitaxial layers has shown to be challenging. This study proposes a new cross-sectional imaging technique to map the vertical temperature distribution in GaN HEMTs. Combining advanced cross-sectioning processing with the recently developed near bandgap transient thermoreflectance imaging technique, the full transient thermal distribution across a GaN HEMT is achieved. The cross-sectional thermal imaging of the

GaN channel is used to study the effects of biasing on the Joule heating profile. Overall, the direct measurement of the GaN channel, capturing both the vertical and lateral gradient, will provide deeper insight into the device's degradation physics and supply further experimental data to validate previously developed electrothermal models.

Recovery from plasma etching-induced nitrogen vacancies in p-type gallium nitride using UV/O3 treatments

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Applied Physics Letters
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Plasma etching of p-type GaN creates n-type nitrogen vacancy (VN) defects at the etched surface, which can be detrimental to device performance. In mesa isolated diodes, etch damage on the sidewalls degrades the ideality factor and leakage current. A treatment was developed to recover both the ideality factor and leakage current, which uses UV/O3 treatment to oxidize the damaged layers followed by HF etching to remove them. The temperature dependent I–V measurement shows that the reverse leakage transport mechanism is dominated by Poole–Frenkel emission at room temperature through the etch-induced VN defect. Depth resolved cathodoluminescence confirms that the damage is limited to first several nanometers and is consistent with the VN defect.

Current Trends in the Development of Normally-OFF GaN-on-Si Power Transistors and Power Modules: A Review

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Journal of Electronic Materials
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Gallium nitride (GaN) power transistors have attracted significant interest in the power electronics industry over the past decade as the next-generation power semiconductor devices. GaN power transistors are suitable for high power and high frequency applications due to their higher electron mobility, temperature tolerance, electrical conductivity, critical breakdown electric field, and breakdown voltage compared to the conventional silicon-based transistors and other wide bandgap (WBG) power transistors. In particular, GaN-on-silicon (GaN-on-Si) technology has opened up the possibility of manufacturing high-performance, low-cost WBG power devices in silicon-compatible fabrication facilities. The first GaN power transistor structure to be developed was the normally-ON depletion mode (D-mode) device. It relies on the highly mobile two-dimension electron gas (2DEG) at the GaN/AlGaN epitaxial layers' interface to provide very low on-resistance. The normally-OFF enhancement mode (E-mode) GaN power transistor soon became available by controlling the 2DEG using various gate structures. This paper provides a review of the developments of GaN power transistors followed by a survey on current state-of-the-art GaN power technologies and applications, including comparisons between GaN growth substrates and developments of enhancement mode (E-mode) device structures and their process techniques. Moreover, developments of power module designs are also addressed, including gate driver designs and their requirements, and packaging techniques for power transistors and power modules.

Study on Self-Parallel GaN-Based Terahertz Hetero-Structural Gunn Diode

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Appl. Sci.
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In this paper, we propose a novel gallium nitride-based multi-two-dimensional-electron-gas (2DEG)-channel self-parallel Gunn diode (SPD) for the first time. In the SPD, a trench anode is etched through at least the bottommost 2DEG channels, which splits all 2DEG channels into two shorter channels with lengths of L1 and L2. Therefore, one SPD is just equal to several shorter diodes in parallel; as a result, we call it a self-parallel Gunn diode. In the symmetrical SPD, the component of fundamental frequency is nearly multiplied as compared with the regular Gunn diode. In the asymmetrical SPD (L2 = nL1, n is a positive integer), the harmonic components are greatly enhanced, specially the nth harmonic. Our work demonstrates that the GaN-based terahertz SPD not only offers an easy transfer between two different frequencies, but also realizes the simultaneous enhancement of oscillation power and frequency.

A Numerical Investigation of Heat Suppression in HEMT for Power Electronics Application

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Silicon
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In this paper, AlGaN/GaN High Electron Mobility Transistor (HEMT) with stacked passivation (Diamond/SiN) is proposed and investigated. The implementation of stacked passivation in HEMT has been shown to be effective in suppressing self-heating effect. Under the gate-terminal, the peak channel temperature of HEMT with stacked passivation is 384 K, whereas it is 393 K for conventional HEMT. The reduction of channel temperature in the proposed device is attributed to good heat-spreading via diamond. The thermal resistance (RTH) is extracted and it is found that RTH of proposed HEMT is 17% lower than that of the conventional HEMT. The transconductance of the proposed GaN-HEMT is also improved by 12%. Furthermore, the maximum drain current of 800 mA/mm at VGS = 0 V and VDS = 5 V is obtained for the proposed HEMT with a gate length of 0.25 µm. The proposed device is considered as one of the most attractive candidates for future high frequency and high-power applications over a wide range of operating temperatures.

Design and Optimization of LNA Amplifier Based on HEMT GaN for X-Band Wireless-Communication and IoT Applications

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Silicon
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Recently, the technology has evolved towards artificial intelligence world which include IoT (Internet of Things) and IoE (Internet of Everything) as communication between machines or between devices is possible. The development of these systems today requires electronic components capable of generating higher power and frequency levels, which is why new technologies have emerged to meet these needs, GaN HEMT technology. It has attracted a lot of attention for microwave power and high temperature applications. More recently, this technology has become a great interest to the international scientific community for the realization of low noise amplifiers which are the main components of wireless communication systems. In this paper, we modeled an LNA amplifier based on HEMT GaN transistors. This amplifier is unconditionally stable in the X-band (8–12) GHz with a gain of 38 dB, a noise factor does not exceed 2.4 dB and lower input and output reflection coefficients (S11, S22). at -14 dB and − 8 dB respectively. The designed amplifier can be integrated

into radar systems, space communications systems and civilian-military radiolocation systems.

Acceptor Decoration of Threading Dislocations in AlGaN/GaN Heterostructures

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We demonstrate that threading dislocations in AlGaN/GaN heterostructures can be spontaneously decorated by acceptors during the epitaxial process. First-principles calculations show that the threading dislocation introduces detrimental deep electronic states both above the valence-band maximum (VBM) and below the conduction-band minimum (CBM) of GaN. Because of the electron transfer between the occupied level above the VBM of the threading dislocation and the defect states of acceptors, acceptors will decorate the threading dislocation, which leads to the shift of the dislocation states. For the occupied deep states above the VBM, the acceptor decoration shifts the deep states toward the VBM, which may constructively contribute to the dislocation tolerance of AlGaN/GaN heterostructures. For the unoccupied states below the CBM, the acceptor-decorated dislocation provides an additional electron-transfer channel besides that through the pure threading dislocations. These two distinct electron-transfer channels are observed in reverse-biased AlGaN/GaN Schottky diodes, which is characterized by two distinct Frenkel-Poole-emission states.

Influence of Al pre-deposition time on AlGaN/GaN heterostructures grown on sapphire substrate by metal organic chemical vapor deposition

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Aluminum (Al) pre-deposition technology was employed to grow high-quality AlGaN/GaN heterostructures on c-plane sapphire substrates by metal organic chemical vapor deposition. The effects of Al pre-deposition time on the structural and transport properties of the heterostructures were investigated in detail. The optimal Al pre-deposition time was found to be 3 s, and the AlGaN/GaN heterostructures grown under the optimal conditions possessed the surface root mean square roughness of 0.312 nm, threading dislocation density of 1.66 × 109 cm−2, two-dimensional electron gas (2DEG) mobility of 1808.09 cm2/V s and wafer resistance non-uniformity of 0.65%. Further, the influence mechanism of Al pre-deposition time on the dislocation density in the GaN buffer layer was revealed through the research on bare AlN nucleation layer grown on sapphire substrates. The results in this work not only demonstrate the great potential of AlGaN/GaN heterostructures with Al pre-deposition technology in electronic device applications, but also provide practical guidance for the growth of high-quality group III nitride materials.

The Study of High Breakdown Voltage Vertical GaN-on-GaN p-i-n Diode with Modified Mesa Structure

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Crystals
https://doi.org/10.3390/cryst10080712

In this paper, we fabricated Gallium Nitride (GaN) vertical p-i-n diodes grown on free-standing GaN (FS-GaN) substrates. This homogeneous epitaxy led to thicker GaN epi-layers grown on the FS-GaN substrate, but a high crystalline quality was maintained. The vertical GaN p-i-n diode showed a low specific on-resistance of 0.85 mΩ-cm2 and high breakdown voltage (BV) of 2.98 kV. The high breakdown voltage can be attributed to the thick GaN epi-layer and corresponds to the mesa structure. Improvement of the device characteristics by the mesa structure was investigated using device simulations. We proved that a deeper mesa depth is able to decrease the electric field at the bottom of the mesa structure. Furthermore, a smaller mesa bevel angle will assist the BV up to 2.98 kV at a 60° bevel angle. Our approach demonstrates structural optimization of GaN vertical p-i-n diodes is useful to improve the device performance.

High-permittivity dielectric edge termination for vertical high voltage devices

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Journal of Computational Electronics
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A novel edge-termination concept using extreme permittivity dielectrics is proposed to effectively manage electric fields in vertical power-devices. This method is expected to be particularly significant for wide band-gap semiconductors, where field termination is a significant challenge due to material and process limitations. Detailed two-dimensional device simulation is used to prove the efficacy of this idea, and to demonstrate that peak electric fields are significantly reduced by this method. We also show an analytical model that gives an intuitive picture into the mechanism of high-permittivity dielectric field plate. Low process complexity and flexibility in the design of power devices can be achieved. We show that junction termination efficiency can be increased from 22.7% (no junction termination) and 50% (conventional field plate) to 73% (high-permittivity-terminated device).

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

Qorvo boosts 2.9-3.5GHz GaN power amplifier by 50% to 150W

SemiconductorToday

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has introduced a gallium nitride (GaN) power amplifier (PA) that delivers a 50% increase in power for improved range, performance and multi-target tracking in S-band (2-4GHz) phased-array radars.

The QPA3070 is said to leapfrog existing industry offerings, providing a first-ever 150W of power for the 2.9-3.5GHz frequency range, 58% power-added efficiency (PAE) and 28dB power gain. Qorvo says that this is possible through its ultra-reliable and highly efficient gallium nitride on silicon carbide (GaN-on-SiC) process technology, which offers superior efficiency, power density and affordability.

The PA delivers these features in a small (7mm x 7mm x 0.85mm) and cost-effective surface-mount package, which enables engineers to design higher-power radar solutions with significant size, weight, power and cost (SWAP-C) improvements, and bring them to market faster.

Soitec Renames EpiGaN to Strengthen its Portfolio of 5G RF and Power Systems

everythingRF

Soitec, an industry leader in designing and manufacturing innovative semiconductor materials, announced a name change for EpiGaN, a company they acquired in 2019. EpiGaN has now become Soitec Belgium. Soitec's GaN business unit acquired a year ago consolidates the company's portfolio of engineered substrates for RF and power markets. EpiGaN's extensive and widely acknowledged expertise complements Soitec's portfolio beyond the current SOI and POI product portfolio and creates new value-added solutions for both 5G RF and power systems.

GaN reinforces Soitec's portfolio beyond silicon

With EpiGaN's acquisition in May 2019, Soitec confirmed its ambition to further extend its portfolio beyond silicon. GaN technologies that are gaining significant traction in RF and power markets represent a natural strategic fit with Soitec's current portfolio of engineered substrates. Targeting the base station's power amplifiers market in the first place, Soitec also aims to penetrate the smartphones and power automotive markets with GaN products later on. Offering a comprehensive portfolio of silicon and non-silicon based engineered substrates, Soitec is well-positioned to support 5G deployment which is expected to be a strong growth lever. Operating as one of the company's business units for over a year now and benefiting from Soitec's global manufacturing footprint and exposure, the EpiGaN BU is offering its customers access to a worldwide sales and support team network.

EpiGaN has become Soitec Belgium

The integration of the business unit has gone one step further last month with a name change. Since June 1st, 2020, EpiGaN N.V has changed its name to Soitec Belgium N.V. and has embraced Soitec's visual identity, allowing the BU to fully reap the benefits of the Group's ecosystem.

EpiGaN's advanced expertise in GaN has been enhanced by Soitec's notoriety, giving the BU and its customers access to the Group's manufacturing scale and expertise.

GaN Systems and BrightLoop partner on power converters

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) and BrightLoop Converters of Paris, France (which manufactures power converters for harsh environments) have announced a strategic partnership to develop AC/DC and DC/DC converter products for electric motorsport and aerospace applications. Leveraging GaN Systems' 650V GaN transistors, BrightLoop is producing a range of converters that are smaller, lighter and more efficient than those currently available in the market, it is claimed.

BrightLoop's most recent family of DC/DC converters, including the 1.9kW, 4.8kW and 9.6kW DC/DC converters designed for hybrid and electric racing, incorporates GaN Systems' transistors and are around half the size and weight of the firm's first-generation DC/DC converter developed without GaN. BrightLoop says that it continues to make advances using GaN to produce lighter and more compact converters.

BrightLoop's DC/DC converters are now used in many of the Formula E teams and the winning team from 2019. The converter's function is to power all the low-voltage electronics including pumps, lighting and radio. Most recently, the World Sporting Consulting (WSC) Group, the motorsport event and racing promotion organization overseeing the Touring Car Racing (TCR) and ETCR (Electric Touring Car Racing) brands, announced BrightLoop as the sole supplier of DC/DC converters for cars in ETCR (the world's first electric touring car championship, beginning this summer).

Additionally, later next year for aerospace applications BrightLoop will unveil a high-performance 5kW AC/DC power factor correction (PFC) product, which also incorporates GaN Systems transistors. It operates from an input voltage of 60-180VAC and achieves 96% efficiency.

"The industries which we service require high reliability and performance and GaN is an important piece in helping us achieve that," says BrightLoop's CEO Florent Liffran. "GaN Systems offers one of the best lines of 650V GaN transistors and, coupled with its unique packaging, allows unprecedented integration," he adds.

"Teaming up with a leader like BrightLoop to demonstrate GaN Systems' products in these very demanding applications proves the value and ruggedness of our GaN in high-reliability power applications," says GaN Systems' CEO Jim Witham.

ALLOS transferring RF & power electronics patents & know-how to new GaN-on-Si entrant Azur Space

SemiconductorToday

On 8 July, IP licensing & technology engineering firm ALLOS Semiconductors GmbH of Dresden, Germany disclosed a deal to sell its gallium nitride (GaN) RF and power electronics business to Azur Space Solar Power GmbH of Heilbronn, Germany, which develops and produces multi-junction solar cells, with a view to focusing on its GaN-on-silicon micro-LED epiwafer technology for up to 300mm.

Patent analysis and technology intelligence firm Knowmade notes that Azur Space is a new entrant in the power electronics business, with no pre-existing intellectual property assets related to GaN-on-Si epitaxy and power GaN device technology, but it does have the ability to leverage its manufacturing expertise and facilities for high-volume production with a relatively limited initial investment (€10m).

Since its foundation in 2014, ALLOS has made its epiwafer technology – inherited from Azzurro Semiconductors – available through licensing and technology transfer to "high-power electronics companies that would like to enter the GaN-on-Si sector and avoid the cost, risk and uncertainty of starting their own epi development from scratch". In other words, ALLOS would enable new players to safely enter the GaN-on-Si business, relying on its patented and proprietary growth techniques and epi-structures.

In 2017, the licensing & technology engineering firm further strengthened its value proposition by disclosing a carbon-doping-free GaN-on-Si technology, offering good dynamic resistance, good crystal quality and extremely low leakage current all at once, enabling customers to overcome the usual trade-off between these parameters when using carbon doping in epi-structures. Moreover, it would provide an effective way for customers to avoid conflicts with well-established IP competitors relying on carbon doping to achieve the power electronics industry's requirements. As of 2017, ALLOS' approach was based on the insertion of multiple interlayers in an unintentionally doped thick GaN buffer layer (Figure 1). Knowmade says that, to its knowledge, neither ALLOS nor Azzurro has filed patents describing such a structure, or how to design and grow the interlayers in order to effectively reduce the leakage current in high-voltage applications.

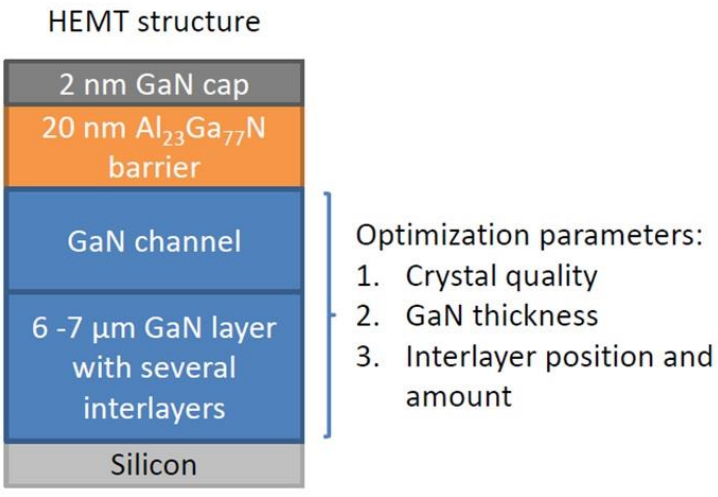


Figure 1: Typical GaN-HEMT epi-structures grown by MOCVD without intentional carbon doping or other doping. Electrical performance is optimized by position and number of interlayers. Source: 'Low vertical leakage current of 0.07µm/mm2 at 600V without intentional doping for 7µm-thick GaN-on-Si' presented at ICNS-12 in Strasbourg, France (July 2017).

At the time of Azzurro's bankruptcy, the GaN-on-Si epi-foundry had filed 29 patent families (i.e. single inventions patented in multiple countries). Most of them were reviewed by Knowmade in the 'GaN-on-Silicon Patent Landscape 2020'. However, since ALLOS was created in 2014 and acquired Azzurro's technology, know-how and patents, the engineering and consulting company has not relied on patents to protect new inventions. As a result, ALLOS' IP portfolio has shrunk to eight alive patent families (21 of Azzurro's inventions were abandoned and no patent application has been filed by ALLOS), grouping less than 50 patents and patent applications filed in the main area of interest for Azzurro's business: Europe (12), USA (9), China (8), Korea (5), Japan (2) and Taiwan (2). Furthermore, as of 2020, all of ALLOS' live patent families have already been the subject of a transfer of rights to Azur Space.

Indeed, the first patent transfers between the two companies occurred in 2015 and concerned the most relevant inventions for power applications, filed by Azzurro in 2013:

'P-doping of group-III-nitride buffer layer structure on a hetero-substrate', to provide good stress management and the high resistivity required for RF & power applications (US Patent 9,496,349);
'Layer structure for a group-III nitride normally-off transistor', with a recess-free design (US Patent 9,773,896).
Both patent families were granted thereafter with protection in main market areas such as Europe, USA, China and Korea, with the notable exception of Japan. Moreover, four domestic granted patents (filed only in Germany), dealing with electronics as well as optoelectronics, were transferred to Azur Space in 2016:

'III-nitride p-channel transistor structures to produce logic components comprises growing an aluminum indium nitride barrier layer on a group-III nitride buffer layer' (patent DE10200403434);
'Field-effect transistors, comprises an aluminum-gallium-indium-nitrogen layer, aluminum-gallium-nitrogen intermediate layer, and another aluminum-gallium-indium-nitrogen layer' (patent DE102006030305);
'Group-III nitride transistor component on a Si substrate for high temperature and microwaves, with a buffer layer formed by gas phase epitaxy', iron-doping of GaN-based buffer layers (patent DE10256911);
'Production of a planar tear-free light emitter structure comprises applying an aluminum-containing group III-V seed layer, aluminum-containing group III-V intermediate layers, and silicon nitride intermediate layers on a Si substrate' (patent DE10151092).
Eventually, ALLOS completed the IP transfer in second-quarter 2020 with two additional patent families related to improvements in terms of stress management when using a masking layer (e.g. SiN) for the growth of high-quality GaN epilayers on silicon substrates, especially for LED applications (EP patent 2,112,699 and US patent 9,406,505).

Interestingly, in 2019 Azur Space also acquired IP rights on two patent families filed by the Ulm University spin-off MicroGaN related to a diode circuit combining a GaN high-electron-mobility transistor (HEMT) and a GaN Schottky barrier diode (EP patent 2,633,555) including a GaN-on-Si embodiment, and a method of contacting a number of GaN devices together in a more compact way (US patent 8,748,944).

In conclusion, the present deal provides Azur Space with very relevant patents to develop GaN-on-Si technology and stand out from competitors, assesses Knowmade. Besides patents, it can rely on ALLOS' experise in the field, although not all aspects of ALLOS' technology are visible in patents. Indeed, the company seems to have put the emphasis on know-how and technology transfer rather than IP licensing in the development of its business. In fact, ALLOS is actively developing its GaN-on-Si technology for micro-LEDs and, according to the latest announcement, will focus its activities on micro-LEDs in the coming years. However, this has not yet translated into patenting activity, so it is likely to follow the same strategy as for power & RF electronics, focusing on trade secrets and technology transfer.

The power GaN patent landscape and GaN-on-Si patent landscape have been evolving rapidly in recent years, notes Knowmade, with numerous innovative startups and major power electronics' players aiming to strengthen their position, to prepare for the promising power GaN markets. For any of them, GaN-on-Si IP is crucial and has fostered multiple acquisitions and partnerships with well-established players in the field. In this very dynamic environment, Knowmade has set up a GaN Power & RF Patent Monitor service to track and analyze, month by month, the latest patenting activity of IP competitors engaged in the development of these technologies.

MACOM Introduces New GaN-on-SiC Power Amplifier Product Line

everythingRF

MACOM Technology Solutions, a leading supplier of semiconductor solutions, introduced their new Gallium Nitride on Silicon Carbide (GaN-on-SiC) power amplifier product line at the IMS 2020 virtual event, which it is branding MACOM PURE CARBIDE™. The company also announced the introduction of the MAPC-A1000 and the MAPC-A1100, its first two new products in the product line.

MAPC-A1000: The MAPC-A1000 is a high power GaN-on-SiC amplifier designed to operate from 30 MHz and 2.7 GHz and is housed in a surface mount plastic package. The easy-to-use general-purpose amplifier integrates an input match which simplifies the customer's design-in effort. The amplifier can deliver more than 25 W (44 dBm) at greater than 50% efficiency from 500 MHz to 2.7 GHz when tested in a circuit designed for operation over 2.2 GHz simultaneous bandwidth.

MAPC-A1100: The MAPC-A1100 is a high power GaN-on-SiC amplifier designed to operate up to 3.5 GHz. The device is capable of supporting both CW and pulsed operations with output power levels of at least 65 W (48.1dBm) in an air cavity ceramic package.

Stephen G. Daly, President and Chief Executive Officer of MACOM, stated that this new product line significantly enhances the capability of their existing RF power portfolio. GaN on Silicon Carbide is a compelling technology and they are excited to begin offering their customers both standard and custom MACOM PURE CARBIDE™ power amplifier solutions.

The two new general-purpose amplifier products are ideal for use in avionics, high power mobile radios, wireless systems and test instrumentation.

RFHIC Introduces GaN SSPAs and Microwave Generators for RF Energy Applications

everythingRF

RFHIC, a leader in GaN RF & Microwave components for telecom, defense, and the RF energy sectors showcased its GaN Microwave Generators and SSPA's at the virtual IMS 2020 exhibition. In their virtual booth they showcased a wide range of products that included:

200 W GaN SSPA from 5725 to 5875 MHz

The RNP58200-C from RFHIC is a GaN Solid-State Power Amplifier that operates from 5725 to 5875 MHz.

