GANEX

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III-N Technology

Coordinated by CRHEA-CNRS research laboratory, this monthly newsletter is produced by Knowmade with collaboration from the managers of GANEX groups. The newsletter presents a selection of newest scientific publications, patent applications and press releases related to III-Nitride semiconductor materials (GaN, AlN, InN and alloys)

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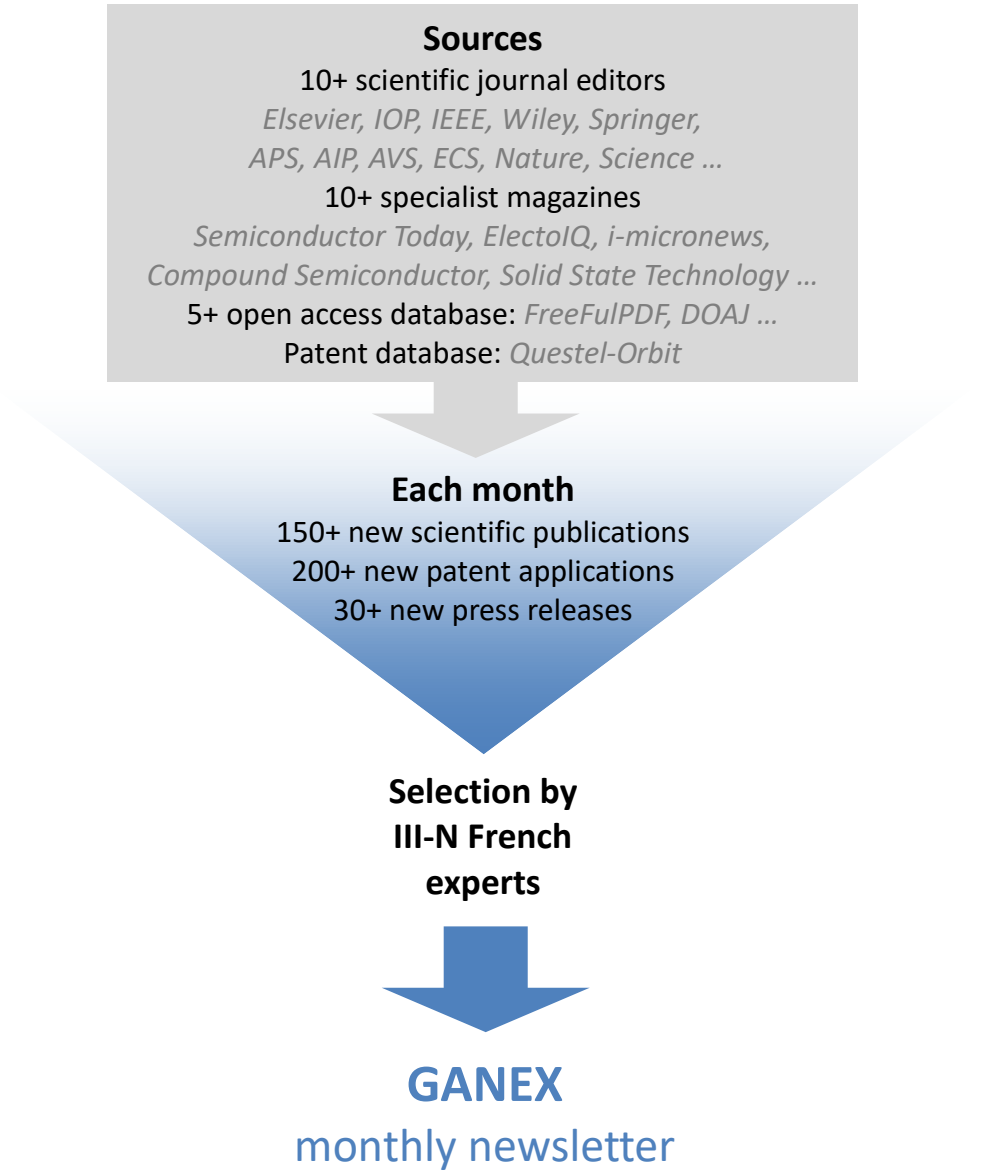
METHODOLOGY