- This amplifier provides an output power of 200 W CW with a gain of 30 dB and an efficiency of 35%.
- It requires a DC supply of 40 V and draws 16 A of current.
- This amplifier is fabricated using RFHIC's cutting edge GaN SiC technology which provides excellent thermal stability in a small form factor.
- It is available in a module that measures 208 x 66 x 32 mm with SMA and N-type connectors and is ideal for industrial, wireless power transfer, medical, and scientific applications.

200 W GaN SSPA from 1295 to 1305 MHz

The RIM1320K0-20 from RFHIC is a GaN Solid-State Power Amplifier that operates from 1295 to 1305 MHz.

- It provides up to 2000 W of output power with a gain of 53 dB and has an efficiency of 65%.
- It can handle up to 10 dBm of input power and requires 50 VDC supply voltage.
- The amplifier is designed using GaN-on-SiC transistors and provides excellent thermal stability.
- It is available in a rugged module that measures 360 x 200 x 46 mm with SMA-Female connectors and is suitable for medical, high power industries, microwave CVD reactors, plasma generators, food science, and MW heating/drying applications.

100 W GaN SSPA Microwave Generator from 2.4 to 2.5 GHz

The RIM25100-20G from RFHIC is a GaN SSPA based microwave generator that operates from 2.4 to 2.5 GHz.

- It is designed for high power ISM (Industrial, Scientific, and Medical) and plasma generation applications with an output power of up to 100 W and an efficiency of 55%.
- The device requires a DC supply of 50 V.
- The SSPA includes PLL and is suitable for use in CW, pulse, and linear applications.
- This microwave generator is available in a module that measures 215 x 120 x 30 mm with an N-type (F) connectors cooling system and is ideal for industrial heating, drying, medical, scientific, and plasma lighting applications.

200 W GaN SSPA Microwave Generator from 2.4 to 2.5 GHz

The RIM25200-20G from RFHIC is a GaN SSPA based microwave generator that operates from 2.4 to 2.5 GHz.

- It is designed for high power ISM (Industrial, Scientific, and Medical) and plasma generation applications with an adjustable power of up to 200 W and an efficiency of 60%.
- The device requires a DC supply of 50 V.
- The SSPA includes PLL and is suitable for use in CW, pulse, and linear applications.
- This microwave generator is available in a module that measures 215 x 120 x 30 mm with an N-type (F) connectors cooling system and is ideal for industrial heating, drying, medical, scientific, and plasma lighting applications.

IMS 2020 was scheduled to take place in Los Angeles, California from 21-26 June 2020. However, due to the COVID-19 pandemic, the event took place virtually from 4 - 6 August 2020. All presentations and materials will stay online until 30 September 2020.

OPPO adopts Navitas' GaNFast power ICs

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA says that phone manufacturer OPPO has adopted its gallium nitride (GaNFast) power ICs to enable what's claimed to be the world's smallest, thinnest and lightest 50W fast charger. Measuring only 82mm x 39mm x 10.5mm (34cc) and as light as 60g, it is the first fast charger that is as thin as the phone itself.

The Mini provides the full 50W via OPPO's SuperVOOC fast-charging protocol, or the USB-C Programmable Power Supply (PPS) specification. The device has the flexibility to charge smartphones, tablets and many types of laptop. It's also the same size as the popular Asian 'Wang Wang' brand rice cookie – which has led many to refer to it as the 'cookie' charger.

The 50W Mini SuperVOOC charger was launched on 15 July by OPPO's chief charging technology scientist Jialiang (Jeff) Zhang. "Using gallium nitride devices to drive transformers to very high frequencies has been the dream of

all technical workers for many years," he says. "GaN devices will trigger a technological revolution in the field of power supplies."

GaN runs up to 20x faster than silicon and enables 3x more power, which translates to up to 3x faster charging in half the size and weight. GaNFast power ICs monolithically integrate GaN power, GaN analog and GaN logic circuits on the same chip, to enable faster, reliable, efficient operation, says Navitas.

For the 50W Mini, the high-speed performance of GaNFast power ICs opened the door to a new circuit topology – the 'pulsed' active-clamp flyback (ACF), which can tolerate a very wide input voltage range while maintaining a steady output to charge the phone battery. This allows the designer to remove the electrolytic 'bulk capacitor' from the system, which can take up 40% of the total volume. In addition, running 16x faster than traditional chargers meant that a traditional 50kHz 'wire-wound' transformer with over 20mm height can be replaced with a new high-speed 800kHz, 8mm planar transformer for an extremely low-profile and lightweight form-factor.

The new topology also allows OPPO's proprietary 'direct-charge' approach to reduce wear-out mechanisms and extend phone battery life.

"The 50W Mini is a great example of a next-generation fast charger, where new materials, new architectures and new component technology combine to create a revolution in power electronics," says Stephen Oliver, Navitas' VP marketing & investor relations. "We're at the point where GaN fast chargers have stepped far beyond boutique accessories and are now addressing high-volume, cost-effective and extremely high-performance markets."

Navitas and Lenovo partner on first GaNFast 90W fast charger for e-sports mobile phones

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA says that the fastest, most powerful charger for Legion e-sports, using GaNFast power ICs, has been launched into mass production and supplied 'in-box' with every Lenovo Legion phone.

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

GaN technology enables the 90W dual USB-C output charger to deliver 40% more power and charge 25% faster than previous best-in-class hardware, it is claimed.

Measuring only 66mm x 62mm x 28mm (115cc), the 90W Legion fast charger can charge a 5000mAh battery to 100% in only 30 minutes, enabled by GaNFast technology. Running 20 times faster than the traditional silicon, it improves the power by three times, making the charging speed three times faster, in half the size and weight of silicon chargers.

"It is a great pleasure for us to establish long-term cooperation and explore more new possibilities with Navitas Semiconductor," says Jin Chen, general manager of Lenovo China's Cellphone Business Department.

"The cooperation with Lenovo is a great milestone because Lenovo is not only a top phone manufacturer but also a top PC device manufacturer," says Yingying (Charles) Zha, VP & general manager of Navitas China. "GaNFast power ICs are a single chip integrating GaN field-effect transistor (FET), GaN digital and GaN analog circuits. It rapidly promotes the commercialization of the new generation of high-frequency, high-efficiency and high-power-density power converters," he adds.

GaN Systems issues 12V Class-D audio amplifier reference designs

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 issued its latest technical manual '12V High-Efficiency Audio Reference Designs using GaN Power Transistors'.

The technical manual was developed in response to the launch of its Class-D audio amplifier evaluation kit in May and from growing customer interest for designs in the 12V market for automotive, marine, powersports and other applications from power system design engineers.

High-quality audio is now a 'must have' across all segments from pro-audio, home-audio and portable audio, says the firm. Class-D audio systems using GaN are not only smaller and lighter but provide better sound quality, it adds.

The new technical manual provides several amplifier designs for 12V input systems using GaN Systems' Class-D audio amplifier evaluation kit, which includes a 2-channel, 200W-per-channel (8Ω) Class-D audio amplifier and companion 400W continuous power audio-grade switch-mode power supply (SMPS), including:

- **Single-Phase and Dual-Phase 12V Boost Converter** design supports both a 'direct' +12V to +18V single-rail power supply and a 'boosted' +12V to +18V single-rail power supply configuration;
- **Direct +12V to +18V VIN Supply to +/-32V VOUT Boost Converter** design supports a 'direct' +12V to +18V VIN supply and allows for the best cost versus power output trade-off, while maintaining the desired audio performance.
-

In audio systems, delivering more power and more channels has typically meant driving up size and weight and sacrificing sound quality. With GaN, designers can provide more power, more channels and better sound quality in small, lightweight solutions, says GaN Systems.

The technical manual, as well as the Class D amplifier and power supply kit and white paper 'See, Feel, and Hear the Difference with GaN Class-D Amplifier and Companion SMPS', are available at www.gansystems.com/class-d.

Transphorm trading on OTC market under symbol TGAN

SemiconductorToday

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V gallium nitride (GaN) field-effect transistors (FETs) — has received approval from FINRA (Financial Industry Regulatory Authority Inc) for its common stock to be listed and quoted on the Over-the-Counter (OTC) market. Transphorm is trade on the OTCQB under the symbol 'TGAN' as of market opeing on 3 August.

Transphorm's public listing marks "an important milestone in the company's evolution," say co-founders Umesh Mishra Ph.D. (chief technology officer) and Primit Parikh Ph.D. (chief operating officer). "The listing of our common stock provides both existing and prospective investors with direct access to invest in Transphorm and participate in our future anticipated growth as we continue to scale Transphorm's high-voltage GaN products for power conversion applications across our growing base of customers," they add.

Transphorm's product portfolio consists of both 650V and 900V GaN FETs for high-voltage power conversion applications ranging from 30W to over 10kW, including the industry's first JEDEC (commercial/industrial)- and AEC-Q101 (automotive)-qualified 650V devices and the only 900V GaN device on the market, it is claimed. With an IP portfolio that exceeds 1000 patents, the firm's products offer the quality and reliability (Q+R) backed by field performance of less than 1 failure per billion hours of operation spanning 65W (adapters/fast chargers) products to 4kW (power supplies/UPS) products. The AEC-qualified devices are currently being evaluated by electric vehicle (EV) power conversion suppliers and design partners for design-in on future automotive applications. Transphorm is actively ramping volume production in support of the growing adoption of its GaN power FETs, targeting power adapter, computing, uninterruptible power supply (UPS), data-center and communications infrastructure applications.

Azur orders Aixtron MOCVD system for entry into GaN high-power electronics & RF epi market

SemiconductorToday

Azur Space Solar Power GmbH of Heilbronn, Germany is using the AIX G5+ C metal-organic chemical vapor deposition (MOCVD) system from deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany for its expansion into the market for gallium nitride on silicon (GaN-on-Si) high-power electronics (HPE) and radio frequency (RF) epitaxial wafers.

Azur Space, which develops and produces multi-junction solar cells for both space and terrestrial concentrated photovoltaic (CPV) applications, is a long-standing Aixtron customer and has been using the AIX 2800G4-TM and AIX 2600G3 systems for its space solar application.

Featuring in-situ cleaning, a cassette-to-cassette wafer handler and Auto-Feed Forward (AFF) individual on-wafer temperature control, the now ordered fully automated AIX G5+ C system guarantees what is claimed to be unmatched epitaxial stability and low defect ratios. Furthermore, Aixtron's Planetary Reactor enables increases

in productivity and performance through the highest throughput, lowest cost of ownership and highest yield performance, the firm adds. The MOCVD platform is used for the production of 150mm and 200mm epiwafers.

With the establishment of a second business line leveraging its III-V manufacturing expertise, Azur Space is positioning itself in the fast-growing market for GaN epiwafers for power electronics and RF applications. With the capacity to operate at higher frequency and in a smaller form factor, demand for these epiwafers is driven mainly by the need for energy-efficient power systems, rapid charging solutions, renewable energies, server farms or the next generation of wireless networks (5G).

"Market entry will be a challenge. However, our more than 25 years of experience in III-V epitaxy technology with development and mass production is ideally complemented by Aixtron's system, so we have a very good starting position," reckons Azur's CEO Jürgen Heizmann. "Importantly, Aixtron's state-of-the-art Planetary Reactor provides us with the excellent quality level of our epiwafers required to capture the future market for high-performance electronics," he adds.

GaN Systems announces 65W QR charger reference design

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has announced a new reference design for a high-power-density 65W QR (quasi-resonant) charger targeted at the consumer electronics market, including mobile phone and laptop computer applications.

The reference design consists of an operating charger and design documentation, providing a complete and simple-to-implement solution that assists customers in accelerating product development, roll out and commercialization, says the firm.

Driven by the immense consumer demand for smaller, lighter, more energy efficient and faster charging devices, GaN has become the technology of choice to deliver these benefits, the company states. GaN makes this possible with attributes such as extremely high switching speed, low on-resistance and zero reverse recovery, it adds. The GaN-based reference design exceeds many designs and is a better alternative to a multi-chip, monolithic solution and other discrete solutions, it is claimed.

Key details include:

- input: 90-265V, ~ 50/60Hz;
- output: USB-C 5V3A, 9V3A/12V3A/15V3A/20V3.25A 65W max;
- EMI: CISPR22 Conduction and Radiation Class B;
- power density with case: 18.5W/in3;
- supports PD3.0, PPS, QC, QC4.0+, BC1.2;
- comprehensive protection: OVP, OCP, SCP and open loop.

GaN Systems says that the 65W QR reference design makes it straightforward for power system designers to develop high-performance charging solutions, while benefitting from fewer re-designs, fewer PCB re-spins, and fewer trips to the lab for testing. The reduced development time enables companies to accelerate the time to market for new products.

"Smaller, lighter and higher power are all features that are shifting from 'want' to 'need' in the consumer electronics markets, and the rapid adoption of GaN is an indication of that shift," says Larry Spaziani, VP of global sales. "This reference design is another great addition to our tools library."

Navitas' GaNFast power ICs used in Spigen's ArcStation Pro

SemiconductorToday

Mobile accessory firm Spigen Inc of Irvine, CA, USA and Navitas Semiconductor Inc of El Segundo, CA, USA have announced a new 20W gallium nitride (GaN) wall charger, the Spigen PowerArc ArcStation Pro, ahead of the expected Apple iPhone 12 release later this year.

Founded in 2009, Spigen makes cases, screen protectors and other accessories for smartphones. The firm recently launched its new brand Spigen PowerArc, specializing in ultra-fast charging solutions for mobile devices.

"Industry rumors indicate that the iPhone 12 will release without an 'in-box' charger," says Spigen's product @ marketing manager Bobby Lee. "The ArcStation Pro proactively fills that void and delivers lightning-fast charging in the smallest possible form factor, with an elegant design and fold-flat AC pins," he adds. "With 20W of charging power and a USB Type-C output, it can also charge AirPods, iPads and any number of other phones and tablets via USB-C to Lightning or USB-C to C cables."

A powerful upgrade over former Apple chargers, the ArcStation Pro embraces GaN technology, which is reckoned to run up to 100x faster than silicon chips. Navitas' GaNFast power ICs monolithically integrate GaN power, GaN analog and GaN logic circuits on the same chip, to enable faster, reliable, efficient operation – in a very small size. At just 39.5mm x34.5mm x 27.7mm (1.55-inch x 1.35-inch x 1.09-inch), and featuring smooth-folding AC-pins, the charger is 30% smaller than Apple's existing 18W wall chargers.

"Spigen's PowerArc is the leading-edge fast charger, ahead of Apple's iPhone 12 and differentiated by its accessible, affordable price point and commitment to quality," comments Stephen Oliver, Navitas' VP marketing & investor relations.

The Spigen PowerArc ArcStation Pro will retail for US$19.99 at the end of August, which is reckoned to be a major saving versus Apple chargers.

Transphorm's Q2 revenue boosted by licensing to Nexperia

SemiconductorToday

For second-quarter 2020, Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has reported revenue of $6.3m, up from $1.1m last quarter and $0.5m a year ago. This was largely due to $5m of licensing revenue from manufacturing partner Nexperia, related to funding of technology development, as well as $0.7m from Transphorm's three-year contract with the US Navy. For first-half 2020, revenue was $7.4m, up from just $1m in first-half 2019.

Operating expenses have been cut from $5.1m last quarter to $4.2m in Q2/2020 (level with a year ago), comprising R&D expenses of $1.6m and sales, general & administrative (SG&A) expenses of $2.6m.
Net loss has been cut further, from $5.9m ($0.21 per share) a year ago and $4.2m ($0.13 per share) last quarter to $2.3m ($0.06 per share) for Q2/2020. During the quarter, cash and equivalents have fallen from $14.6m to $9.4m.

Highlights in first-half 2020 are listed as:

- introducing SuperGaN Power FETs with the launch of the Gen IV GaN platform;
- partnering with Microchip Technology Inc to combine high-reliability GaN with a digital signal controller in support of accelerating GaN adoption;
- announcing Hangzhou Zhongheng Electric Co's development of an ultra-efficient, GaN-based power module using Transphorm's GaN devices;
- raising $19.7m in net proceeds from a private placement of common stock in February; and
- having its common stock listed on the OTC market and being recently granted DTC eligibility.

"We continue to successfully expand our comprehensive portfolio of high-voltage GaN power conversion devices, while working to drive increased adoption of our products for targeted applications, including the emerging opportunity in fast-charging power adapters," says CEO Mario Rivas. "Although the COVID-19 pandemic has impacted certain customers, resulting in delays of their internal development programs that could adversely affect the pace of adoption and revenue in the near-term, we are confident that our pipeline of customer engagements and design wins will drive future long-term growth."

EPC doubles performance of 200V eGaN FET family

SemiconductorToday

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – says that it is advancing the performance capability while lowering the cost of off-the-shelf gallium nitride transistors with the introduction of its EPC2215 and EPC2207 200V eGaN FETs. Applications include class D audio, synchronous rectification, solar MPPTs (maximum power point trackers), DC-DC converters (hard-switched and resonant), and multi-level high-voltage converters.

The EPC2215 (8mΩ, 162Apulsed) and the EPC2207 (22mΩ, 54Apulsed) are about half the size of the prior-generation 200V eGaN devices and double the performance. The performance advantage over a benchmark silicon device is hence even higher. The EPC2215 has 33% lower on-resistance, yet is 15 times smaller in size. Gate charge (QG) is ten times smaller than the silicon MOSFET benchmark with the new technology and, like all eGaN FETs, there is no reverse recovery charge (QRR), enabling lower-distortion class D audio amplifiers as well as more efficient synchronous rectifiers and motor drives.

"This latest generation of eGaN FETs achieve higher performance in a smaller, more thermally efficient size, and at a comparable cost to traditional MOSFETs," says co-founder & CEO Alex Lidow. "The inevitable displacement of the aging power MOSFET with GaN devices is becoming clearer every day."

EPC worked in collaboration with Semiconductor Power Electronics Center (SPEC) at University of Texas at Austin to develop a 400V, 2.5kW-capable eGaN FET-based four-level flying capacitor multi-level bridgeless totem-pole rectifier that is suitable for data-center applications using the new EPC2215 200V device. "The advantageous characteristics of eGaN FETs allowed this converter to achieve high power density, ultra-high efficiency, and low harmonic distortion," comments professor Alex Huang.

The EPC2215 is priced at $2.84 each and the EPC2207 at $1.49 each (in 2.5k reels), with half-bridge development boards EPC9099 and EPC90124, respectively, both priced at $118.75.

Avoiding mobility collapse in high-voltage gallium nitride power devices

SemiconductorToday

Japan's SCIOCS Co Ltd has claimed the highest mobility achieved at room temperature for n-type gallium nitride (n-GaN) with low carrier density of the order of 1015/cm3 [Hajime Fujikura et al, Appl. Phys. Lett., vol117, p012103, 2020]. Such low-doping layers are key components of vertical power devices with voltage ratings up to 10kV. The requirement is for thick drift layers to reduce electric fields, while maintaining conductivity (proportional to the mobility and free carrier density).

The SCOICS material avoided an effect called 'mobility collapse', which is associated with carbon (C) contamination. Such contamination is almost unavoidable in the usual metal-organic chemical vapor deposition (MOCVD) used in commercial manufacturing – organic molecules, of course, contain large amounts of C. Also, the C incorporation is highly sensitive to off-angle variations in the GaN crystal structure, of the order of 0.3°, leading to high free-carrier density variations across a wafer.

Instead, the SCIOCS team used hydride vapor phase epitaxy (HVPE), which employs gallium metal and ammonia (NH3) as the source materials, avoiding the presence of C. A further advantage of HVPE is a much faster growth rate over MOCVD – more than 100µm/hour versus a few microns/hour, respectively.

To enable precise control of the silicon (Si) doping needed for low-electron-density material, the researchers have developed a 'quartz-free' (QF) HVPE process – quartz consists of crystalline silicon dioxide (SiO2). The QF-HVPE growth was achieved by removing quartz from the high-temperature regions of the equipment. A further advantage is the avoidance of oxygen contamination, which has an n-type doping effect on GaN.

The researchers used their QF-HVPE process at atmospheric pressure, and the temperature was set at 1050°C. The substrate was 2-inch, +c-oriented, Si-doped, n-type freestanding GaN produced using a void-assisted separation method developed at SCIOCS. The QF-HVPE growth rate was around 1µm/minute. The threading dislocation density of the n-GaN layers was uniform in the 1-3x106/cm2 range.

Samples for capacitance-voltage analysis were grown directly on the freestanding substrate. For Hall measurements, a C-doped insulating interlayer up to 10µm thick was introduced.

The team was able to produce n-GaN layers with controllable Si concentrations ([Si]) as low as 1.5x1015/cm3, according to secondary-ion mass spectrometry (SIMS). By contrast, MOCVD samples tend to bottom out [Si] at around 9x1015/cm3.

While the carrier concentration is typically considerably below the Si-doping level in MOCVD, 2.5x1015/cm3 in the case above, for the QF-HVPE samples produced with 1.5x1015/cm3 [Si] the carrier concentration was around 1015/cm3.

The SIMS analysis also showed [C] and [O] at less than 5x1014/cm3. With [C] kept below this level, the team was able to maintain mobility at very low free-carrier densities (Figure 1). By deliberately introducing C into the HVPE growth process, the researchers demonstrated a mobility collapse effect similar to that seen with MOCVD.

The free-carrier density threshold for mobility collapse in MOCVD has been found to be around 2-3x [C]: 3x1017/cm3 with [C] at 1x1017/cm3, and 2x1016/cm3 for 9x1015/cm3 [C].

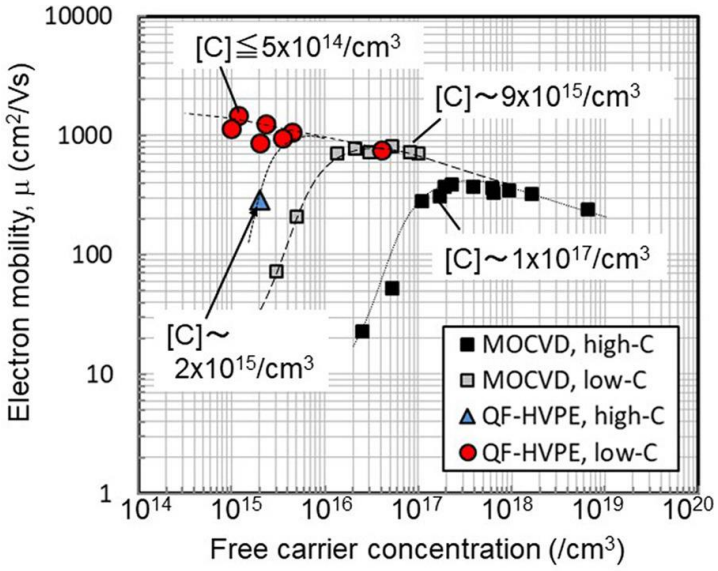


Figure 1: Free-electron density versus mobility in n-GaN layers grown by MOCVD and QF-HVPE with 'low' and 'high' [C]. MOCVD data from samples grown on sapphire at North Carolina State University et al, and reported in 2016.

The highest mobility of 1470cm2/V-s in the low-[C] QF-HVPE process was found with the free electron density at a very low value of 1.2x1015/cm3. The researchers comment: "This is the highest reported room-temperature mobility for GaN crystals thus far."

By introducing a small piece of carbon into the QF-HVPE chamber, the [C} level rose to 2x1015/cm3. A layer with [Si} at 4x1015/cm3 saw the free-carrier density drop to 2x1015/cm3. The mobility was a paltry 288cm2/V-s.

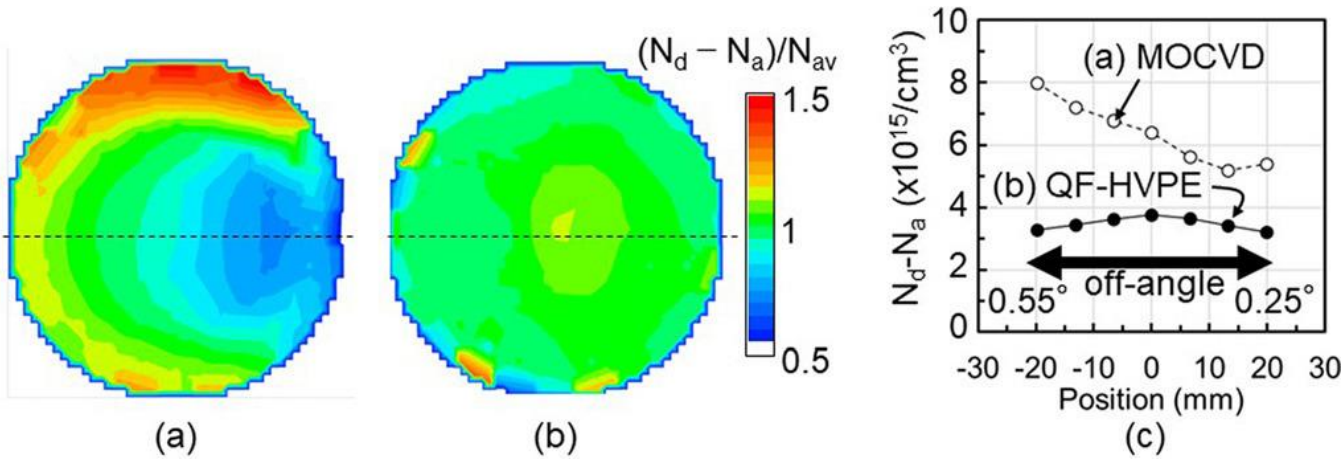


Figure 2: Net carrier concentrations over 2-inch wafers grown by (a) MOCVD and (b) QF-HVPE, according to contactless capacitance-voltage measurements. (c) Line profiles of carrier concentrations along horizontal broken lines in (a) and (b).

The team also measured carrier density uniformity across wafers grown by MOCVD and QF-HVPE (Figure 2). The average carrier densities were 7x1015/cm3 and 3.4x1015/cm3, respectively.

The carrier density non-uniformity in the MOCVD had a standard deviation of 16.7%. The researchers comment: "This large variation can be attributed to the off-angle-dependent C-incorporation efficiency, as reported

previously." For the QF-HVPE, the non-uniformity/standard deviation was 4.0% of the already low average carrier density.

Photoluminescence study of the QF-HVPE n-GaN showed sharp 363nm-wavelength near-band-edge emission peak, along with weak broad green emissions centered around 520-530nm. Such green luminescence is associated with nitrogen vacancies. There was no sign of yellow luminescence that is usually attributed to C contamination.

SCIOCS emerged out of Hitachi Cable, and then was part of Hitachi Metals, but is now part of the Sumitomo Chemicals Group. The company is located in the city of Hitachi, where the first company of the same name was founded in 1910.

Transphorm's second 900V GaN FET enters high-volume production

SemiconductorToday

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) — says that its second 900V GaN FET is now in production.

The TP90H050WS offers a typical on-resistance of 50mΩ with a 1kV transient spike rating and is now JEDEC qualified. The primary target markets are broad industrial and renewable energy, including applications such as photovoltaic inverters, battery charging, uninterruptable power supplies (UPS), lighting and energy storage. Additionally, with the 900V portfolio, Transphorm is working its way up the voltage range to include three-phase applications.

Introduced last year, the TP90H050WS is the firm's second 900V device following the TP90H180PS. The two-chip normally-off power transistor delivers a ±20V gate robustness in a standard TO-247 package, increasing its reliability and designability for power systems. The combination of Transphorm's high-speed GaN and the thermally robust TO-247 package enables systems to reach greater than 99% efficiency while generating up to 10kW of power in typical half-bridge configurations with bridgeless totem-pole power factor correction (PFC).

"Transphorm's work on its 900V platform illustrates the capability of high-voltage gallium nitride power transistors," says Philip Zuk, VP of technical marketing & NA sales. "This device gives us the ability to support applications that were not previously accessible to us," he adds. "We have received strong interest when sampling these 50mΩ FETs… Their availability status has shifted now to high-volume production to meet customer demand."

900V GaN in application

Illinois Institute of Technology (IIT) is currently working with the TP90H050WS in an ARPA-E Circuits program that uniquely brought together Transphorm's product with IIT's solid-state switching topologies. The project aims to generate reliable solid-state circuit breaker (SSCBs) for renewable energy microgrids. It includes developing an autonomously operated, programmable and intelligent bi-directional SSCB using the 900V GaN devices.

"Our SSCB project required a non-traditional power conversion solution that not only outperformed mechanical circuit breakers speed-wise, but also helped us reduce power loss," says Dr John Shen, IIT. "Transphorm's GaN technology surpassed our expectations. It delivered the full package. High power density, reliable bi-directionality, and, as the only 900V GaN device on the market, unprecedented power output in a small package," he adds.

900V evaluation board

Transphorm continues to simplify development efforts with its DC-to-AC inverter evaluation board. Designed using four TP90H180PS 170mΩ FETs, the TDINV3500P100-KIT uses a full-bridge topology to support single-phase inverter systems operating at or above 100kHz.

The evaluation board, along with both in-production 900V transistors, are available through distributors Digi-Key and Mouser.

Power Amp Wars Begin For 5G

SemiconductorEngineering

Demand is increasing for power amplifier chips and other RF devices for 5G base stations, setting the stage for a showdown among different companies and technologies.

The power amplifier device is a key component that boosts the RF power signals in base stations. It's based on two competitive technologies, silicon-based LDMOS or RF gallium nitride (GaN). GaN, a III-V technology, outperforms LDMOS, making it ideal for the high-frequency requirements for 5G. But GaN is expensive with some challenges in the fab. And LDMOS (laterally-diffused metal-oxide semiconductor) has some limitations, but it isn't going away.

Nonetheless, 5G is a fast-moving but complex market. In just one part of the supply chain, device makers manufacture RF chips like power amplifiers in fabs. From there the devices are shipped to base station vendors for integration. A so-called macro base station is a system located at a cell tower, which provides RF wireless coverage over a wide area.

Generally, the power amplifier device for previous-generation 3G base stations were based on LDMOS. LDMOS, a mature and inexpensive technology, took the early lead in the 4G base station market. Over time, GaN power amps made significant inroads in 4G, at the expense of LDMOS. Power amplifiers are small circuits that convert a low-power RF signal into a higher power signal in base stations and other systems. The power amplifier isn't the only device in the base station. These other devices are based on various processes.

Nonetheless, GaN-based power amps also are gaining steam in 5G. As in 4G, China's base station vendors are adopting GaN-based power amp devices for their initial deployments of 5G systems in China. Other base station vendors are following suit.

There are several reasons for that. 5G, a next-generation wireless technology that's faster than today's 4G, is being deployed in two different areas – sub-6GHz and mmWave (28GHz and above). Generally, at higher frequencies, LDMOS runs out of steam, prompting the need for GaN. Compared to LDMOS, GaN has higher power densities and operates over a much wider frequency range.

"The need for dense, small-scale antenna arrays in 5G infrastructure is resulting in key challenges around power and thermal management in RF systems. With their improved wideband performance, efficiency and power density, GaN devices offer the potential for more compact solutions that can address these challenges," said David Haynes, managing director of strategic marketing at Lam Research.

LDMOS isn't going away, though. Some mobile operators are deploying both low- and high-frequency bands for 5G. LDMOS is suited for the lower bands. So both GaN and LDMOS will find a place in 5G. "In macro stations, GaN has gradually been taking market share from LDMOS following its wide adoption in Huawei's 4G LTE infrastructure equipment," said Ezgi Dogmus, an analyst at Yole Développement. "In the sub-6GHz regime in 5G we see tough

competition between LDMOS and GaN in lower-power active antenna systems. GaN is being adopted in bands where large bandwidth capacity is needed."

Regardless, the numbers are staggering. The total GaN RF market will increase from $740 million to more than $2 billion by 2025, with a CAGR of 12%, according to Yole. Telecom infrastructure and military radar are the main drivers for RF GaN. In another example, China built 130,000 5G base stations in 2019, with plans to install 500,000 more in 2020, according to Handel Jones, chief executive of IBS. By 2024, China's goal is to deploy 6 million systems, Jones said. Japan, Korea, the U.S. and others are also making a big push in 5G.

The numbers don't tell the entire story. In RF GaN, there are other dynamics, including:

GaN transistor technology features gate lengths at 1µm and above, although some are developing 90nm and below processes.
RF GaN suppliers are moving from 100mm to 150mm wafer sizes to reduce costs.
Most RF GaN devices use silicon carbide (SiC) substrates. Several vendors are working on competitive silicon substrates for RF GaN.
The U.S. and China are embroiled in a trade war. Many U.S. chip vendors are prohibited from selling products to Huawei. It's still unclear how all of that will play out.
Evolving base stations
Today's wireless networks revolve around the 4G LTE standard, which operates from the 450MHz to 3.7GHz frequency bands. 4G is fast but complicated. It consists of more than 40 frequency bands, plus the 2G and 3G bands.

Evolving base stations
Today's wireless networks revolve around the 4G LTE standard, which operates from the 450MHz to 3.7GHz frequency bands. 4G is fast but complicated. It consists of more than 40 frequency bands, plus the 2G and 3G bands.

The 4G LTE network consists of three parts – a core network, radio access network (RAN), and end-user devices like smartphones. Run by a mobile operator, the core network handles the overall functions in the network.

The RAN consists of giant cell towers, which is where the base stations are located. The RAN is basically a relay system with a multitude of cell towers in a given region.

A base station itself consists of two separate systems, the building baseband unit (BBU) and the remote radio head (RRH). The BBU, which is situated on the ground, handles the RF processing functions. It serves as the interface between the base station and the core network.

The RRH, which is on top of the cell tower, consists of three or so large rectangular boxes. An antenna unit resides on the top of the tower. The RRH handles the conversion of RF signals, while the antenna transmits and receives the signals.

Inside the RRH box, there is a set of chips, which consists of a transmit and receive chain. In simple terms, a digital signal is received in the unit. It is converted to analog, upconverted to an RF frequency, amplified, filtered and then sent out via an antenna, according to "everything RF," a technology site.

"A relatively high-end LTE base station might have four transmitters. On every tower, there's going to be four power amplifiers sending signals out to capture and send data to customers," said Dan McNamara, an analyst at

Mobile Experts, a research firm. “On each tower, there’s three of them. Think of it as a pie. Each one handles a certain circle in terms of the way the signals radiate out from the tower. So, there’s actually 12 (transmitters).”

Meanwhile, operators are now deploying 5G. Compared to 4G, 5G promises to deliver mobile network speeds with a 10X lower latency, a 10X higher throughput and a 3X spectrum efficiency improvement. “Mobile communication systems are migrating from 4G to 5G,” explained Sheng-Chi Hsieh, a researcher at ASE, in a recent paper at ECTC. “The new radio (NR) frequency bands are distributed in two defined frequency ranges (FR), which are FR1: 450MHz to 6GHz and FR2: 24.25GHz to 52.6GHz. There are three dimensions to improve the performance, which are massive IoT, low latency, and the enhanced mobile broadband (eMBB), for the usage of massive connectivity, ultra-high reliable and low latency, and capacity enhancement, respectively.”

Each nation has a different 5G strategy. For 5G, China uses 3.5GHz as the frequency. Then, a 5G base station resembles a 4G system, but it’s on a much larger scale. For sub-6GHz in 5G, let’s say you have a macro base station. The power levels at the antenna range from 40 watts, 80 watts or 100 watts.

On the RRH board, you have various devices such as power amps, low-noise amplifiers (LNAs), transceivers and others. The RF process is complex with several steps. “Think of the transceiver is the baseband digital side of things. Coming out of this transceiver, (a signal) goes into the RF. In general, you have some type of receive path. And for us, this is GaAs-based. It can also be silicon-based. It’s basically LNAs and there’s a switch,” explained James Nelson, director of 5G infrastructure accounts at Qorvo. “In this case, a lot of our modules that we make on the receive side are dual channel. That’s why you see effectively two power amplifier sections or transmit sections on the top and on the bottom. They would be identical because this is a dual channel. Where GaN plays is in these amplifier blocks. The amplification can be done a lot of different ways.”

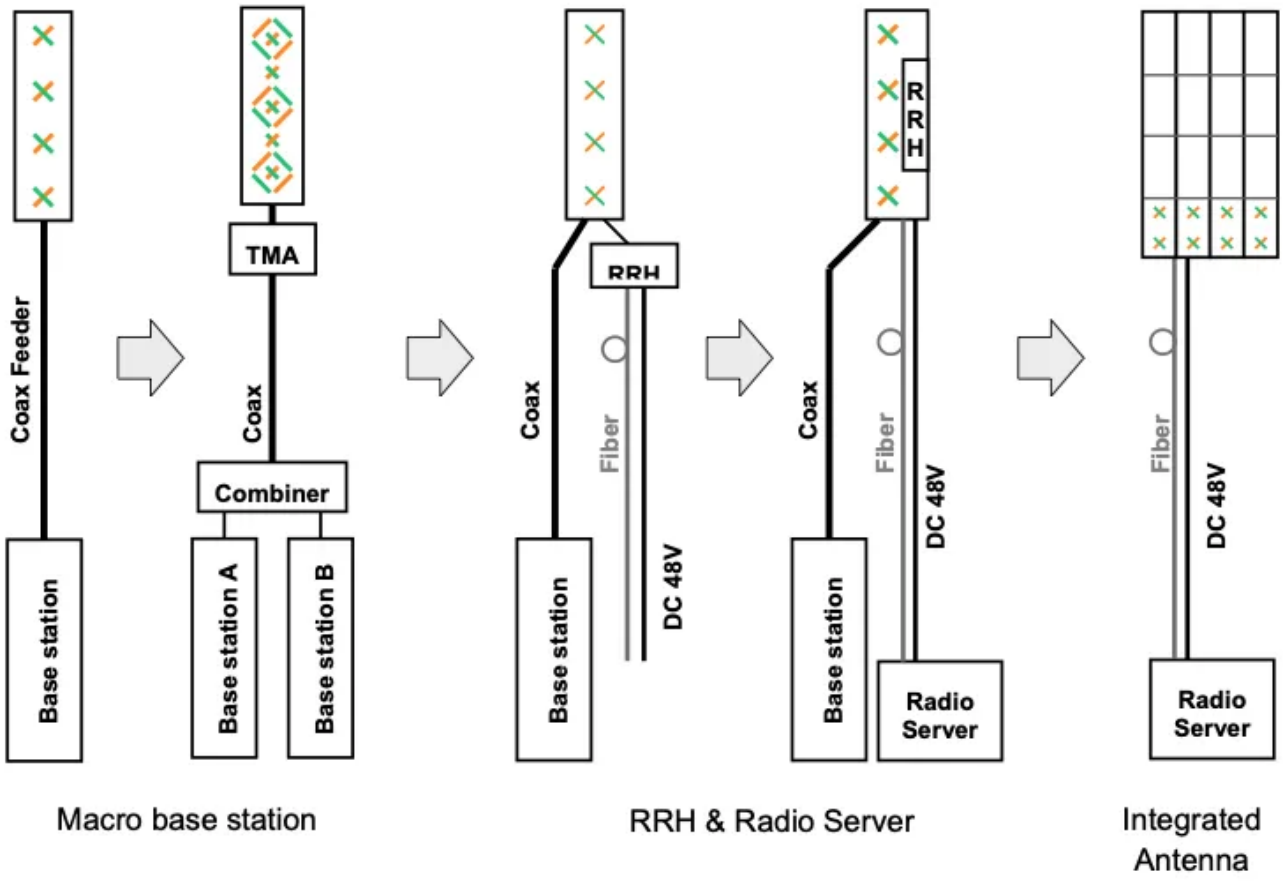


Fig. 1: Evolution of macro base stations and antennas. Source: 5G Americas

5G is different in other ways. Instead of 12 transmit chains, as in 4G, there are 32 or 64 transmit chains in 5G. “The equivalent system in 5G is going to have 32 or 64 power amplifiers in each radio times 3. It’s a huge amount of material that is needed,” Mobile Experts’ McNamara said.

The next step is to integrate some or all of the RRH into the antenna. These integrated base stations make use of massive MIMO antenna systems. Incorporating tiny antennas, massive MIMO communicates with users via beamforming techniques.

In the U.S, meanwhile, 5G is fragmented. Some telecoms are deploying a faster version of 5G using mmWave frequencies at 28GHz. Today, mmWave is limited to fixed-wireless services. It’s a niche market with various challenges. The big 5G deployment in the U.S. will occur when carriers begin to deploy C-band technology at 3.7GHz. The timing of C-band is unclear.

GaN vs LDMOS
Read more

Siltronic orders Aixtron system to ramp GaN-on-Si epi production

SemiconductorToday

To strengthen its position in the emerging gallium nitride on silicon (GaN-on-Si) market, silicon wafer manufacturer Siltronic AG of Munich, Germany has ordered an additional metal-organic chemical vapor deposition (MOCVD) system to be used for the production of 150mm and 200mm GaN-on-Si epiwafers for radio-frequency (RF) and power applications.

For shipment in fourth-quarter 2020 from deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany, the AIX G5+ C system is fully automated and equipped with in-situ cleaning and a cassette-to-cassette transfer module for high epitaxial stability and low defect ratios. The Planetary Reactor includes Aixtron’s Auto-Feed Forward (AFF) individual on-wafer temperature control and has an 8x150mm and 5x200mm configuration.

RF, power devices and circuit are enabling high switching frequencies and efficient energy management with high power densities. These features are required for rapidly growing applications such as data centers, renewable energy and the next generation of wireless networks (5G), notes Aixtron. Alongside the smaller form factor, GaN-on-Si is a suitable candidate for rapid charging and car electrification.

“The GaN-on-Si market is an important future growth field. We have been very active early on within the GaN Power Program of imec, the research institute for nanoelectronics, to provide our customers with leading-edge performance,” says Siltronic’s CEO Dr Christoph von Plotho. “To position ourselves competitively in this market, we need a reactor which allows us to deliver our customers with the best performance epiwafers while ramping up volume at lowest costs. We see the AIX G5+ C as the ideal solution in this regard both for GaN Power and RF devices to serve the growing applications and megatrends. The use of GaN-on-Si technology also makes a central contribution to improving the energy balance through decarbonization,” he adds.

“GaN-on-Si technology has made impressive breakthroughs in the last years and devices are rapidly gaining acceptance into both consumer and industrial products for power and RF application,” comments Aixtron’s president Dr Felix Grawert. “The AIX G5+ C is a fully mature platform dedicated to these advanced applications.”

IVWorks and IntelliEPI partner on MBE-grown GaN epi

SemiconductorToday

IVWorks Co Ltd of Daejeon, South Korea – which was founded in 2011 and manufactures 100-200mm gallium nitride (GaN) epitaxial wafers for RF & power electronics applications – and Intelligent Epitaxy Technology Inc (IntelliEPI) of Richardson, TX, USA – which was founded in 1999 and manufactures molecular beam epitaxy (MBE)-grown epitaxial wafers – have announced a joint partnership on technology and business development for GaN epitaxial materials based on MBE technology. The two firms have been collaborating closely since 2018 on developing production-scale manufacturing of GaN epiwafers by MBE. The framework of the technical and marketing alliances was formalized in 2019.

GaN/Si (up to 200mm) and GaN/SiC (up to 150mm) now available for evaluation

IVWorks, which uses hybrid-MBE technology to produce GaN epiwafers, has developed the Domm machine-learning-based artificial intelligence (AI) epitaxy system, which is said to dramatically improve productivity and scalability.

Hybrid-MBE growth is performed with a hybrid nitrogen source of ammonia and plasma for optimal quality and high growth rate. In addition, IVWorks' Domm AI technology uses a deep learning algorithm to detect and analyze reflection high-energy electron diffraction (RHEED) patterns, which can monitor crystal growth at the atomic level during MBE growth in real-time. Furthermore, a prediction model is created by learning the validity and correlation of the dataset that integrates classified RHEED patterns, growth conditions, and quality results of the epiwafers. This prediction model can be applied to epiwafer manufacturing to maximize productivity.

IntelliEPI specializes in arsenide (As)-, phosphide (P)- and antimonide (Sb)-based MBE epiwafer production as well as gallium antimonide (GaSb) substrate manufacturing, with products including a range of epiwafers for microelectronics and optoelectronics device applications. IntelliEPI says it will leverage its strength in high-volume MBE production, equipment modification and component manufacturing to rapidly bring GaN to its product line.

"By partnering with MBE epiwafer production experts such as IntelliEPI, we will accelerate the role we play in supplying high-quality GaN epiwafers to the global semiconductor industry through the revolutionary AI manufacturing system, while enhancing market penetration and response," reckons IVWorks' CEO Dr Young-kyun Noh. "Thanks to IntelliEPI's long experience of compound semiconductor epiwafer business and large-scale production, we will be able to significantly strengthen competitiveness for the GaN epi business," he adds.

"This partnership will advance MBE GaN growth by combining AI technology from IVWorks and IntelliEPI's large-scale production MBE growth capabilities and related equipment expertise," says IntelliEPI's president & CEO Dr Yung-Chung Kao. "IntelliEPI will work closely with IVWorks to develop a global business based on MBE GaN technology for RF and power device markets."

HRL's ultra-linear GaN HEMTs exceed 30GHz targets in DARPA's DREaM project

SemiconductorToday

HRL Laboratories LLC of Malibu, CA, USA (which is co-owned by The Boeing Company and General Motors) says that a team led by principal investigator Dr Jeong-Sun Moon has met and exceeded the performance metrics defined by the US Defense Advanced Research Project Agency (DARPA) Dynamic Range-enhanced Electronics and Materials (DREaM) program, which aims to improve dynamic range in millimeter-wave (mm-wave) electronics.

Specifically, HRL has demonstrated a low-noise gallium nitride (GaN) high-electron-mobility transistor (HEMT) with record linearity – the ratio between output third-order intercept power (OIP3) and DC power consumption (PDC) – for such devices. OIP3/PDC of 20dB at 30GHz was achieved, at least 10 times greater than conventional GaN HEMTs [International Microwave Symposium, 2019]. In parallel, HRL's DREaM GaN transistors demonstrated power-added efficiency (PAE) of greater than 70% at 30GHz, which is said to be a vast improvement over reported PAEs of other mm-wave T-gated AlGaN/GaN HEMT devices [Electronics Letters, April 2020].

Picture: The DREaM project's ultralinear GaN HEMTs enable secure ultra-wideband communication with higher data rates while reducing power draw on end-user platforms, such as ships, aircraft or satellites. © 2020 HRL Laboratories.

"We began our efforts in the DREaM project to develop advanced ultra-linear GaN transistors for mm-wave frequencies that enable transmission and reception without distortion across the electromagnetic spectrum," Moon says. "This technology will enable secure ultra-wideband communication with higher data rates, while reducing the draw on the power sources of end-user platforms, such as ships, aircraft or satellites."

With the initial goals reached, DARPA will now take the DREaM program into its second phase. With an even more challenging amplifier performance goal of 94GHz, DARPA hopes to implement wideband low-noise amplifiers with ambitious end-user needs in mind.