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SCIENTIFIC PUBLICATIONS

Selection of new scientific articles

GROUP 1 - LEDs and Lighting

Group leader: Benjamin Damilano (CRHEA-CNRS)

Information selected by Benjamin Damilano (CRHEA-CNRS)

Stress and dislocation control of GaN epitaxial films grown on Si substrates and their application in high-performance light-emitting diodes

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Journal of Alloys and Compounds
https://doi.org/10.1016/j.jallcom.2018.09.031

GaN-based light-emitting diodes (LEDs) on Si substrates are promising to replace conventional lamps due to the advantages of energy-saving and low-cost of LEDs grown on large-size Si substrates. However, high-density dislocations and cracks of GaN epitaxial films are usually formed that limit the further development and application of GaN-based LEDs. To circumvent the issues, the step-graded AlGaN buffer layers are carefully designed to grow GaN epitaxial films on Si substrates. The mechanisms of dislocations and stresses for GaN epitaxial films controlled by step-graded AlGaN buffer layers are also investigated by analyzing dislocations evolution and stresses relaxation at the hetero-interfaces. Afterwards, 3.0 µm-thick high-quality GaN epitaxial films grown on Si substrates have been obtained, and high-quality GaN-based LED wafers are obtained accordingly with small full-width at half-maximums (FWHMs) for GaN(0002) and GaN(10–12) X-ray rocking curves of 272 and 297 arcsec, respectively. The corresponding vertical-structure LED chips reveal high-performance with a high light output power of 592 mW and a small working voltage of 2.77 V @ 456 nm, at a current of 350 mA. This work provides an effective approach for the growth of high-quality crack-free GaN epitaxial films on Si substrates for the fabrication of high-performance GaN-based devices.

Near-infrared light emitting diodes based on the type-II InGaN-ZnSnN2/GaN quantum wells

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Optical Materials
https://doi.org/10.1016/j.optmat.2018.09.005

The near-infrared spectral region is being used for various fields of applications. Near infrared emitters based on InGaN-ZnSnN2 material systems have not been proposed yet. In this paper, a novel type-II InGaN-ZnSnN2/GaN quantum well (QW) light emitting diode structure is presented for the near-infrared emission. Computations are based on the self-consistent solutions of Schrödinger and Poison equations. In the proposed structure, the emission wavelength (λ) and the overlap of electron and hole wave functions () are studied with current densities, for different dopings, compositions and well widths of the structure. It is found that the and the radiative efficiency are more than 30% and 40% respectively. The large overlap of electron and hole wavefunctions should make QW light emitting diodes in the near infrared range based on these structures feasible.

GaN LEDs fabricated using SF6-plasma RIE

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IET Micro & Nano Letters
https://doi.org/10.1049/mnl.2018.5083

In this work, the authors report a cost-effective fabrication method for making gallium nitride (GaN) light emitting diode (LED) arrays using SF 6 plasma in a conventional reactive-ion etching (RIE) system. The etch rates for GaN were investigated with different radio-frequency power and carrier substrates. The surface roughness due to the etching was also determined for the various recipes used. The optical

intensity and the temperature change during operation of the fabricated LED's were investigated. The effect of post-fabrication annealing on enhancement in the electrical and optical properties of the LED's was investigated.

Improving modulation bandwidth of c-plane GaN-based light-emitting diodes by an ultra-thin quantum wells design

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Optics Express
https://doi.org/10.1364/OE.26.024985

The GaN-based light emitting diodes (LEDs) have a great potential for visible light communication (VLC) due to their ubiquitous application in general lighting, but the modulation bandwidth of conventional c-plane LEDs is limited by carrier recombination rate in InGaN quantum wells (QWs) due to the polarization-field-induced quantum confined Stark effect (QCSE). Furthermore, the high modulation bandwidth on c-plane sapphire substrates can only be achieved at high current densities. Here, blue LEDs with ultra-thin InGaN QWs (1nm) and GaN barriers (3nm) are grown on c-plane sapphire substrate to suppress QCSE and extend the cut-off frequency from 214 MHz for conventional LEDs to 536 MHz at a current density of 2.5 kA/cm2, which is comparable to devices grown on semi-polar substrates.