HRL's team also includes engineers Bob Grabar, Joel Wong, Mike Antcliffe, Erdem Arkun, Isaac Khalaf, Peter Chen, Chuong Dao, Andrea Corrion and Dave Fanning. The work is supported by the United States Air Force (USAF) under Contract No. FA8650-18-C-7802.

DOE STTR contract for SMI and SUNY Poly to co-develop 600V/20A GaN for Evs

SemiconductorToday

Structured Materials Industries Inc (SMI) of Piscataway, NJ, USA – which provides chemical vapor deposition (CVD) systems, components, materials and process development services – has been awarded a Phase I Small Business Technology Transfer Research (STTR) contract by the US Department of Energy (DOE) to develop pervasive manufacturing infrastructure for GaN (>20A/>600V) qualified for electric vehicle power electronics.

For the project, SMI is partnering with the State University of New York (SUNY) Polytechnic Institute Albany. The team will address issues related to the production of uniform-quality GaN materials on large-area substrates (4-inches and above), design and develop power devices that will perform at high current and high voltage (>20A, >600V, for electric vehicle on-board electronics) and develop production pathways. SMI will focus on developing novel reactor concepts to increase GaN material quality/uniformity across large wafer sizes, while SUNY will use reactor technology to optimize the developed materials and device structures on a 4" substrate. SMI will help to enable the commercialization of both device and reactor technology.

"Our partner at SUNY-Albany, professor Shahedipour-Sandvik, is an expert in the growth of III-N materials and device fabrication and was the first to report enhancement operation in an AlGaN/GaN HEMT," says SMI. The SUNY-Albany team recently reported a novel integrated body-diode AlGaN/GaN HEMT power device that enables dynamic tuning of the turn-on voltage (Von) and substantially reduces off-current (Ioff).

"We are designing a concept MOCVD system to improve the yield and quality of GaN devices for vehicle power electronics," says principal investigator and SMI research scientist Dr Arul Arjunan. "The concept system will lead [us] to grow films with both thickness and quality uniformity. In addition to this, we will aim to improve the quality of the film to achieve better devices than currently existing," he adds. "The success of this program will increase the efficiency of hybrid electric and electric vehicles."

In Phase I the team will demonstrate GaN power devices at the 100mm wafer scale, which can operate at >600V and >10A (with a Phase I reach goal of >20A and >600V). "At the end of the Phase I program we will define the product scale-up pathways for 100mm, 150mm and 200mm wafer production and packaged device production and we will firm-up customers for the developing processes and device technology," says SMI.

"Improving power efficiency and lowering costs will help bring greater numbers of more environmentally friendly vehicles to market sooner," believes SMI's president & CEO Dr Gary S. Tompa.

Panasonic completes transfer of semiconductor business to Winbond subsidiary Nuvoton

SemiconductorToday

Panasonic Corp of Osaka, Japan has completed the transfer of its semiconductor business – which is mainly operated by Panasonic Semiconductor Solutions Co Ltd (PSCS) – to Taiwan-based Nuvoton Technology Corp, a semiconductor company under the umbrella of Winbond Electronics Corp group, following the receipt of regulatory approvals.

Since the transfer was announced last November, Panasonic and Nuvoton have been collaboratively pursuing anti-trust clearance and other customary regulatory approvals from the competent authorities, with a target effective date of 1 June. However, the closing date was postponed due largely to the COVID-19-induced delay in clearance processes. The transaction has now been completed with all the necessary approvals obtained.

Restructuring of the semiconductor business, announced along with the transfer, has already been completed prior to the transaction.

Panasonic says that, going forward, it remains committed to focusing on its B-to-B business. In the industrial solutions business, it has identified 'Automotive CASE', 'Information Network Infrastructure' and 'Automation/Labor-savings' as three key areas of focus.

Following completion of the transfer, PSCS is being renamed Nuvoton Technology Corporation Japan.

The transaction includes all shares of PSCS, equipment and inventories of Panasonic Semiconductor (Suzhou) Co Ltd, and assets, liabilities and contracts related to predefined specific business of Panasonic Industrial Devices Semiconductor Asia.

Nuvoton not only acquires PSCS' R&D manpower, plus sensing, microcontroller and component technologies but also land in Nagaokakyo City, Kyoto Prefecture and four other locations. In the long term, Nuvoton is expected to enhance the technology capabilities, diversify the product line, enlarge its business scope as well as revenue growth, gain additional market shares and therefore increase its visibility in both Japan and the global market.

Through the acquisition, Nuvoton aims to capture the long-term growth trends in the industrial automation and automotive sectors, create a strategic position for its industrial growth, expand global sales channels and boost its influence in the global semiconductor industry.

IGaN establishing $73m GaN Epi Centre by mid-2021

SemiconductorToday

Following what it says are demonstrated successes in pilot lines of customers, Singapore-based IGSS GaN Pte Ltd (IGaN) – which develops and commercializes gallium nitride-on-silicon/silicon carbide (GaN-on-Si/SiC) technology – is setting up an Epi Centre as a combined commercial and global joint lab for 4-8" metal-organic chemical vapor deposition (MOCVD) of GaN.

With IGaN, its holding company IGSS Ventures (IGSSV) and select partners investing US$73m to expand GaN epi production capacity and mass production of 8" GaN fabrication technologies, the GaN Epi Centre should be operational by mid-2021.

The Epi Centre aims to capitalize on demand from applications such as power and renewable energy, 5G wireless communication and data centres, which require high switching frequencies, efficient energy management and the ability to perform under high power densities.

The Epi Centre brings together customers, universities, research institutes and tool vendors to collaborate on the future development of GaN technologies, as the quality of epiwafers is critical to GaN device manufacturing, notes Raj Kumar, IGaN's CEO and founder of IGSSV.

"What the industry lacks today is a concerted effort to enhance the overall GaN ecosystem to lower cost barriers so that technology adoption can happen at the pace the market is moving," says Kumar. "We projected more than nine years ago that, at 8" wafer dimensions, GaN-on-Si capabilities become a competitive and powerful solution to create the right balance between superior performances and cost competitiveness. A commercial centre and joint lab hosting several top specialist brands and leading vendors is a timely market response to creating strategic partnerships that fast-track innovation, growth and customer value," he adds. "Capitalizing on the recognizable Singapore brand, second-to-none IP standards, its known semiconductor infrastructure and IGaN's in-house expertise, I truly believe we can set standards, create benchmarks and lead the global movement in GaN adoption."

IGaN credits its roots in the proprietary GaN-on-Si growth recipe resulting from hundreds of millions of dollars of research by various research institutes and university groups in Singapore over 14 years. The firm itself subsequently spent six years refining the technology and going beyond its original licensing capabilities, securing multiple partnerships focused on strengthening its capacity to supply 8" GaN-on-Si epiwafers.

"Singapore's existing semiconductor environment, strengths and industry framework form an instrumental base to develop an ecosystem for niche technologies," reckons Raj. "Case in point for us is IGaN's collaboration with Nanyang Technological University. Established to develop a GaN manufacturing technology that can be adopted by existing silicon wafer fabs to produce high-volume and low-cost GaN products, such partnerships and our global customer base have paved the way for the eventual realization of our Epi Centre vision next year."

Transphorm releases 4kW analog-controlled bridgeless totem-pole GaN evaluation board

SemiconductorToday

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has made available its newest evaluation board. Designed for single-phase AC-to-DC power conversion up to 4kW, the TDTTP4000W065AN uses the bridgeless totem-pole power factor correction (PFC) topology with a traditional analog control. This pairing provides fast and easy access to the conversion efficiency made possible by Transphorm's latest SuperGaN FETs without the need for firmware development required when using digital signal controllers (DSCs).

The TDTTP4000W065AN offers power systems engineers an upgrade in efficiency over standard CCM boost PFC designs that use superjunction MOSFETs.

The evaluation kit is rated at 4kW highline (180-260V) and 2kW lowline (90-120V). The main advantages of the analog totem-pole solution are said to be as follows:

- Maintenance power — power required to support basic functionality such as powering up and supplying chipsets — is a relatively fixed amount in any system. Therefore, as an application's power level decreases, the maintenance power becomes a larger percentage of the system's overall power loss. Compared with a DSP solution, Transphorm's analog board requires lower maintenance power at the onset, increasing overall system efficiency.
- No DSP firmware programming is needed, suitable for standard CCM boost AC-to-DC PFC power stages.

For engineers requiring more design flexibility, Transphorm released the TDTTP4000W066C in April. This DSC-based 4kW AC-to-DC board also uses the bridgeless totem-pole PFC with the company's SuperGaN FETs. However, it integrates a dsPIC33CK DSC board from Microchip that has been pre-programmed and is backed by dedicated firmware support.

"Transphorm's analog evaluation board provides an unprecedented opportunity to access our highly efficient GaN in the easiest way possible," says Philip Zuk, VP of worldwide technical marketing & NA sales. "Much like the preceding digital board, it gives power system engineers a choice that the high-voltage device market was previously lacking," he adds. "Regardless of the end-application's targeted value proposition, we have the diverse toolset and the most robust GaN possible."

The TDTTP4000W065AN employs Transphorm's SuperGaN Gen IV TP65H035G4WS FETs in the board as the fast-switching leg with low-resistance silicon MOSFETs in the slow-switching leg. The resulting performance is similar to that of its digitally controlled counterpart, the TDTTP4000W066C.

The TP65H035G4WS is a 650V device with a 35mΩ on-resistance in a TO-247 through-hole package with an inherently high thermal dissipation ability. This feature eliminates the need to parallel devices for higher power output, a design method required by competitive surface-mount GaN solutions. Also, as with all other Transphorm

GaN devices, the SuperGaN FETs can be driven with a threshold voltage (Vth) of 4V and standard off-the-shelf gate driver operating from 0V to 12V.

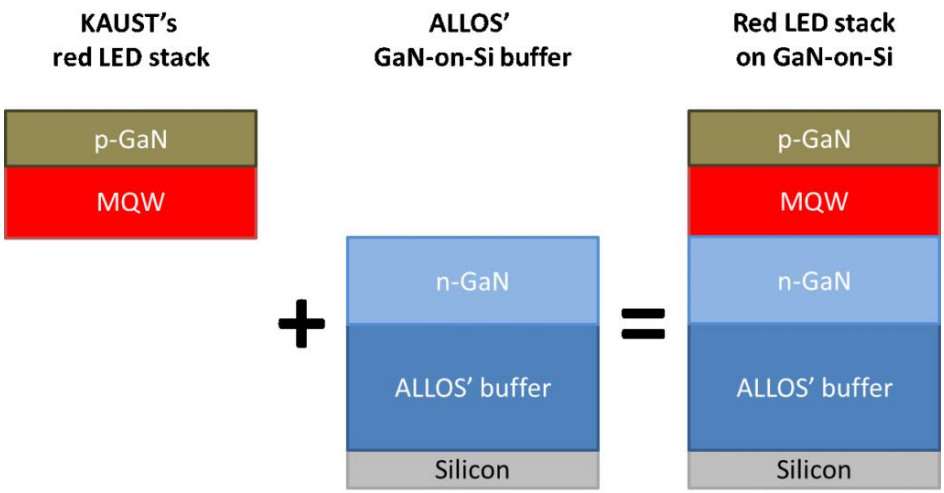
OPTOELECTRONICS

Allos and KAUST collaborate on Nitride red LEDs

i-micronews

Allos Semiconductors has engaged in a collaboration with Professor Ohkawa and his team at King Abdullah University of Science and Technology (KAUST) for realising high efficiency nitride-based red LEDs on large diameter silicon substrates.

In the collaboration the teams are addressing fundamental issues like the large lattice mismatch and the quantum-confined Stark effect (QCSE) which are preventing the adoption of red nitride-based LEDs for practical industry usage. In particular, for the emerging field of micro LED displays there is a strong demand to enable red LEDs on large diameter wafers in addition to the established blue and green color LEDs in the nitride system in order to reduce manufacturing complexity and cost.



In this context, Ohkawa and team have developed an InGaN-based red LED stack with low forward voltage of less than 2.5 V and high efficiency by using local strain compensation and a modified MOCVD reactor design. The researchers have already grown red LEDs on sapphire- and Ga2O3-substrates. For potentially higher performance red LEDs by using strain-engineering on wafer-level – in particular for large wafer diameters – the team is now extending its work to silicon substrates by collaborating with Allos.

This also enables huge advantages for mass production due to the scalability of up to 300 mm and thus processibility in silicon process lines. For micro LED displays – in particular the monolithically integrated micro displays for e.g. augmented reality (AR) application – this is another important enabler.

The unique high crystal quality of Allos' GaN-on-Si technology with threading dislocation density (TDD) of ~2 x 108 cm-2 is the pre-condition to achieve at least the same performance red LED as on sapphire. Furthermore, Allos' precise strain-engineering – which enables excellent emission uniformity for blue and green LED as well as flat bow wafer for 200 and 300 mm diameters – is used to optimise the growth conditions for red LED.

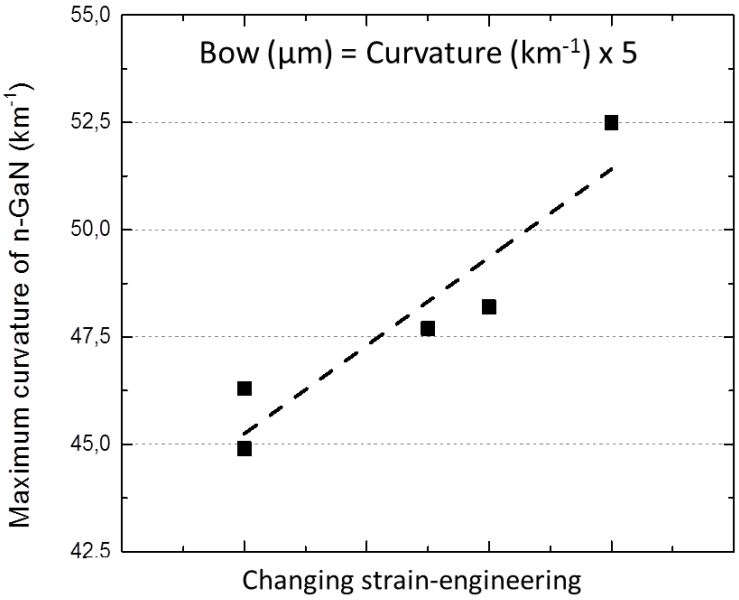


Figure 1: Allos' in-line process control enables +/- 5 µm bow range

Both teams combine their echnologies to handle strain and optimise crystal growth conditions for GaN-on-Si and red LEDs. To this end, the KAUST team will grow its red LED stack on top of Allos' GaN-on-Si-buffer layers, which will be fine-tuned during the collaboration to optimise the performance of KAUST's red LED stack. The picture at the top shows how Allos' established methods of integrating different LED stacks with its high crystal quality and strain-engineering buffer technology are used.

Dr. Nishikawa co-founder and CTO of Allos, commented: "From personal experience I am aware how challenging it is to realise high efficiency red LED. From Allos' side we can provide our established blue and green high quality GaN-on-Si micro LED epiwafers of up to 300 mm diameter. Furthermore we see the opportunity that our unique strengths in strain-engineering can contribute to improved red LED performance."

Commenting on the opportunity, Ohkawa said: "Our team has developed a high efficient red LED stack and continues to push the boundaries in this very challenging field. When talking to Allos, we of course were interested in the scalability up to 300 mm – but the capability to control the strain-engineering so precisely and in such a large process windows promises more progress for red LED performance."

'633-nm InGaN-based red LEDs grown on thick GaN underlying layers with reducing in-plane residual stress' by D. Iida et al; Applied Physics Letters 116, 162101 (2020)

'Demonstration of low forward voltage InGaN-based red LEDs on β-Ga2O3 substrates', by D. Iida et al; Applied Physics Express 13, 031001 (2020)

'Metalorganic vapor-phase epitaxial growth simulation to realise high-quality and high-In-content InGaN alloys' by K. Ohkawa et al; Journal of Crystal Growth 512, pp.69-73 (2019)

Improving MOCVD tunnel junctions for gallium nitride µ-light emitting diodes

SemiconductorToday

University of California Santa Barbara (UCSB) in the USA claims the lowest forward voltage for gallium nitride (GaN)-based micro-sized light-emitting diodes (µLEDs) with epitaxial tunnel junctions (TJs) grown by metal-organic chemical vapor deposition (MOCVD) [Panpan Li et al, Optics Express, vol28, p18707, 2020]. The voltage was only marginally higher than that achieved with indium-tin oxide (ITO) transparent conductive electrodes.

The UCSB team used a selective-area growth (SAG) technique to create a tunnel junction layer with perforations. The perforated holes in the TJ were used to enable escape of hydrogen during annealing aimed at activating the underlying p-GaN layer of the junction. Hydrogen passivates the magnesium acceptor levels of the p-GaN, inhibiting their ability capture electrons and create holes in the valence band. Although molecular beam epitaxy (MBE) can be used to avoid hydrogen in GaN TJ structures, MOCVD is preferred for manufacturing.

Industry is looking to use µLEDs in a range of applications: "wearable devices, large-area displays, augmented reality (AR) and virtual reality (VR), and high-speed visible light communications (VLC)," are mentioned in the paper. The potential advantages of µLEDs over liquid crystal displays (LCDs) or organic LEDs include ultra-high resolution and lower power consumption.

Hoped for benefits of using TJ structures over conventional p-electrodes include simpler fabrication, improved current spreading, and lower photon absorption. New device architectures could be enabled with direct integration of blue/green/red µLEDs in cascade structures connected with TJs.

The UCSB researchers used standard industry blue indium gallium nitride (InGaN) LED epitaxial wafers grown on patterned sapphire substrate (PSS) with a target emission wavelength around 440nm. Silicon-doped n+-/n-GaN layers were added selectively to provide the perforated tunnel junction. (Figure 1).

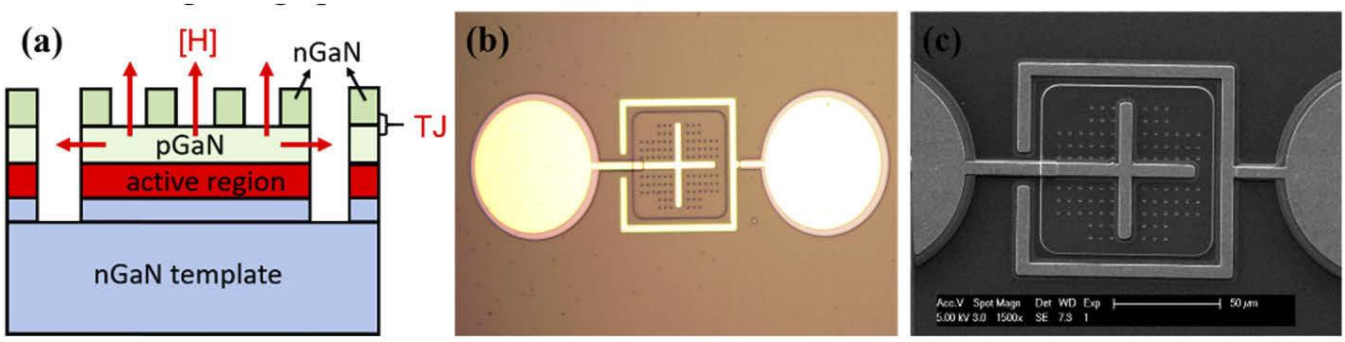


Figure 1: (a) Schematic structure of GaN TJ µLEDs through SAG; (b) microscope and (c) scanning electron microscope images of fabricated 80µmx80µm device.

In fact, the MOCVD process was preceded by growth and patterning of silicon dioxide into pillars on the p-GaN surface, which provided sacrificial structures for the hole perforations. The n+- and n-GaN layers were then grown at 1000°C with target silicon doping concentrations of 1.5x1020/cm3 and 3x1018/cm3, respectively.

The LED fabrication consisted of mesa etch with silicon tetrafluoride reactive ions, removal of the silicon dioxide pillars using buffered hydrofluoric acid, 700°C annealing in nitrogen to drive out hydrogen from the p-GaN, the formation of an omni-directional reflector from 7-pairs of silicon dioxide and tantalum pentoxide layers, and the deposition of aluminium/nickel/gold for the contacts and metal pads.

Testing was carried out with diced devices mounted on silver headers and encapsulated in silicone. It was found that the emitted radiation was much more uniform across the device, compared with similar reference MOCVD TJ-µLEDs without the perforations of the n+-/n-GaN layers. In fact, the emissions were greater at the edges of the reference devices, most likely due to the sidewall out-diffusion of hydrogen during annealing.

The electrical performance of the TJ-µLEDs with perforations was also superior, giving much tighter and lower forward voltage for a given injection current density. By contrast, the reference devices showed increased forward voltage for larger areas, indicating the reduced effectiveness of sidewall out-diffusion of hydrogen during annealing in these cases.

The forward voltage for 20A/cm2 injection decreased approximately linearly with area in the reference devices: 3.7V at 100µm2 and 4.6V at 10000µm2. By contrast, the performance of similarly-sized perforated TJ-µLEDs at 20A/cm2 varied only between 3.24V and 3.31V.

The team points out that the forward voltages in the perforated TJ-µLEDs were only 0.2-0.3V higher than in conventional µLEDs with ITO electrodes on the p-GaN. The researchers comment: "To the best of our knowledge, these forward voltages are the lowest for the GaN LEDs with TJs grown by MOCVD, and comparable to the lowest for GaN LEDs with TJs grown by MBE."

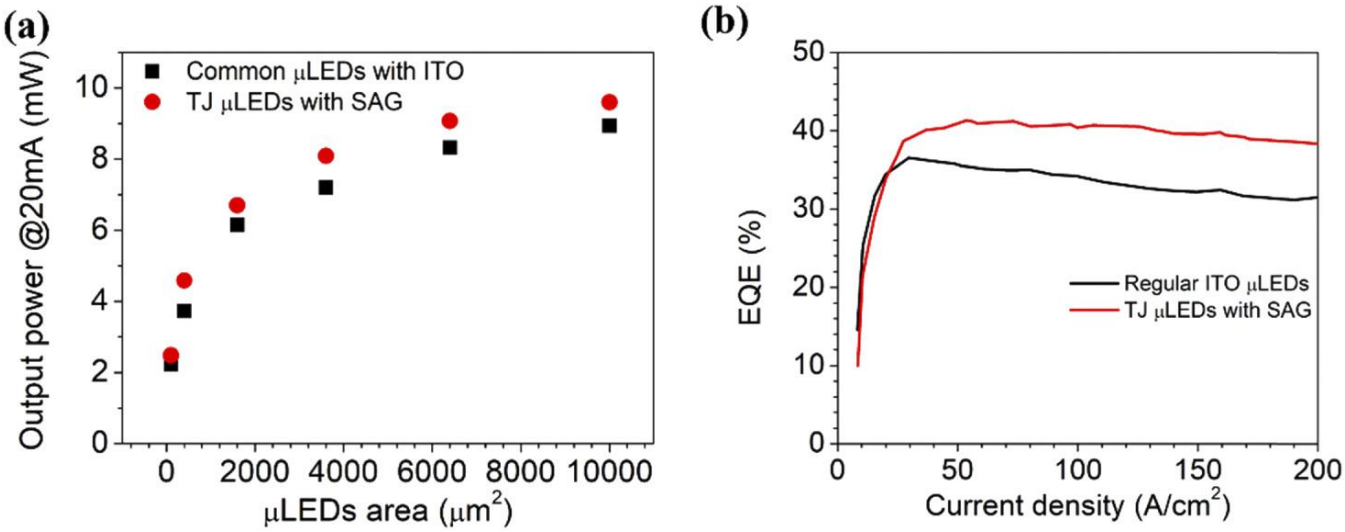


Figure 2: (a) Output power at 20mA versus various sizes in TJ µLEDs with SAG and ITO µLEDs; (b) EQE versus current density for 40µmx40µm devices.

In fact, the perforated TJ-µLEDs showed improved performance over ITO-based devices in terms of light output power at higher injection currents (Figure 2). At 20mA, the increase in output power was of the order of 10% at all device sizes.

The external quantum efficiency (EQE) was 40% at 100A/cm2 injection for a 40µmx40µm TJ-µLED, compared with 35% for a similar-sized reference device. The researchers credit the improved EQE on improved light extraction of the perforated TJ layer. Further positive factors could be "improved current spreading and reduced light absorption of the TJs", according to the team.

IES and IUVA pursue ANSI standards for characterizing UV-C sources

LEDs Magazine

The Illuminating Engineering Society (IES) and the International Ultraviolet Association (IUVA) have announced a collaboration that will yield standardization of lighting measurement (LM) methodologies for both LED and conventional-lamp sources that are specifically targeted at disinfection. The initiative will focus on UV-C-band (100–280-nm) LEDs and lamps that right now are surging in interest relative to the ability of that UV-C energy to deactivate the coronavirus. The separate LED and lamp projects will yield ANSI (American National Standards Institute) standards by the end of this year with the partners planning for more supporting standards in 2021 and beyond.

The ability of UV-C radiation to deactivate viruses and other pathogens has been studied sporadically for more than a century. We hosted a webcast on the topic recently, and the speaker Bob Karlicek, director of the Center for Lighting Enabled Systems & Applications (LESA) at Rensselaer Polytechnic Institute, covered some of the history and noted that interest wanes somewhat when pandemics pass. We have written quite a lot about UV-C disinfection of water and air using LEDs and there are products in the market even at the consumer kitchen-faucet level.

Moreover, both UV-C in immediate disinfection and UV-A, or short-wavelength 405-nm violet light, in continuous disinfection applications have been widely discussed as tools than can battle healthcare associated infections (HAIs). Still, it's the coronavirus pandemic that has raised the UV-C interest level to all-time highs.

The initial LM standards being pursued will guide manufacturers in characterizing and publishing specifications on UV-C sources and will allow product developers to more easily evaluate competing sources. "The Illuminating Engineering Society is dedicated to developing standards and providing educational content on UV-C to help reduce the number of healthcare-associated infections and the transmission of pathogens, such as the SARS-CoV-2 virus," said Brian Liebel, IES director of standards and research. Working with the International Ultraviolet Association, we feel confident that our organizations can effectively deliver much-needed measurement and testing standards to evaluate new products as they come to market."

As mentioned earlier, one of the new standards will focus on UV-C LEDs. Think of it as analogous to the LM-80 standard for characterizing visible-light LEDs. The second standard will focus on characterization of low-pressure mercury and xenon lamps.

The timeframe for development of the standards is tight, but the need for speed is clearly evident. "The standardization work is being undertaken by a task group formed within the IES Testing Procedures Committee," said Alex Baker, manager of government affairs and public policy at the IES. "The task group's drafts will be balloted within the committee. Following any necessary revisions and the ANSI public comment period, IES hopes to publish the first two ANSI/IES/IUVA standards by year's end. Additional UV measurement standards are envisioned in 2021."

The IES found a natural collaboration partner in the IUVA. "IUVA, through its Healthcare/UV Working Group, has been working on developing industry consensus-based standards for UV disinfection since 2018," said Troy Cowan, the IUVA working group's coordinator. "Establishing this partnership with IES is a key component of making that happen. We needed representation of the entire lighting sector to build industry-consensus, and IES delivers that. Thanks to IES' and IUVA's collaborative efforts, these new ANSI standards will eliminate much of the ambiguity and uncertainty in UV output measurement. This will improve accuracy and quality, and give the healthcare industry a credible basis for assessing output of UV disinfection devices for the first time."

Stabilized InGaN Red Micro LEDs Structure Presented by KAUST

LEDInside

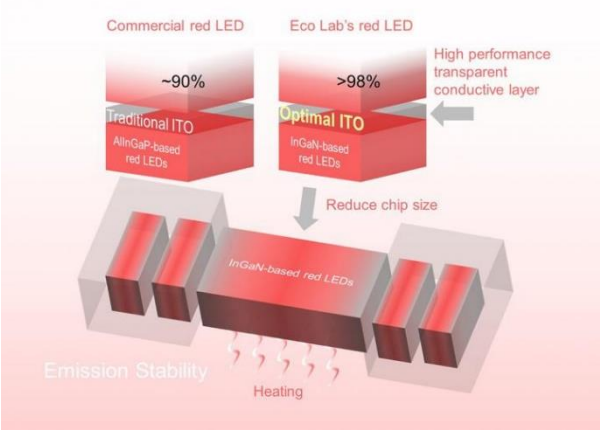
Researchers of King Abdullah University of Science and Technology (KAUST) have been working on improve efficiency of red Micro LEDs and they recently announced the achievement of manufacturing stable red Micro LED based on InGaN.

A major challenge facing the development of Micro LEDs is to integrate red, green and blue light into a single LED chip. Current RGB LEDs are made by combining two kinds of materials with InGaP red LEDs and InGaN blue and green LEDs. "Creating RGB displays requires the mass transfer of the separate blue, green and red LEDs together," said KAUST researcher Zhe Zhuang. An easier solution would be to create different-colored LEDs all on a single semiconductor chip.

Since InGaP semiconductors are unable to emit blue or green light, the only solution to making monolithic RGB Micro LEDs is to use InGaN. This material has the potential to shift its emission from blue to green, yellow and red by introducing more indium into the mix. And InGaN red LEDs have been predicted to have better performance than the current InGaP ones.

Zhuang, Daisuke Iida, Kazuhiro Ohkawa and their colleagues have succeeded in growing high-quality indium-rich InGaN to fabricate red LEDs using the nanofabrication facilities at the KAUST Core Labs.

The team also developed excellent transparent electrical contacts using a thin film of indium-tin-oxide (ITO)1, which allows for a current to pass through their InGaN-based amber and red LEDs. "We have optimized the fabrication of the ITO film to realize low electrical resistance and high transmittance." The team demonstrated that these characteristics significantly improved the performance of InGaN red LEDs. They also carefully studied InGaN red LEDs of different sizes and at various temperatures. Changes in temperature affect the output light power and cause different color impressions, making them crucial for practical device performance.



"A critical disadvantage of InGaP red LEDs is that they are not stable when operated at high temperatures," explained Zhuang. "Therefore, we created InGaN red LEDs of different designs to realize very stable red-light InGaN sources at high temperatures." They have developed an InGaN red LED structure where the output power is more stable than that of InGaP red LEDs2. Also, its emission color shift at high temperatures was less than half of that of those made with InGaP.

Toyoda Gosei develops DUV LED light module for sterilization

SemiconductorToday

Taking advantage of technology accumulated over 30 years in the development and production of blue light-emitting diodes, Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has developed a deep-ultraviolet (DUV) LED light module for use in the sterilization of water, air and surfaces.

Deep UV LEDs emit short-wavelength ultraviolet light that can destroy the genetic materials of viruses and bacteria. They are promising as a new sterilizing light source that can be used in place of mercury lamps, for which there is environmental concern.

With the aim of spreading applications of this technology, Toyoda Gosei has been developing products in modules or units with waterproof or heat-dissipation features. In a joint experiment conducted with Japan's Biomedical Science Association (a certified non-profit organization consisting of specialists from national research institutes and universities in medicine, pharmaceutics, veterinary medicine, agriculture etc) using human coronavirus 229E (HCoV-229E), which has genetic materials similar to those of the virus that causes Covid-19 (SARS-CoV2), these modules were demonstrated to be highly effective in sterilization.

Toyoda Gosei is cooperating with the Toyota Group and other companies to develop applications for water, air and surface sterilization that contribute to safer and healthier living.

The rise of UV-C LEDs

LEDs Magazine

The 1980s inventions enabling the synthesis of high-quality gallium-nitride (GaN) on a common substrate material (sapphire) provided an unprecedented platform for the development of visible-spectrum LEDs: a fully optically transparent and robust compound semiconductor material system specifically suited for the efficient generation of blue light, the primary light source necessary to enable full color solid-state lighting (SSL). This Nobel Prize winning work sparked decades of global investment and massive research and development that would completely revolutionize lighting and displays.

Even in the early days of developing this material system, it was understood that aluminum/gallium (Al/Ga) substitution could generate AlGaN materials, providing a platform for wider-bandgap (shorter-wavelength) emitters. In particular, the importance of ultraviolet germicidal irradiation (UVGI) for surface, air, water, and food disinfection was already well known at the time (primarily using mercury, Hg, lamps) and not lost on LED researchers who immediately recognized the potential benefits of a compact, high-intensity, solid-state, Hg-free source of radiation. Yet the performance of these AlGaN-based LEDs, emitting in the ultraviolet C-band (UV-C), has lagged dramatically behind that of their blue brethren in terms of efficiency and cost. Why? Many assume this is due to low market pull and associated low investment (compared to the situation for displays and illumination, for example), but a more fundamental aspect is technical: GaN, the backbone semiconductor for SSL, is not transparent to UV-C radiation. This aspect is devastating to the performance of any optoelectronic device, and solutions to this problem have been incredibly elusive, until now.

Photon extraction efficiency cannot be ignored

Photons emitted within an optically dense material (such as GaN or AlGaN) must exit that material at fairly low angles of incidence in order to match necessary electromagnetic boundary conditions and radiate outside. For example, blue light in GaN experiences a refractive index of ~2.4, resulting in an escape probability into air of approximately 5%, which means light may bounce around up to 20 times inside a GaN-based LED chip before it finally escapes. If such a device included no optical loss mechanisms, this wouldn't matter, but that's not the case. Even a 10% loss per pass can be catastrophic to overall performance, and the situation is similar for UV-C radiation in AlGaN when compared to blue light in GaN.

Now, imagine embedding an opaque (~100% absorbing) layer inside such a chip. In that case, generated photons have just one chance to escape, or they are lost, putting a ceiling on photon extraction efficiency at ~5%. Even using an encapsulating medium (to increase the ambient refractive index) will, at most, double the escape probability to ~10%. This is the situation for all UV-C LED structures that include GaN layers: The photon extraction

efficiency is limited to a paltry ~5–10%, putting a very low ceiling on the entitled power-conversion efficiency (PCE) of the LED.

UV-C-transparent p-type layers

Why does one use GaN in UV-C LEDs? The reason is the fundamental need to have good p-type behavior for a functioning diode. For GaN, the ionization energy for magnesium (Mg, the acceptor impurity) is quite high, yet it is manageable and allows producing approximately one positive charge carrier (hole) for every ten or so Mg impurity atoms. For AlGaN, the situation is worse, and becomes dramatically so by the point at which the Al/Ga ratio reaches what is necessary for UV-C transparency, generally resulting in highly resistive p-type material that does not easily pass electrical current and to which it is difficult to make ohmic contact, resulting in unworkably high forward voltages. To avoid this problem, the UV-C LED industry has for years tried to make do with GaN:Mg p-contact layers, in spite of the very high price to be paid on photon extraction efficiency. The result has been devices with reasonable forward voltages but with paltry single-digit PCEs, relegating UV-C LEDs to niche applications, as for blue LEDs in the 1990s.

Thankfully, recent breakthroughs have achieved UV-C-transparent epitaxial stacks, propelling the PCE of UV-C LEDs beyond 10% for the first time. Last February, at SPIE Photonics West in San Francisco, RIKEN/Panasonic announced they were able to successfully incorporate a p-type AlGaN:Mg stack and, while the resistivity of the layers resulted in an admittedly high forward voltage (~9V versus a bandgap voltage of 4.5V at 275 nm), they achieved an external quantum efficiency above 20% (a lower limit to the extraction efficiency, and a testament to the improvement made possible with the fully transparent epitaxial stack).

Tunnel junctions are another active area of research, in which p-type layers can be “replaced” by n-type layers and offer improved transparency. Meanwhile, Bolb, Inc., from Livermore, CA, recently developed a field-assisted tunneling contact, based on AlN and exploiting built-in polarization fields of the Wurtzite AlGaN crystal structure, to form an all-transparent UV-C LED with low forward voltage. Following up from earlier work, the company’s best reported devices now exhibit a 6.0V forward voltage and a PCE of 10.6% at 271 nm, and it is shipping UV-C LED products today, including high-power modules and arrays. Perhaps even more remarkable, Bolb’s LED design has yet to include many of the sophisticated photon extraction techniques that it is entitled to, such as those used in blue LEDs.

Roadmap for UV-C LEDs

Indeed, these breakthroughs in UV-C-transparent epitaxial stacks entitle, for the first time, the UV-C LED sector to the technology improvement roadmap that performed so well for blue LEDs and transformed the lighting industry. The best reported GaN-based visible-spectrum LEDs exhibit PCEs above 80%. These devices have estimated photon extraction efficiencies approaching 90%, compared to 5–10% for conventional UV-C LEDs using absorbing p-GaN contact layers (which cannot make use of the “tricks” that worked for blue LEDs). Transparent UV-C LED structures, as demonstrated by Bolb, Inc. and RIKEN/Panasonic, can absolutely make use of such tricks, such as reflective p-contact metallization, patterned substrates, textured surfaces, microcavity effects, and volumetric shaping. The wide range of techniques for improving blue-LED photon extraction efficiency (many based on patents that have — or are nearly — expired) provide a blueprint for how they can be exploited and employed for UV-C-transparent LED structures, potentially leading to a dramatic acceleration in improved performance (and reduced cost/W) in the coming decade, ushering in game-changing applications for health and safety, much as GaN-based blue LEDs did for mobile, displays, and illumination.

Market analysts, even prior to COVID-19, predicted a UV LED market exceeding $1 billion in a few years, to be compared with the lighting LED market, which was $5.8 billion in 2019, after growing for many years now. In addition, large LED players, including Nichia and San’an, are notably investing in the UV-C LED market, no doubt

in expectation of healthier profit margins compared to today's general lighting LEDs. This sets up an interesting dynamic, since these large companies have capital and established sales channels, but do not necessarily have access to the technology or intellectual property that pure-play UV-C LED startup companies have, similar to the situation that red LED companies experienced when GaN-based blue LEDs came on the scene in 1990s. However, there remain peculiar challenges for UV-C LEDs compared to their blue LED counterparts.

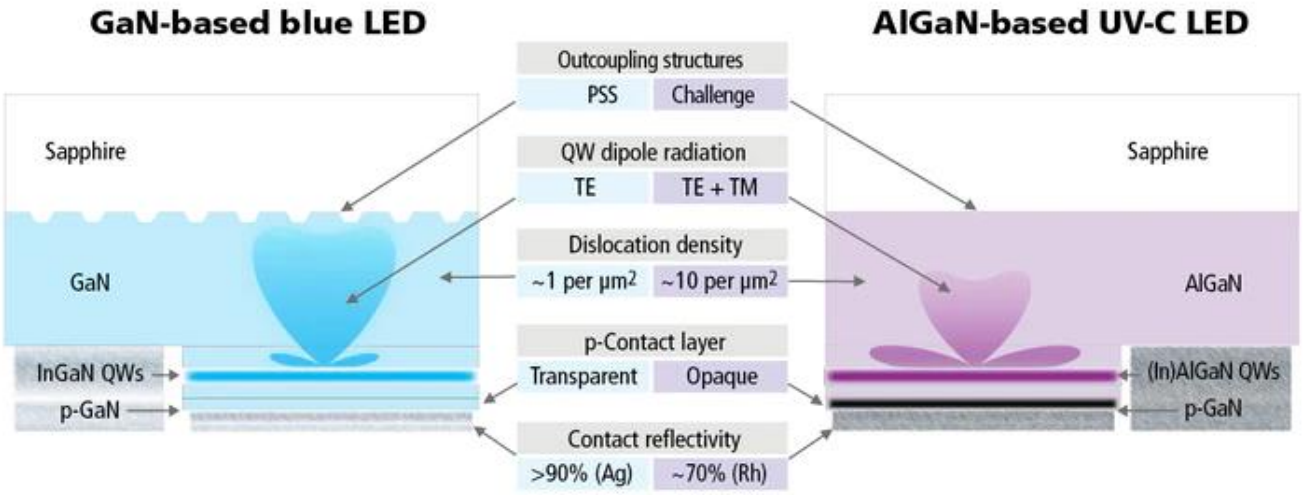


Figure 1 illustrates some of these comparative challenges, for the case of blue and UV-C LED structures grown on sapphire and incorporated into a flip-chip design (suitable for high-power operation). On the epitaxial side, low adatom mobility means AlGaN deposition tends to be more "sticky" than GaN deposition, thwarting lateral growth and making dislocation reduction more challenging. Indeed, most UV-C LED structures have dislocation densities ~10× higher than blue LEDs, which reduces internal quantum efficiency. This same sticky behavior also makes growth on patterned sapphire substrates (PSS) challenging, meaning that UV-C LEDs cannot as easily make use of enhanced extraction efficiency using this technique common for blue LEDs.

In addition to the aforementioned p-contact layer challenge (GaN:Mg is transparent in the blue, but opaque in the UV-C), there is also the issue of the p-side ohmic contact reflectivity. For blue LEDs, silver (Ag) is both a good ohmic contact and very high optical-quality mirror. Unfortunately, due to plasmon resonance, Ag does not maintain those reflective properties in the UV-C (its reflectivity drops below 20%); therefore, alternative metallizations are required. One such metallization working reasonably well today for UV-C LEDs is rhodium (Rh), which makes a decent ohmic contact to AlGaN but has a reflectivity in the UV-C of ~70%, compared to ~90% for Ag reflectivity in the blue. Finally, blue LEDs benefit from InGaN/GaN quantum wells (QWs), which exhibit only transverse electric (TE) dipole radiation. This means that more light is radiated upwards, out of the primary surface of the LED chip, than sideways, which further helps extraction efficiency. For AlGaN/AlGaN QW structures, as Al/Ga ratio is increased (e.g., to achieve shorter wavelength emission), transverse magnetic (TM) dipole radiation emerges, increasing the relative amount of lateral radiation, which can be trapped within the epitaxial layers and is more susceptible to loss within the LED chip.
Read more

Signify CEO reports strong demand for UV-C but refrains from quantifying sales

LEDs Magazine

Signify's CEO has reported "strong demand" in the company's all-out ramp up of UV-C products aimed at killing the coronavirus, although it is too early to forecast sales, which in the second quarter did not prevent a 22.5% decline in overall corporate revenue amid the pandemic. Cost cutting enabled a profit.

Boss Eric Rondolat signaled the UV-C push this past April, when the company began adding capacity and developing disinfection systems using UV-C, a form of ultraviolet radiation emitted by the company's conventional mercury-vapor technology.Sales of conventional (non-LED) products tumbled 25.2% on a comparable basis in the second quarter ending June 30, but UV-C and conventional horticultural lighting products mitigated the fall.

"The division showed a solid performance partly as a result of strong demand for UV-C and horticultural lighting," Rondolat said on a conference call with analysts discussing second quarter results last Friday. "We believe that the decline in sales is lower than the overall market decline, resulting in continued market share gains."

On a non-comparable basis, sales for the conventional group slipped by 26.5% to €211 million ($247.38M). Signify acquired Cooper Lighting Solutions in the US and China's Zhejiang Klite Lighting Holdings Co., Ltd. since the second quarter of 2019, so sales of those two entities are not included in "comparable." Income for the conventional business was down 11% at €45M ($52.76M).

Rondolat told analysts that Signify's UV-C efforts "will continue at a very high pace until the end of the year." The company is applying 35-year old mercury tubes and is developing luminaires, chambers, robots, and other products to help deliver virus-killing UV-C in different environments. For example, ceiling-mounted fixtures can point UV-C upwards at circulating air in schools and offices; clothing retailers and supermarkets can put garments and carts in UV-C tunnels and chambers; and robots on wheels can shine UV-C down either side of aisles while stores are closed.

UV-C is hazardous to skin and eyes and thus cannot be used directly when people are present. Boston University has determined that a Signify UV-C light source would almost always deactivate the coronavirus that causes COVID-19 if dosed at the right level.

Rondolat outlined a broad market for UV-C products including schools, retails, offices, manufacturing plants, warehouses, and many others. But he refrained from quantifying the revenue potential.

"We're developing the applications at this point in time," he said when one analyst pressed him for details. "We are sizing the market as we speak because it's evolving on a daily basis. It's a moving target at this point in time."

Most people would agree that "moving target" probably also describes the general economy as the pandemic continues. Signify weathered the last quarter by using €43M ($50.42M) in cost cutting to help stimulate a 61.5% spike in corporate net income to €81M ($94.97M), even as sales tumbled 22.5% on a comparable basis. On a non-comparable basis, including Cooper and Klite, sales slipped only 0.6%, to €1.47 billion ($1.72B).

The savings came mostly from a three-month initiative in which staff volunteered to take a 20% reduction in work and pay. Some of it came from government support in countries including the US, Canada, France, Germany, and Singapore.

The employee slowdown scheme has ended, so Signify will not be able to duplicate its one-time effect in the third quarter.

"We're not pursuing that initiative in Q3," Rondolat said. "It was only something that we really wanted to do in Q2."

Rondolat also noted that the market for LED goods and services has been characterized by less price pressure than in normal times, which helped support profit margins. He anticipated that the situation "will continue for a while," although he expects competitive pricing pressures to eventually return.

Like many companies amid the health crisis, Signify withdrew specific financial guidance earlier this year, and is not yet issuing a new forecast.

Rondolat told one analyst that he expects a "sequential improvement in both Q3 and Q4," but cautioned that "the situation is extremely volatile and a level of uncertainty remains."

The world's largest lighting company also reported that free cash flow increased to €158M ($185.26M), up from €121M ($141.87M) a year earlier. That stands out in contrast to industry number-two Osram, which has been eating through cash. Osram, which has been acquired by Austrian sensor maker ams, is scheduled to report quarterly results tomorrow.

In other second-quarter developments, Signify reported that its integration of Cooper is ahead of schedule, and that Signify expects to achieve carbon neutrality by the end of this year.

Compound Photonics unveils IntelliPix all-in-one micro-display technology platform

SemiconductorToday

Compound Photonics US Corporation (CP, also known as CP Display) of Vancouver, WA, USA, a provider of compact high-resolution microdisplay technologies for augmented reality (AR) and mixed reality (MR) applications, has unveiled its IntelliPix Microdisplay Technology Platform for micro-LEDs featuring multiple video pipeline and system integration innovations addressing power optimization, latency and bandwidth use (all key barriers to the true AR experience needed for widespread consumer adoption).

CP claims that it is now the only player in the market to introduce a micro-LED-focused, constant-current (iDrive) technology platform with a MIPI interface that enables pixel-to-pixel uniformity in the emerging sub-5µm-pixel micro-LED display space for AR/MR near-eye applications.

"At its core, CP departs from the traditional full-bandwidth, raster-based pipeline dating back to the birth of NTSC toward a data flow optimized for real-time AR applications," says co-CEO & chief technology officer Edmund Passon. Given that AR imagery, in general, does not fill the entire field of view, only transmitting active-pixel data results in the ability to drastically increase performance for those active pixels while reducing overall display sub-system power. "We have again revolutionized the drive architecture to manage images intelligently at the pixel level," he adds. "IntelliPix also integrates its real-time video pipeline and programmable drive scheme with adjustable constant-current iDrive or voltage-driven (vDrive) options into a single-chip solution. The overall technology advancement in IntelliPix enables up to 100x faster modulation while consuming 4x to 12x less system

power across the video pipeline versus CP's previous platforms while unlocking the real potential for micro-LED and future phase-based holographic systems."

Legacy video pipelines transport full frames/bandwidth to the display subsystem where every transition moves electrons, reducing battery life. OnDemand Pixels (the key component of IntelliPix) optimizes the drive of pixels based on both content and use environment. This proprietary feature provides significant power saving as the system modulates video parameters across the field of view, dependent on user activity. This active-pixel-based approach also enables the bursts of increased performance by making more bandwidth and higher refresh rates available for demanding content regions. Additionally, when combined with eye tracking, OnDemand Pixels opens the door to foveated rendering with attendant benefits for optimized processing on the SoC/AP.

IntelliPix's 100x modulation speed increase takes full advantage of the faster response time of micro-LEDs, which can be applied to higher bit depth, refresh rates, or the ability to add multiple focal planes. For phase-based holographic systems, the 100x increase enables complex waveforms providing near-zero ripple. The platform also retains all key features of CP's current NOVA display drive architecture to achieve low latency and on-the-fly frame-by-frame control to avoid image lag.

The IntelliPix single-chip design eliminates traditional distinctions between display pixel drive (backplane) and display driver IC (DDIC) functions to reduce the overall physical volume and power consumption. Combined with CP's integration capabilities for micro-LED array bonding, device packaging & testing and optical engine designs, the IntelliPix platform opens up new possibilities for meeting or exceeding AR display size reduction demands.

Available for demo in early 2021, the IntelliPix Microdisplay Technology Platform is customizable for resolutions up to 2048 x 2048 and beyond at pixel pitches from ~1.5µm and upwards. CP is presently engaged with micro-LED technology partners and eco-system providers for initial early integration.

During Display Week 2020 (3-4 August), CP's head of business & corporate development Mike Lee is presenting IntelliPix at the SID Business Conference and discussing with the display community about how the technology platform presents the opportunities for the industry to accelerate mainstream AR adoption.

Nitride files amended complaint in US against Digi-Key

SemiconductorToday

Japan's Nitride Semiconductors Co Ltd (which was spun off from Tokushima University in 2000 and claims to have developed the first highly efficient ultraviolet light-emitting diode) says that it has filed an amended complaint against global electrical components distributor Digi-Key Corp in the US District Court for the District of Minnesota, alleging that UV LED products supplied by various LED companies – such as Lite-On Semiconductor, Luminus Devices, and Vishay Intertechnology – are infringing its UV LED patent.

Nitride first filed a patent infringement suit against Digi-Key in the US District Court for the District of Minnesota in September 2017.

With professor Shiro Sakai at Tokushima University, Nitride Semiconductors developed highly efficient UV-LEDs as early as 2000. It has continued to manufacture and sell UV-LEDs, and says that it has invested in R&D to develop and enhance its UV-LED technology.

To protect its UV LED patented technology, Nitride initiated its patent enforcement campaign starting in 2017. Subsequently, earlier this year a judgment was issued by the US District Court for the Northern District of

California against RayVio Corp for infringing Nitride's UV LED patent, as well as validating patent. The US Patent & Trademark Office has also confirmed the validity of the key claims of Nitride's patent in its final judgment on an Inter Parte Review case filed by RayVio.

Nitride says that, since it considers its intellectual property rights to be vitally important company assets, it will take any action necessary to enforce its patent against infringers in any country and uphold its patents and other intellectual property rights.

Trading Factories as Strategies for Display Makers to Focus on New Technology

LEDInside

Accelerating the development of new display technologies is the goal for worldwide display manufacturers and some of them have decided to sell or buy new facilities as a move to approach their target.

Samsung Display has sold its LCD factory in China to Chinese display maker CSOT, a company under TCL group, to further cut down its LCD capacity, which goes in line with Samsung's plan to quit LCD business. By ending its LCD panel production, Samsung aims to expand its development in QD displays and OLED displays. The Korean giant has also reportedly to begin manufacturing Mini LED backlight TVs in 2021.

As Samsung is selling the LCD factory in China for US$ 1 billion, the company will have liquidity to increase investment for its developing technologies covering QDs, OLED and Mini LED.

Meanwhile, Sharp is taking over a LCD plant from JDI in Japan. Many believe that instead of increasing its capacity of LCD display for iPhone, Sharp is buying the factory to strengthen its Micro LED development. The company may set up research lines for Micro LED display in the plant.

Seoul Viosys Sees UVC LED Business Bloom in 3Q20

LEDInside

After years of investment on UV LED R&D, Seoul Viosys has become one of the leading UV LED companies in the world. The company covers products with full range of wavelengths and its UVA LED and UVC LED products are taking leading positions in the industry.

As COVID-19 epidemic keep sweeping the world, awareness of public health and health management has increased significantly. Many consumers and branding vendors have also begun to pay much attention to UVC LED-related products with disinfecting functions. According to "TrendForce 2020 Deep UV LED Application Market and Branding Strategies," Seoul Viosys UV LED revenue ranked first in the world in 2019. LEDinside had the honor to invite Ridge Lin, Sales Director in Greater China of Seoul Viosys, to share the latest UVC LED development.

(Ridge Lin, Sales Director in Greater China of Seoul Viosys)

In response to the COVID-19 epidemic, the UV lamps are in high demand. UV mercury lamps are mainly used for sterilization and disinfection in large spaces, such as schools and hospitals. However, UVC LEDs that deliver only single wavelength of 275nm cause less safety concerns regarding the irradiation. In addition, with small and compact size, UVC LED can fully meet the market demands for small spaces and surface disinfection for daily objects like door handles, shoe cabinets, shoe soles, and more.

Seeing the demands in the market, Seoul Viosys has been committed to improve the efficiency of UVC LED in 2019 and 2020. The optical power of 275nm UVC LED has reached 20mW without changing the current output (100mA) and has been mass produced and shipped targeting the air-conditioning sterilization application market. In addition, the 50mW multi-chips UVC LED products are at the phase of stable shipment to fulfill the requirements of different customers.

Observing the UVC LED market demands in 2020, Lin indicated that Seoul Viosys will focus on three fields:

1. UVC LED manufacturers have been committed to developing home appliance brands for many years. As UVC LED technology gets mature and branding acceptance improves, UVC LED will eventually see the growth breaking period in 2020.

2. As the white light market competition is very fierce, UVC LED has created another new market of compact lighting products for lighting players.

3. Seoul Viosys has also successfully broken into manufacturers in 2020 that have never involved in the UV LED field in the past, and it is believed that there will be a major breakthrough in 3Q20.

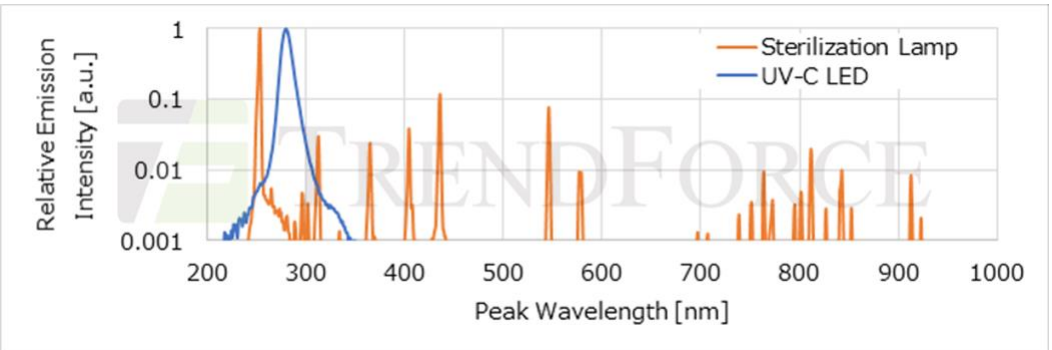
Eventually, Seoul Viosys has demonstrated 2L/Min UV-C LED purifier in the market, and the sterilization effect can achieve 99.99%.

Nichia UVC LED Optical Power Increased to 70mW, Targeting to Replace Mercury Lamp in the Disinfection Market

LEDInside

Nichia, the Japan-based leading LED manufacturer, has been dedicated to innovation of LED technology for a wide range of applications. LEDinside had an opportunity to interview Yoshihiko Naito, Deputy General Manager of Nichia's Hong Kong subsidiary to learn more about the upgraded technology progress of Nichia in UVC LED.

Naito indicated that the wavelength of mercury lamp is concentrated at 254nm, but it will only produce up to 70% UVC. However, UVC LED is designed for a single wavelength emission, which produces 100% UVC without wasting power intensity.

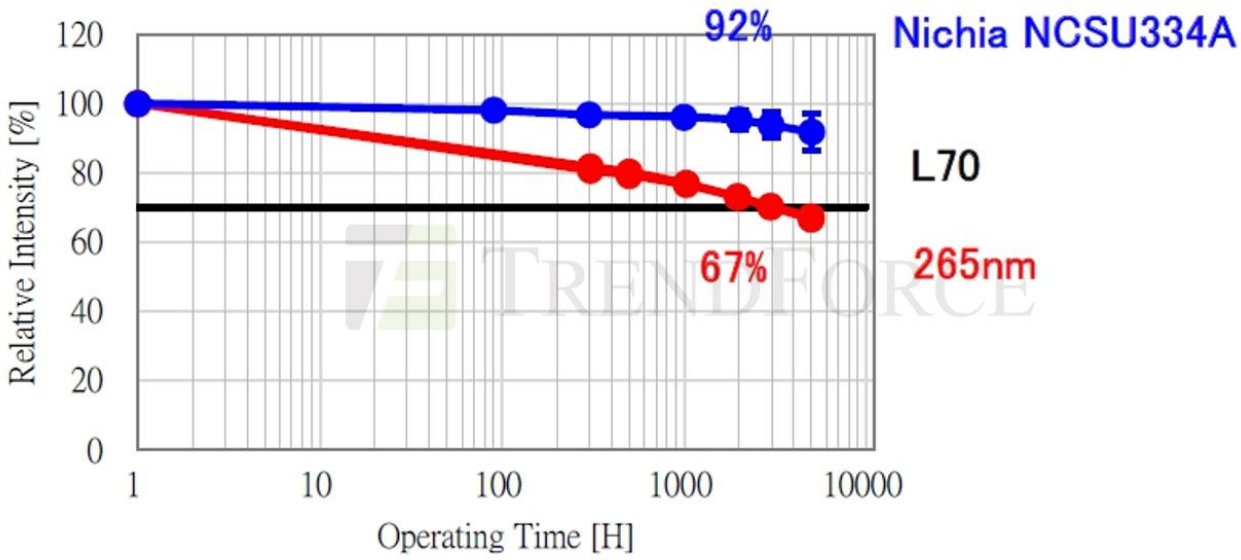


Nichia has successfully proposed 280nm 55mW UVC LED in the market in 2019. Regarding product development, if the wavelength of a LED is less 280nm, the efficiency sufficiently would drop by 50%. The shorter the wavelength of UVC LED is, the more difficult it is to provide high power products. Therefore, Nichia focuses on 280nm UVC LED development and enhances the optical power.

Part No.	Nichia NCSU334A&B	
Peak Wavelength	280nm	265nm
I_F	350mA	350mA
Radiant Flux	55mW -> 70mW	40mW
V_F	5.2V -> 5.5V	6.8V
Efficacy (W/W)	3.0% -> 3.6%	1.7%
Reliability	Advantage	

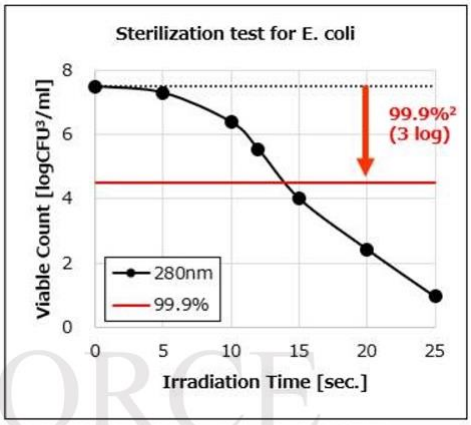
The value in right is based on a specification and adjusted to be the same conditions.

Nichia's NVSU334A, a 280nm UVC LED, can maintain 92% of efficiency after using 5,000 hours while the 265nm decreases to 67% at the same point.

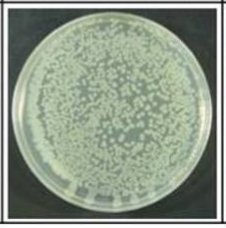
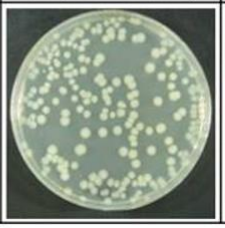
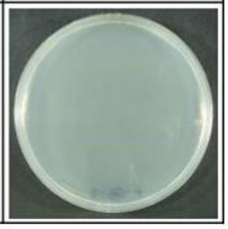


According to the results of disinfection test, the disinfection level was confirmed to be 99.9% for E. coli in the evaluation within 14 seconds of irradiation with fixed working distance of 50 mm using Nichia's 280nm 59mW UVC LED.

Part No.			NCSU334A	Unit
Wavelength Rank			280	nm
Test Condition	Number of LED		1	pc.
	I_F		350	mA
	Peak Wavelength		280	nm
	Radiant Flux		59	mW
	Working Distance		50	mm
Irradiation[1] Time	Gram Negative Bacteria	E. coli	14	sec.
		P. aeruginosa	6	
	Gram Positive Bacteria	S. aureus	11	



Note: This data has been tested by an external agency.
[1] Irradiation time for 99.9% sterilization.
[2] 3 log (10^3) decrease = 99.9% sterilization
[3] CFU = Colony Forming Unit

Irradiation Time	0 sec. (10,000 dilution)	5 sec. (10,000 dilution)	10 sec. (10,000 dilution)	15 sec. (10,000 dilution)	20 sec. (10,000 dilution)
E. coli Peak Wavelength 280nm Radiant Flux 59mW					

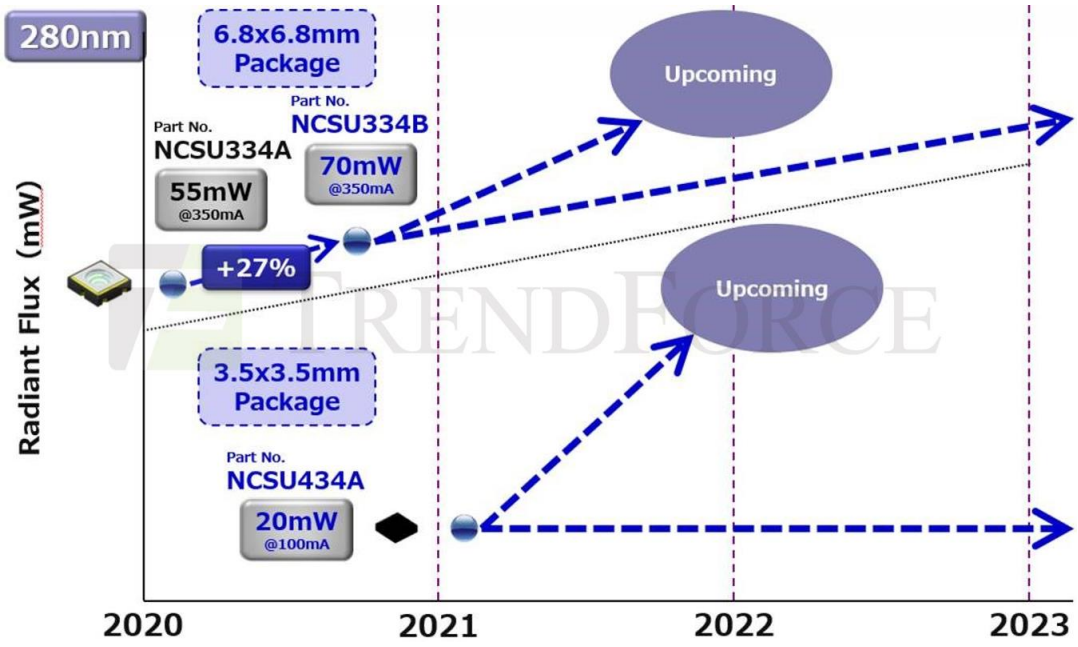
Note: This data is a reference value, hence Nichia cannot make guarantee these results. Please treat this data the as reference.

Nichia has successfully launched 280nm 70mW UVC LED in September 2020 with an external quantum efficiency of 3.6%. The estimated time to achieve the disinfection level of 99.9% for E. coli is only 12 seconds under the same conditions above.

Part No.			NCSU334A → **B**	Unit
Wavelength Rank			280	nm
Test Condition	Number of LED		1	pc.
	I_F		350	mA
	Peak Wavelength		280	nm
	Radiant Flux		59 → **(70)**	mW
	Working Distance		50	mm
Irradiation Time for 99.9% Sterilization	Gram Negative Bacteria	E. coli	**14** → **(12)**	sec.
		P. aeruginosa	**6** → **(5)**	
	Gram Positive Bacteria	S. aureus	**11** → **(9)**	

Note: This data has been tested by an external agency.
This data is a reference value, hence Nichia cannot make guarantee these results. Please treat this data the as reference.

In addition, Nichia plans to launch 3535 LED 20mW products (100mA) in early 2021. Nichia will continuously increase the output of UVC LED and expand its UVC portfolio in the near future.



Regarding Nichia's UVC LED market strategies, Naito indicated that the target markets of sterilization include water disinfection and general lighting applications. Nichia believes that UVC LED products will ultimately replace mercury lamps to achieve sustainable goals. Nichia prioritizes environmental responsibility so that it introduced UV LED solution for disinfection instead of using mercury lamp. Nichia is pursuing higher performance, longer product lifetime and higher reliability products in the industry.

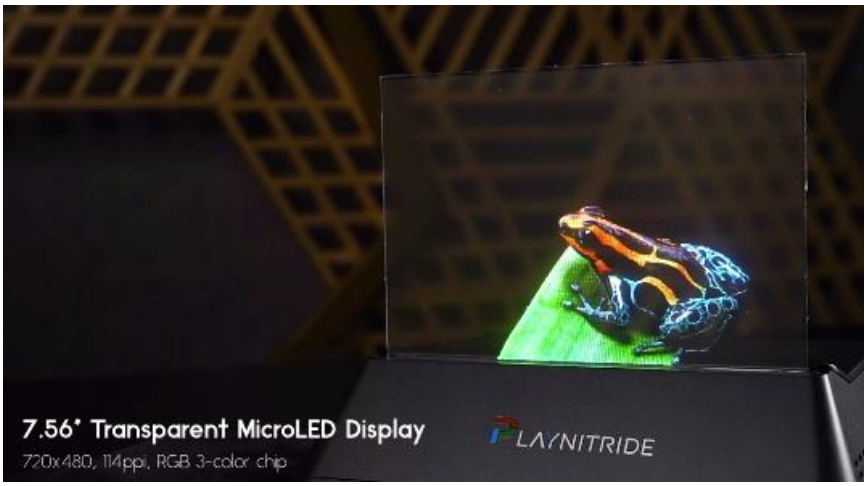
Beyond UVC LEDs for disinfection, Nichia also offers UVB and UVA portfolio to provide solutions for curing, printing and more for its clients.

Radiant Flux	Peak Wavelength (nm) N: Narrow Directivity					
	280	365	375	385	395	405
60W~		N		N	N	
10W~						
3500mW~						
1000mW~		N		N	N	N
500mW~	UV-C					
70mW	NEW					
~20mW	Under Development					

QD Color Conversion and Wafer Technologies Drive Micro LED Display Mass Production

LEDInside

Micro LED technology developers from Taiwan unveiled their latest progress in quantum dots (QD) color conversion and wafer production. Lextar introduced its progresses in reliable QD development to realize full color Micro LED displays while PlayNitride shared its achievement of 6-inch Micro LED epitaxial wafers with advanced uniformity.



(Image: screenshot from PlayNitride video)

Lextar, a vertical integrated LED company based in Taiwan, shared that the company has been working on deploying QD color conversion technology on Micro LED display. Since Micro LED is too small to combine with phosphor, using QD is a more feasible approach to develop full color Micro LEDs. However, since QDs are very small in size, they are fragile and uneasy to apply as well. After focusing on QD for more than 10 years, the R&D team of Lextar has overcome the challenges and built QD in package for Micro LED displays. Lextar also noted that using Micro LED with shorter wavelengths can further improve the efficiency of QD.

Lextar and Epistar have set up a new holding company ENNOSTAR to advance their development in Micro/Mini LED as well as in VCSEL and other sensing and data transmitting technologies. The two companies aim to avoid double investment and research on these projects and to focus on their expertise through the partnership. Lextar will address in packaging and modular solutions while Epistar will concentrate in wafer and chip processing.

On the other hand, Micro LED company PlayNitride revealed its progress in Micro LED wafer production. It has achieved the mass production standard of uniformity with its 6-inch Micro LED wafer production. Charles Li, PlayNitride CEO, noted that combining its mass repair solution and the wafer with advanced uniformity, Micro LED displays are in the last phase to volume production.

The company developed a solution to integrate 16 RGB Micro LEDs on a PCB substrate, named PixeLED Matrix. Based on the approach, PlayNitride aims to further reduce production for Micro LED display production.

Micro LED Hetero-integration Paves the Way for Innovative Display Applications

LEDInside

The ultimate display technology Micro LED has improved significantly in wafer technology, full color performance and mass transferring recently. Taiwan-based industry players have shared their insights of the technology at an industry gathering last week.

Jennifer Y-C Lin, Senior Associate Vice President of AUO, indicated that Micro LED will be a key technology to drive innovative applications in the era of 5G connection and IoT, especially as the world heavily impacted by the COVID-19 pandemic. She explained that in addition to excellent display performance, Micro LED can be integrated with sensors and driver ICs to create a wide range of human-machine interface enabling various smart interactions between people. Moreover, Micro LED displays are more robust comparing to OLED displays and can be deployed in different scenarios without affected by environmental factors like heat, humidity and more. Therefore, the goal of "Display Everywhere" is more likely to be achieved with Micro LED technology.

(Image: Google)

Dr. Yen-Hsiang Fang of Electronics and Optoelectronic System Research Laboratories at ITR addressed the edge of adopting Micro LED display technology for AR applications. He pointed out that the hetero-integration connecting Micro LED, Micro sensors and Micro ICs will fully realize next-gen AR applications. AR displays for the future will need to track the movement of eyeballs with lens-free cameras and transmit the real-time data for further information process and interaction with other devices.

"We have to change our mindset when facing Micro LED technology," highlighted Fang. He considered it more efficiency to first look into the requirements of applications with system and product developers and then trace back to optimize the production for such advanced display technology. Recently ITRI presented a flexible full color Micro LED display module targeting wearable applications and continues to develop Micro LED for AR products.

Wafer-scale micro-LEDs transferred onto adhesive film for planar and flexible displays

SemiconductorToday

Researchers at the Guangdong Institute of Semiconductor Industrial Technology (GISIT), the University of Tokyo, and Foshan Debao Display Technology Co Ltd have recently developed a tape-assisted laser lift-off transfer (TALT) technique, addressing the industry's problems of massive chip transfer and heterogeneous integration of micro-LED for high-resolution display purposes [Zhangxu Pan et al, 'Wafer-Scale Micro-LEDs Transferred onto an Adhesive Film for Planar and Flexible Displays', Advanced Material Technology, https://doi.org/10.1002/admt.202000549].

Recognized as a next-generation display technology in the display industry, micro-LEDs have many advantages such as higher brightness, lower power consumption, longer lifetime, higher resolution and faster response speed compared with conventional liquid crystal display (LCD) and organic light-emitting diode (OLED) display technologies. They are therefore expected to have very good application prospects in wearable electronic devices, outdoor displays and augmented reality/virtual reality (AR/VR) head-mounted displays.

However, the volume production of high-resolution micro-LED display devices currently faces many challenges. Among them, how to quickly and accurately transfer and integrate millions of micro-LED chips onto the drive circuit is a major hurdle to be overcome. Although a variety of transfer technologies for micro-LEDs have been proposed, there is still ample room for improvement in their transfer speed and placement accuracy. In addition, most of these transfer technologies are focused on the optimization of the chip transfer technology itself, but less attention is paid to their compatibility with subsequent bonding processes.

The joint teams have exploited the merits of both laser lift-off and tape transfer to fabricate wafer-level thin-film micro-LEDs. The novel TALT technique for fabricating thin-film micro-LEDs transferred to a temporary adhesive substrate is shown in Figure 1. An adhesive tape is laminated onto the micro-LED arrays on a sapphire substrate [Figure 1(a)]. The sapphire substrate is then taken off by laser lift-off (LLO). As a result, wafer-scale micro-LED arrays are then released to the first adhesive tape [Figure 1(b)]. Before flip-chip bonding to a driver board, micro-LEDs must be turned upside down. This is achieved by attaching another tape with stronger adhesion to the full LED arrays on the first tape [Figure 1(c)]. Because of the stronger adhesion, micro-LEDs can be released to the second tape. This is achieved by simply peeling away the first tape [Figure 1(d)]. Now, transferrable thin-film micro-LEDs, which are particularly suited to flip-chip bonding, are ready [Figure 1(e)].

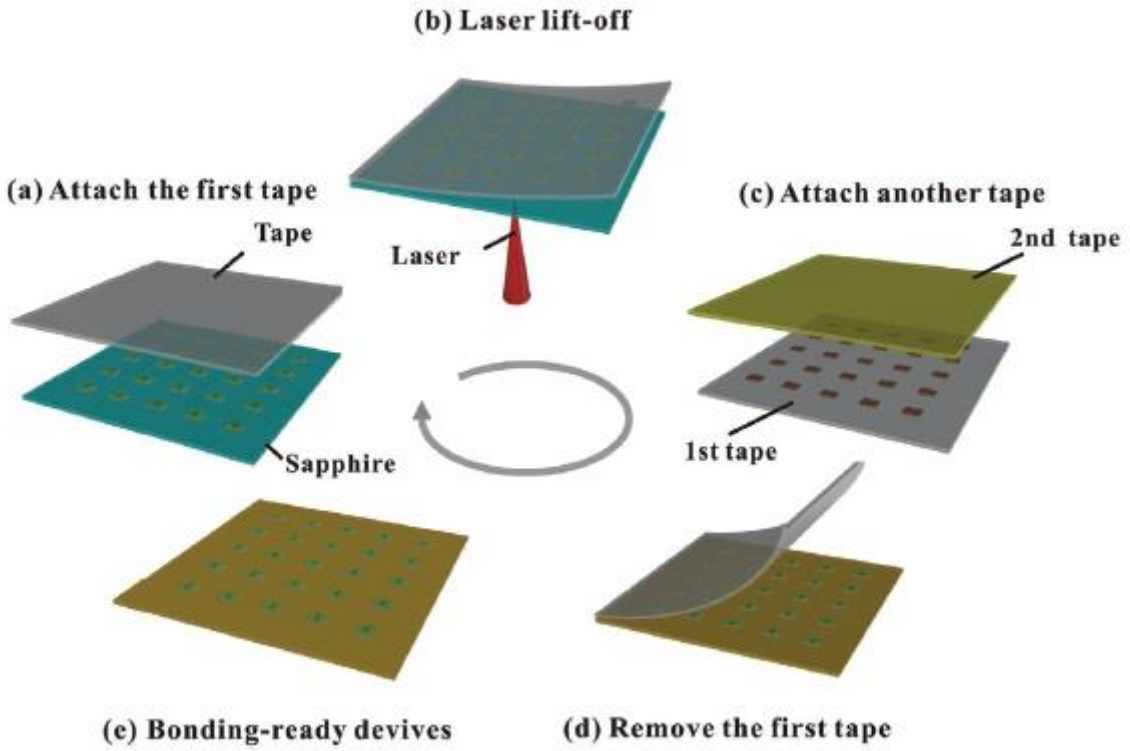


Figure 1.

Working procedure of TALT technique for wafer-level micro-LED transfer.

The resulting wafer-level micro-LED thin film is shown in Figure 2. The results in Figures 2(a) and (b) clearly show that a very high yield of micro-LED lift off (up to 99.9%) can be achieved under optimized LLO conditions. Both the optical and electrical tests suggest that the device before transfer and after transfer shows minimal degraded device performance [Figures 2(c) and (d)]. The researchers believe that this method has the potential for wafer-scale production, and can even be scaled up to larger-size wafers.

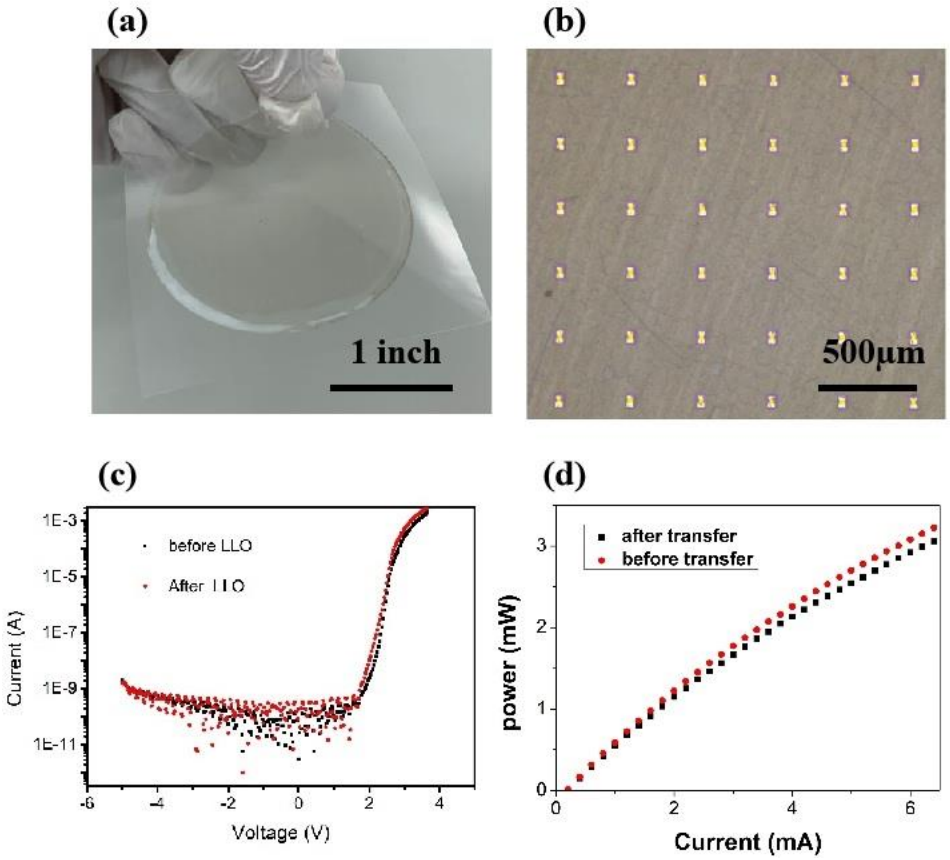


Figure 2. Wafer level micro-LEDs transferred to an adhesive tape, and their electrical and optical performance.

The researchers also particularly emphasize that the TALT technology is suitable not only for wafer-level transfer of micro-LEDs but also for flip-chip bonding for good electrical connection. Indeed, the researchers have further demonstrated both rigid and flexible micro-LED prototypes with convincing device performances, based on the TALT technique and the bump-less bonding process that the same joint team has developed. Representative flexible micro-LED devices are shown in Figure 3.

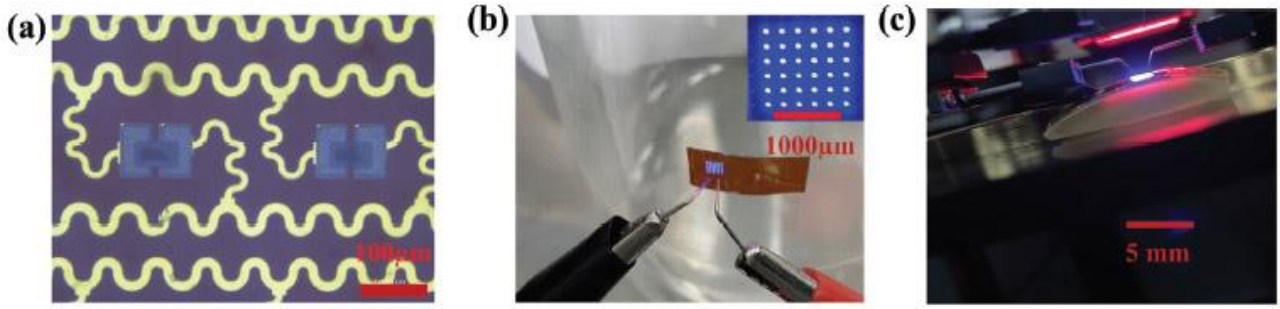


Figure 3. Flexible micro-LED display prototypes.

The researchers reckon that this technique paves the way for fast assembly of micro-LEDs with high yield and excellent placement accuracy. The method is also promising for fabricating high-resolution micro-display devices for potential applications in areas such as VR/AR headsets, wearables and mini-projectors.

Seoul Viosys mass producing Violeds module to sterilize Coronavirus

SemiconductorToday

Ultraviolet LED product maker Seoul Viosys Co Ltd (a subsidiary of South Korean LED maker Seoul Semiconductor Co Ltd) says that, using its Violeds UV LED technology, it has developed an optimal module designed to sterilize 99.9% of the coronavirus in 3 seconds, and has begun mass production. Also, using this technology, Seoul Viosys is developing a 'Photon Shower' product that can contribute to the safety of medical staff and patients who have been struggling amid the COVID-19 pandemic.

The BIO research team at Seoul Viosys has been conducting numerous R&D projects with in-house laboratories cultivating and sterilizing various bacteria and viruses. In April, a Violeds sterilization test conducted with a research group at Korea University proved that Violeds does sterilize coronavirus. By applying this technology, Seoul Viosys is producing the VAC air purifier, which is optimally designed to sterilize filters by 99.9% in 30 seconds, and the VSM+ multi-sterilizer, which sterilizes the surface of everyday objects by 99.9% in 10 minutes.

The new Photon Shower is a whole-body sterilization solution that uses only light to sterilize various germs on the surface of people's clothes in seconds when they enter it. This sterilization function can also be applied to a conventional air shower that is used for dust removal only.

Infections in hospital are also serious. According to the US CDC (Centers for Disease Control and Prevention) statistics, 14,000 people die annually from hospital infections in the USA alone. Using Violeds technology, Photon Shower can contribute to minimizing infections in hospitals in the future, says Seoul Viosys.

"There are countless industrial fields where the Violeds module, which sterilizes 99.9% of viruses on the surface of everyday objects in just three seconds, can be applied," notes Seoul Viosys. "It has been supplied to US escalator manufacturers to be applied to escalator handle sterilization solutions, and we expect global customer demand to increase in the future."

Violeds is a UV LED technology that uses only light to sterilize, and is optimally designed depending on application area by considering the following five factors: wavelengths from 200nm to 400nm, distance to objects, light irradiation time, brightness of light (intensity), angle and area of irradiation surface. The technology has already been applied to the International Space Station (ISS) of the National Aeronautics and Space Administration (NASA), and is also applied to various home appliances and automobiles, including air conditioners, air purifiers, water purifiers and dishwashers.

Everlight convicted in Korea for misappropriating Seoul Semi's trade secrets

SemiconductorToday

South Korean LED maker Seoul Semiconductor Co Ltd says that the Korean Suwon District Court has convicted Taiwan-based Everlight Electronics Co Ltd of criminal misappropriation of its trade secrets. Three former employees of Seoul who left the company and went to work at Everlight were also criminally convicted of trade secret misappropriation. Everlight and the former employees are subject to criminal sentences, says Seoul Semiconductor.

Everlight was sentenced to the maximum criminal fine permitted under Korean law for the commission of such a crime. The Court also sentenced the former employees with criminal probation with the possibility of prison time.

According to Seoul Semiconductor, the criminal investigation began as a result of Everlight's solicitation of a former engineer and sales employee from Seoul. The former employee had special knowledge of Seoul's automotive LED technology utilizing its proprietary WICOP (wafer-level integrated chip on PCB) technology – the world's first package-less LED – in which Seoul invested KRW560bn over seven years. The former employee used a false name while working at Everlight to escape detection, Seoul Semiconductor says. The Korea Prosecutors' Office criminally indicted Everlight for violating the Industrial Technology Protection Act, as well as the Trade Secret Protection Act. The former employees were charged and arrested with the same violations.

Seoul says that it has achieved US$1bn of annual revenue in LED sales, and that it invests about 10% of its revenue into R&D every year and holds more than 14,000 global patent rights.

"Intellectual property is a ladder that enables small businesses and young entrepreneurs to compete with global conglomerates. It allows people to break through barriers of class and origin with rapid business growth," says Seoul's founder Chung Hoon Lee. "Intellectual property enables industrial revolutions. It gives us a tool to fight global poverty, facilitate culture and research activities, grow small businesses into global enterprises, and drive the national economy by creating jobs," he adds. "We should not allow unethical companies to steal intellectual property for monetary gain."

European Commision approves ams' Osram acquisition

LEDs Magazine

The verdict is in: The European Commission has approved the acquisition of Osram by Austrian optical sensor maker ams, ruling that the combination of the two companies poses no competitive threat in the European Economic Area.

The decision yesterday — a day when LEDs Magazine suggested the approval might finally come — removes the remaining regulatory uncertainty to the deal that ams clinched via public stock purchases of Osram last December.

While ams continues to find ways to pay for a much larger company, it can now do so knowing that the EC's Competition department (formally known as the Directorate-General, Competition) has decided that other players in the optical sensor and photonics market do not have to worry about unfair competition from the combined entity.

"The European Commission has approved unconditionally, under the EU Merger Regulation, the proposed acquisition of OSRAM by AMS," the EC said in a press release. "The Commission concluded that the transaction would raise no competition concerns in the European Economic Area." (Although ams spells its name with all small letters, the EC used all capital letters.)

As a quick Government 101 review, the EC is the executive branch of the European Union. The European Economic Area (EEA) consists of the EU's 27 member countries plus Norway, Iceland, and Liechtenstein. The UK left the EU on Jan. 31 and is in a transition period as it and the EU try to reach an exit agreement.

In the countries where the EC has jurisdiction, "the Commission found that the transaction, as notified, would not significantly reduce head-to-head competition between the companies in the markets for optical semiconductors," the press release stated.

As Munich-based Osram continues to define itself as more of a "high tech" and "high tech photonics" company and less of a general illumination outfit, it has been regularly releasing new optical LED and laser chips aimed at a wide array of applications such as facial recognition, car navigation, augmented and virtual reality, digital photography, and health monitoring, to name some.

Some of those areas would seem to overlap with Premstaetten-based ams, which is known as a key supplier of optical facial recognition chips to Apple for the iPhone.

The EC outlined a number of reasons why the ams–Osram combination would not be anti-competitive. Among them, it noted:
"The companies have low to moderate combined market shares for certain light sensors and laser diodes for which their offers overlap and in most of those cases their respective products are not close substitutes from a customer perspective. A number of competitors offer viable alternatives to the companies' products, and barriers to entry do not seem to prevent the emergence of new market entrants. The fast-evolving products and market dynamics as well as sophisticated buyers do not allow the companies to exert significant market power. A majority of market participants consulted by the Commission appears to be either supportive of the transaction or not concerned by it."

The EC's approval yesterday, July 6, came in the spirt if not the letter of the "second quarter of 2020" timeframe that ams has anticipated, slipping by 6 days.

Ams said in its own press release that it expects to close the transaction by July 9 (Thursday).

"The EU regulatory approval constituted the last remaining condition precedent for closing the transaction which is now fulfilled," the company said. *"ams therefore expects the payment of the offer price to the holders of the tendered shares and the closing of the takeover offer on 9 July 2020."*

Meanwhile, it appears that ams and Osram will continue to be hamstrung in their efforts to integrate their operations, because ams did not acquire a large enough share of Osram to attain what Germany regulators call a "domination agreement." Osram CEO Olaf Berlien noted earlier this year that without a domination agreement, the two companies are effectively limited in the information they can share as they discuss synergies.

Domination requires 75% ownership. At LEDs' last count, ams had about 64%, a number that ams indicated in its press release will have crept up to 69% upon the expected July 9 closing — still short of 75%.

So ams was earlier this year planning a second course of action in which it would ask Osram shareholders to grant domination via an extraordinary voting session. LEDs has asked ams where that effort stands, but we have not received an answer.

The lack of domination has also deprived ams of access to Osram's cash (dwindling as it is). That has prompted ams to seek other sources of funding including stocks and bonds to help pay back money it borrowed to acquire Osram in a €41 per share deal that valued Osram at €4.58 billion back in November.

The financial challenge is indicative of a company trying to acquire another that at the outset was nearly four times its size.

While Osram has shrunk and ams has grown since the acquisition efforts started, Osram is still substantially bigger, with 2019 revenue of €3.46B ($3.91B at today's exchange rate) compared to $2.08B for ams (ams reports in US dollars).

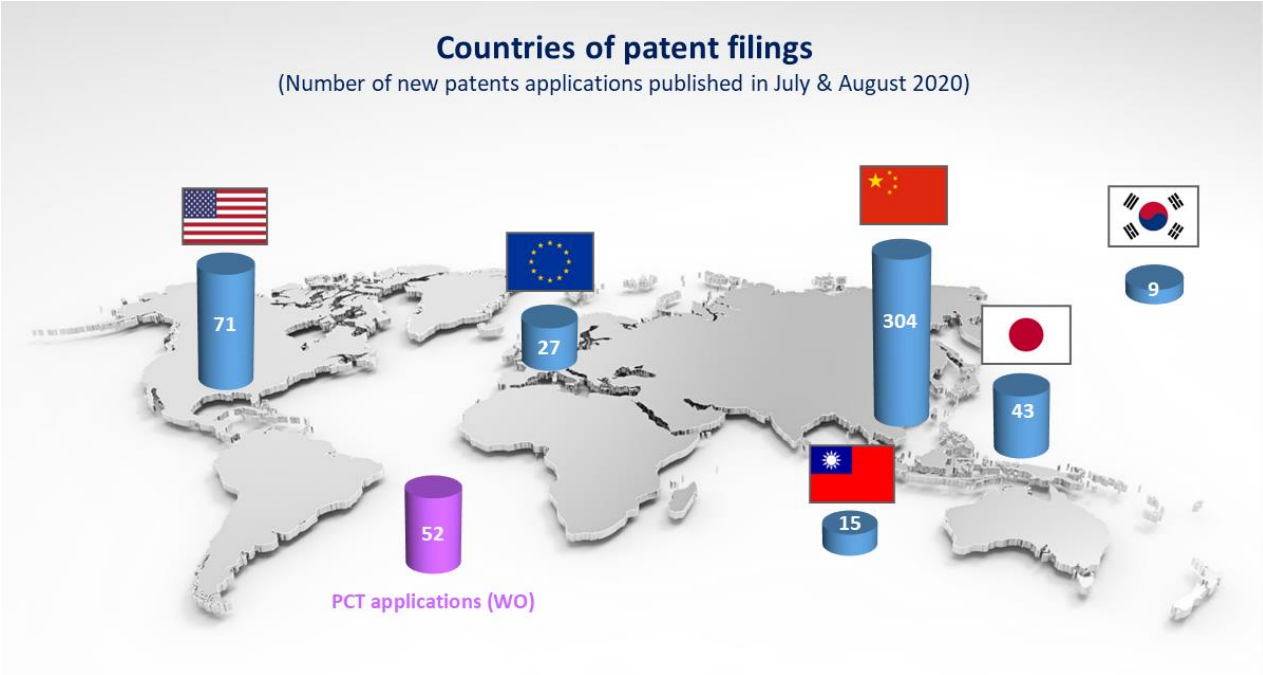
The acquisition saga took another turn recently, when Reuters reported that the Austrian Financial Market Authority (FMA) is probing possible insider trading of ams shares.

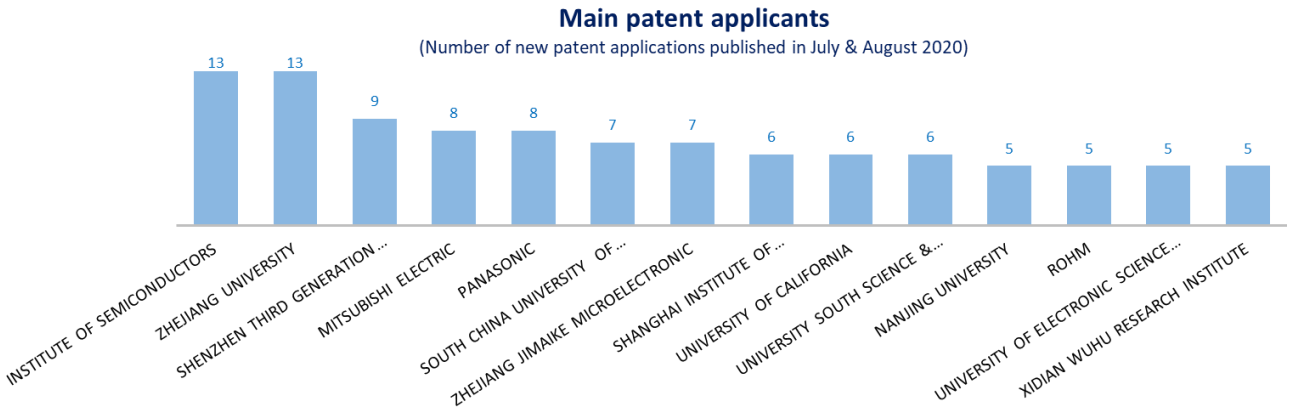
But while the acquisition will continue to have its difficulties, ams has at last leapt over the regulatory hurdle of European competition overseers.

Exactly how ams will mix and match Osram's photonics with its own offerings remains to be seen. The same could be said of Osram's non-chip businesses which include horticultural lighting, automotive headlamps, and conventional mercury lamps which have come to the fore recently for their disinfection potential in the fight against the coronavirus. Osram's IoT lighting program including Lightelligence appears to be under question.

PATENT APPLICATIONS

More than 450 **new patent families** related to GaN technology were published in **July & August 2020**.



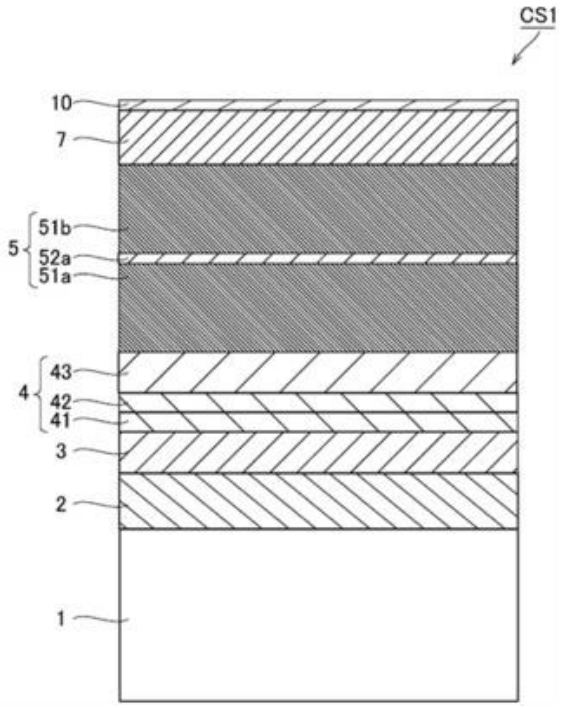


Other patent applicants: Changchun Institute of Optics Fine Mechanics & Physics Chinese Academy of Sciences, Foshan Guoxing Semiconductor Technology, HC Semitek, Huainan Normal University, Innoscience Technology, Institute of Microelectronics Chinese Academy of Sciences, Intel, Osaka University, Siemens, Suzhou Institute of Nano Technology & Nano Bionics Chinese Academy of Sciences, Wuhu Qidi Semiconductor, Xiamen Sanan Optoelectronics, Akoustis, Beijing Huafeng Test & Control Technology, Chen Jiyu, Chongqing University, Chung Yuan Christian University, Delta Electronics, Facebook Technologies, Guangdong Institute of Semiconductor Industrial Technology, Jiangsu Nata Opto Electronic Material, King Abdullah University of Science & Technology, Magna, Nichia, Nichia Chemical Industry, Nikkiso, Sciocs, Shandong Inspur Huaguang Optoelectronics, Southeast University Nanjing, Stmicroelectronics, Sumitomo Chemical, Toyoda Gosei, Xiamen Changelight, Xiangneng Hualei Optoelectronic Corppration, Yixing Qurong Photoelectric Technology, 13th Research Institute of China Electronics Technology, Air Water, Analog Devices, China Chippacking Technology, Chongqing Kangjia Optoelectronic Technology Research Institute, Chongqing Konka Photoelectric Technology Research Institute, Collaborative Research Engineering Science & Technology Center, Elux, Enkris Semiconductor, Global Wafers, Hatchip, Hebei University of Technology, Heyuan Choicore Photoelectric Technology, Heyuan Tianhe Third Generation Semiconductor Industry Technology Research Institute, HRL Laboratories, Huaxia Semiconductor Shenzhen, Imec VZW, Jezetek, Jiangxi Litkconn Optical Research Institute, Kyungpook National University Industry Academic Cooperation Foundation, Mitsubishi Chemical, Nanjing Nanda Optoelectronic Engineering Research Institute, Nanjing University of Aeronautics & Astronautics (NUAA), National Chiao Tung University, National Institute For Materials Science, No 55 Institute of China Electronics Science & Technology, Northrop Grumman Systems, Northwestern Polytechnical University, Nuvoton, Panasonic Intellectual Property Management, Shanghai Xitang Semiconductor Technology, Sharp, Shenzhen Jiahua Microelectronics, Shenzhen Vmax New Energy, Sumitomo Electric Device Innovations, Sumitomo Electric Industries, Sun Yat Sen University, Toyota Motor, Vanguard International Semiconductor, Wuxi Si Power Micro Electronics, Wuxi Wuyue Semiconductor, Wuxi Zhongxiang Technology, Xidian University, Zhonghe Bosemi Chongqing Semiconductors, Zhongshan Institute of Modern Industrial Technology South China University of Technology, 58th Research Institute of CETC, ABB Schweiz, Adeka, Aisin Seiki, Analog Devices International Unlimited, Anhui University of Chinese Medicine.

Compound semiconductor substrate

Publication Number: WO2020/149184, JP2020113693
Patent Applicant: AIR WATER

Provided is a compound semiconductor substrate which can be improved in the in-plane uniformity of a current-voltage property in the vertical direction. The compound semiconductor substrate has a center and an edge that is located apart by 71.2 mm from the center as observed planarly. When the thickness at the center in a GaN layer in the compound semiconductor substrate is defined as W1 and the thickness at the edge in the GaN layer is defined as W2, the thickness error ΔW expressed by the formula: ΔW(%) = | W1-W2 | ×100/W1 is more than 0% and 8% or less. The average carbon concentration at the center of the GaN layer as determined in the depth direction is 3×1018 /cm3 to 5×1020 /cm3 inclusive. When the carbon concentration at a depth-direction center position of the GaN layer at the center of the GaN layer is defined as a concentration C1 and the carbon concentration at a depth-direction center position of the GaN layer at the edge of the GaN layer is defined as a concentration C2, the concentration error ΔC expressed by the formula: ΔC(%) = | C1-C2 | ×100/C1 is 0 to 50% inclusive.



Group III-nitride high-electron mobility transistors with buried p-type layers

Publication Number: WO2020/159934
Patent Applicant: CREE

An apparatus includes a substrate. The apparatus further includes a group III-nitride buffer layer on the substrate; a group III-nitride barrier layer on the group III-nitride buffer layer, the group III-nitride barrier layer including a higher bandgap than a bandgap of the group III-nitride buffer layer. The apparatus further includes a source electrically coupled to the group III-nitride barrier layer; a gate electrically coupled to the group III-nitride barrier layer; a drain electrically coupled to the group III-nitride barrier layer; and a p-region being at least one of the following: in the substrate or on the substrate below said group III-nitride barrier layer.

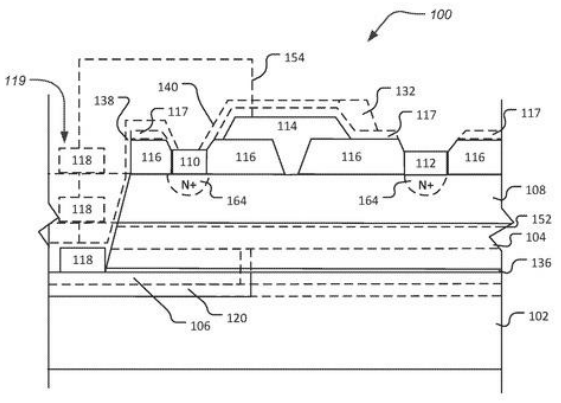
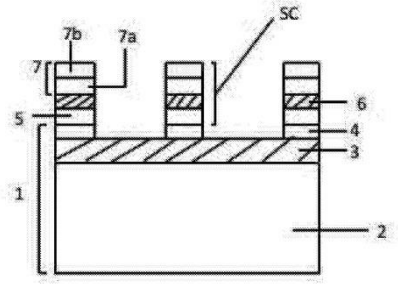


Figure 1

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

Publication Number: WO2020/144072, FR3091622
Patent Applicant: SOITEC

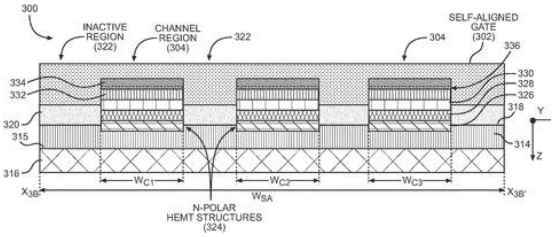
The invention concerns an optoelectronic semiconductor structure (SC) comprising an active InGaN-based layer (6) disposed between an n-type injection layer (5) and a p-type injection layer (7), the p-type injection layer (6) comprising a first InGaN layer (7a) and, disposed on said first layer (7a), a second layer (7b) composed of a plurality of Al GaInN elemental layers, each elemental layer having a thickness less than its critical relaxation thickness, two successive elemental layers having different aluminium and/or indium and/or gallium compositions.



Process of fabricating high efficiency, high linearity N-polar gallium-nitride (GaN) transistors

Publication Number: US10749009
Patent Applicant: QORVO

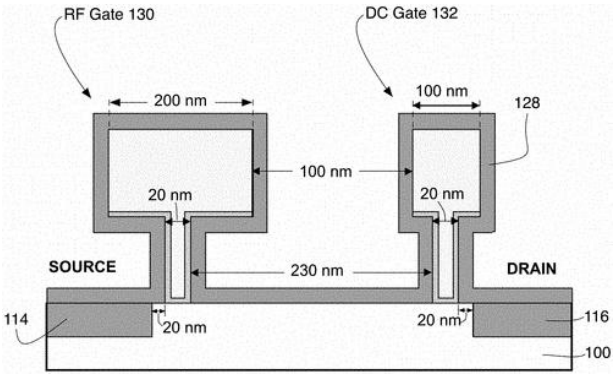
Fabricating high efficiency, high linearity N-polar gallium-nitride (GaN) transistors by selective area regrowth is disclosed. A demand for high efficiency components with highly linear performance characteristics for radio frequency (RF) systems has increased development of GaN transistors and, in particular, aluminum-gallium-nitride (AlGaN)/GaN high electron mobility transistor (HEMT) devices. A method of fabricating a high efficiency, high linearity N-polar HEMT device includes employing a selective area regrowth method for forming a HEMT structure on the Nitrogen-face (N-face) of a GaN buffer, a natural high composition AlGaN/AlN back barrier for carrier confinement, a thick undoped GaN layer on the access areas to eliminate surface dispersion, and a high access area width to channel width ratio for improved linearity. A problem of impurities on the GaN buffer surface prior to regrowth creating a leakage path is avoided by intentional silicon (Si) doping in the HEMT structure.



Method of making a dual-gate HEMT

Publication Number: US10734498
Patent Applicant: HRL LABORATORIES

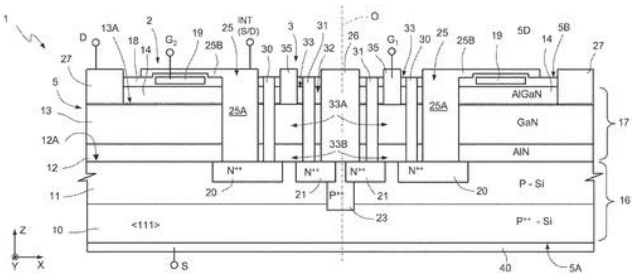
A four-terminal GaN transistor and methods of manufacture, the transistor having source and drain regions and preferably two T-shaped gate electrodes, wherein a stem of one of the two T-shaped gate electrodes is more closely located to the source region than it is to a stem of the other one of the two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



HEMT power device operating in enhancement mode and manufacturing process thereof

Publication Number: US20200243518, CN111490043, EP3690928
Patent Applicant: STMICROELECTRONICS

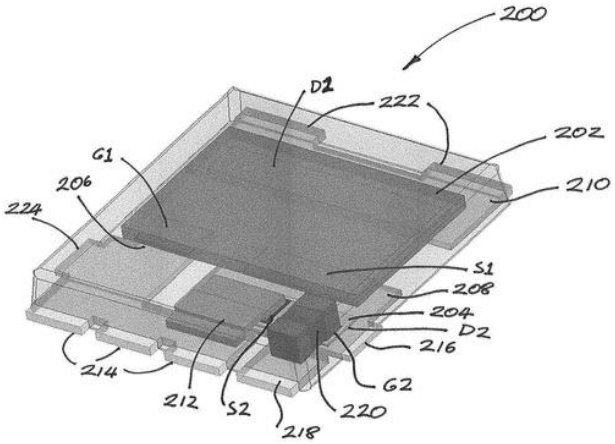
The power device is formed by a D-mode HEMT (2) and by a MOSFET (3) in cascade to each other and integrated in a chip (51) having a base body (16) and a heterostructure layer (17) on the base body. The D-mode HEMT (2) comprises a channel area formed in the heterostructure layer; the MOSFET (3) comprises a first and a second conduction region (20, 21) formed in the base body, and an insulated-gate region (33A, 33B) formed in the heterostructure layer, laterally and electrically insulated from the D-mode HEMT. A first metal region (25) extends through the heterostructure layer, laterally to the channel area and in electrical contact with the channel area and the first conduction region (20).



Cascode semiconductor device and method of manufacture

Publication Number: US20200243426, EP3690937, CN111490030
Patent Applicant: NEXPERIA

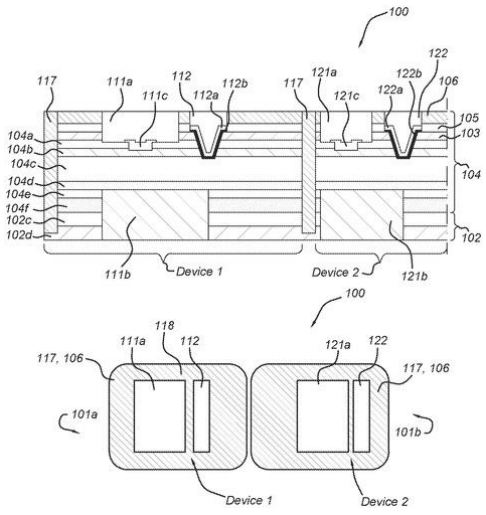
This disclosure relates to a discrete semiconductor device and associated method of manufacture, the discrete semiconductor device comprising: a high voltage depletion mode device die; a low voltage enhancement mode device die connected in cascode configuration with the high voltage depletion mode device die; wherein the high voltage depletion mode device comprises gate, source and drain terminals arranged on a first surface thereof and the gate source and drain terminals are inverted with respect to the low voltage enhancement mode device die; and wherein the low voltage device is arranged adjacent to the high voltage device.



Group III-nitride based vertical power device and system

Publication Number: US20200243678, EP3686924
Patent Applicant: IMEC

A vertical power device having a top side and a bottom side, the vertical power device comprising a substrate; a layered group III-Nitride based device stack formed atop the substrate, the group III-Nitride based device stack; a first vertical group III-Nitride based device and a second vertical group III-Nitride based device formed in the group III-Nitride based device stack, wherein the first vertical group III-Nitride based device and the second vertical group III-Nitride based device are electrically connected; and a first vertical device isolation structure that isolates the first vertical group III-Nitride based device from the second vertical group III-Nitride based device. A vertical power system integrating vertical power devices. A process for fabricating a vertical power device.

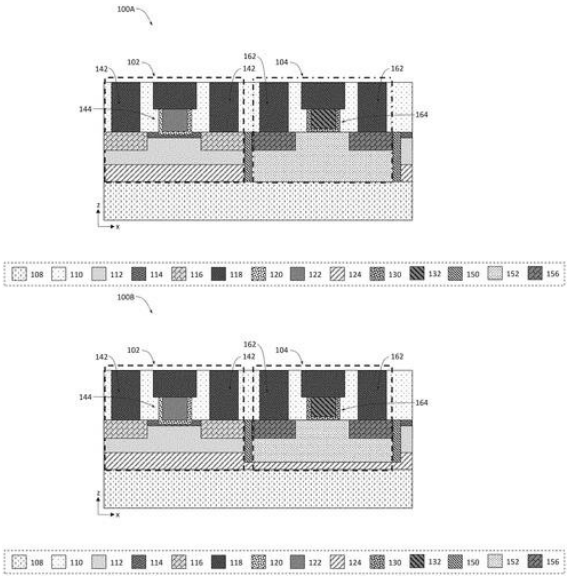


Integration of III-N transistors and non-III-N transistors by semiconductor regrowth

Publication Number: US20200273860, DE102020101433

Patent Applicant: INTEL

Disclosed herein are IC structures, packages, and devices that include III-N transistors integrated on the same support structure as non-III-N transistors (e.g., Si-based transistors), using semiconductor regrowth. In one aspect, a non-III-N transistor may be integrated with an III-N transistor by depositing a III-N material, forming an opening in the III-N material, and epitaxially growing within the opening a semiconductor material other than the III-N material. Since the III-N material may serve as a foundation for forming III-N transistors, while the non-III-N material may serve as a foundation for forming non-III-N transistors, such an approach advantageously enables implementation of both types of transistors on a single support structure. Proposed integration may reduce costs and improve performance by enabling integrated digital logic solutions for III-N transistors and by reducing losses incurred when power is routed off chip in a multi-chip package.

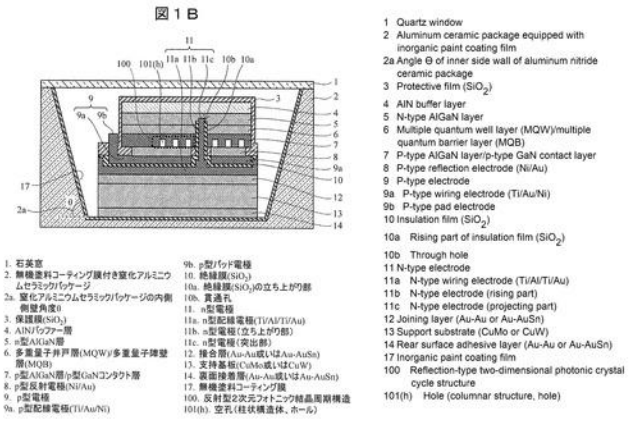


Deep ultraviolet LED device and manufacturing method therefor

Publication Number: WO2020/138146, JP2020107778

Patent Applicant: DAI NIPPON PRINTING

In order to realize a deep ultraviolet LED device having a high WPE and a high output, enhancement of LEE and improvement of efficiency droop caused by heat of the deep ultraviolet LED device are necessary. This deep ultraviolet LED device has a design wavelength λ (200-355 nm) and is characterized by having: a deep ultraviolet LED element that has, in the following order, a rear surface adhesive layer (Au-Au or Au-AuSn), a support substrate (CuMo or CuW), a joining layer (Au-Au or Au-AuSn), an n-type wiring electrode (Ti/Al/Ti/Au), an insulation film (SiO2), a p-type wiring electrode (Ti/Au/Ni), a p-type reflection electrode (Ni/Au), a p-type GaN contact layer, a p-type AlGaN layer, a multiple quantum barrier layer (MQB), a multiple quantum well layer (MQW), an n-type AlGaN layer, an AlN buffer layer, and a protective film (SiO2), wherein the n-type wiring electrode (Ti/Al/Ti/Au) extends so as to be exposed to an n-type AlGaN layer part through a through hole obtained by being coated and insulated with the insulation film (SiO2) and has a reflection type two-dimensional photonic crystal that has a plurality of holes disposed at positions in a range of the thickness direction of the p-type reflection electrode (Ni/Au) and the p-type GaN contact layer but not beyond the interface between the p-type GaN contact layer and the p-type AlGaN layer, a reflection type two-dimensional photonic crystal cycle structure has a photonic band gap open with respect to a TE polarization component, a cycle a of the reflection type two-dimensional photonic crystal cycle structure satisfies Blagg's condition with respect to light having the design wavelength λ, a degree m in Bragg's conditional expression mλ/neff=2a (note that m represents a degree, λ represents the design wavelength, neff represents an effective refractive index of the two-dimensional photonic crystal, and a represents a two-dimensional photonic crystal cycle) satisfies m=3, and a R/a ratio satisfies 0.3≤R/a≤0.4 when R represents the radius of the hole; an aluminum nitride ceramic package that has a surface having the deep ultraviolet LED element mounted thereon, that has an inorganic paint coating film having a reflection rate of 91% or higher, and that has an angle of the inner side wall of the package of 60-75°; and a quartz window that is provided to the outermost surface of the aluminum nitride ceramic package and that seals the deep ultraviolet LED element.

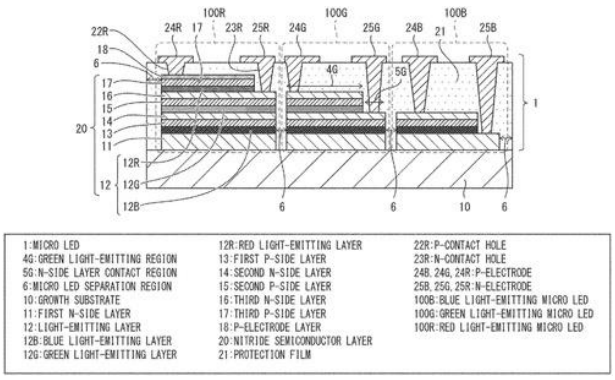


Micro light-emitting diode and manufacturing method of micro light-emitting diode

Publication Number: US20200266233

Patent Applicant: SHARP

A micro light-emitting diode includes a first micro light-emitting diode including a first light-emitting layer and emitting light at a first wavelength, and a second micro light-emitting diode including the first light-emitting layer and a second light-emitting layer emitting light at a second wavelength longer than the first wavelength, in which the second light-emitting layer is a nitride semiconductor layer doped with a second rare earth element, and a nitride semiconductor of the first micro light-emitting diode and the nitride semiconductor of the second micro light-emitting diode are separated from each other.

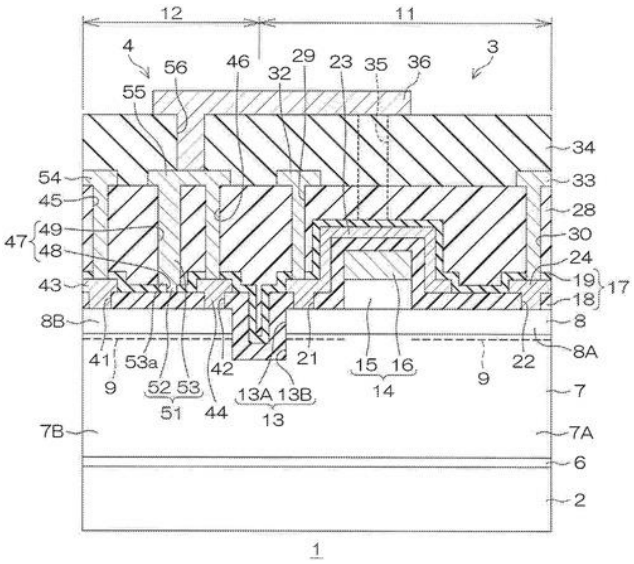


Nitride semiconductor device

Publication Number: US20200251586, JP2020126922

Patent Applicant: ROHM

A nitride semiconductor device 1 includes a first transistor 3 which is constituted of a normally-off transistor and functions as a main transistor and a second transistor 4 which is constituted of a normally-on transistor and arranged to limit a gate current of the first transistor. The first transistor 3 includes a first electron transit layer 7A constituted of a nitride semiconductor and a first electron supply layer 8A which is formed on the first electron transit layer and constituted of a nitride semiconductor. The second transistor 4 includes a second electron transit layer 7B constituted of a nitride semiconductor and a second electron supply layer 8B which is formed on the second electron transit layer and constituted of a nitride semiconductor. A gate electrode 51 and a source electrode 44 of the second transistor 4 are electrically connected to a gate electrode 16 of the first transistor 3.

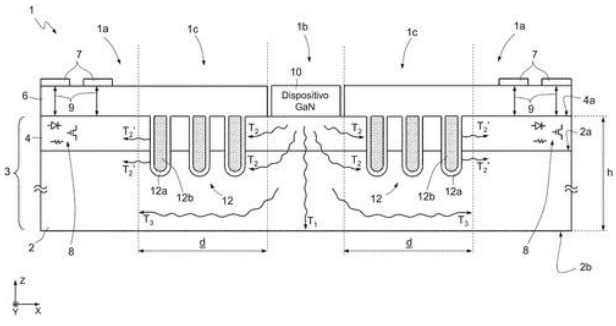


Semiconductor die with improved thermal insulation between a power portion and a peripheral portion, method of manufacturing, and package housing the die

Publication Number: EP3686923, US20200243496, CN111490016

Patent Applicant: STMICROELECTRONICS

A semiconductor die (1) comprising: a structural body (3) including a power region (1b) and a peripheral region (1a), surrounding the power region (1b); at least one power device (10) in the power region (1b); and trench-insulation means (12), extending in the structural body (3) starting from the front side towards the back side along a first direction (Z), adapted to hinder conduction of heat from the power region towards the peripheral region along a second direction (X) orthogonal to the first direction (Z). The trench-insulation means (12) have an extension (d), in the second direction (X), greater than the thickness (h) of the structural body along the first direction (Z).



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