Tuning photonic crystal fabrication by nanosphere lithography and surface treatment of AlGaN-based ultraviolet light-emitting diodes

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Materials & Design
https://doi.org/10.1016/j.matdes.2018.08.058

Photonic crystal processing was performed using nanosphere lithography as a low-cost procedure to enhance the quantum efficiency of AlGaN-based ultraviolet light emitting diodes. Spectral transmissivity/reflectivity and photoluminescence measurements, in conjunction with finite-element modeling and electromagnetic simulations, provide an indication of radiance enhancement with a photonic crystal periodicity comparable to the emission wavelength. To recondition the plasma-damaged sidewalls, post-processing methods based on high temperature annealing and surface treatment were evaluated, which in general, established a significant increase in light extraction efficiency. X-ray photoelectron spectroscopy clarified the formation of surface oxides and hydroxides on the as-fabricated nanostructures, and their dissolution after wet-chemical processing is linked to enhanced optical output. Hydroxyl-termination was found to prevail after KOH etching, but significantly reduced after HCl or H3PO4 treatment. The two-step sequence of HCl followed by KOH treatment provided the best quality nanotextured surface for optical emission in this study, as indicated by the nearly 14.5-fold enhancement in photoluminescence intensity.

Surface Plasmon Coupling in GaN:Eu Light Emitters with Metal-Nitrides

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Scientific Reportsvolume
https://doi.org/10.1038/s41598-018-31821-8

Metal-nitrides of hafnium nitride (HfN), zirconium nitride (ZrN) and titanium nitride (TiN) are investigated as plasmonic materials to enhance the internal quantum efficiency of a GaN:Eu red light emitter. Theoretical calculations are performed to

evaluate the surface plasmon polariton dispersion relation and Purcell enhancement factor for a single metal-nitride layer on top of the GaN:Eu emitter. Our findings suggest that among the metal-nitrides investigated in this study, TiN is the most promising candidate for use as plasmonic material to increase the internal quantum efficiency in GaN:Eu red light emitters.

Performance enhancement of ultraviolet light emitting diode incorporating Al nanohole arrays

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Nanotechnology
https://doi.org/10.1088/1361-6528/aaddc8

Enhanced photoluminescence and improved internal quantum efficiency were demonstrated for ultraviolet light emitting diodes (UV-LEDs) with Al nanohole arrays deposited on the top surface. The effects of the thickness and periodicity of the plasmonic structures on the optical properties of UV-LEDs were studied, and an optimized nanohole array parameter was illustrated. Classical electrodynamic simulations showed that the radiated power is mostly concentrated along the edge of the Al nanohole arrays. Even though no obvious dip was observed in the transmission spectra associated with localized surface plasmon resonance, significant improvements in radiatiative recombination and light extraction efficiency were demonstrated, indicating the influence of Al nanohole arrays on the light emission control of UV-LEDs. It is anticipated that the enhanced luminescence can be obtained for various emitting wavelengths by directly adjusting the periodicity and morphology of the Al nanohole arrays and this new technology can alleviate crystal quality requirements of III-nitride thin films in the development of high efficiency UV optoelectronic devices.

Bow reduction of AlInGaN-based deep UV LED wafers using focused laser patterning

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IEEE Photonics Technology Letters
https://doi.org/10.1109/LPT.2018.2869218

We investigated the effect of bow reduction of AlInGaN-based deep-ultraviolet light-emitting diode (DUV LED) wafers using internally focused laser patterning. The laser-induced stress inside of the sapphire substrate was found to increase with increasing density of laser lines and decreasing distance of the laser lines to the back surface of the sapphire substrate. By adjusting the laser process the convex bow of DUV LED wafers could be almost completely eliminated. This bow reduction resulted in an improved uniformity of the LED forward voltage across the wafer compared to the reference wafer without laser patterning.

Finite growth of InGaN/GaN triple-quantum-well microdisks on LiAlO2 substrate

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AIP Advances
https://doi.org/10.1063/1.5041883

We have grown high-quality InxGa1-xN/GaN triple-quantum-well microdisks on LiAlO2 substrate by plasma-assisted molecular beam epitaxy. The InxGa1-xN/GaN microdisk with a hexagonal shape of oblique face 28o-angle off c-axis was achieved. The mechanism of the termination of awl-shaped growth and the growth rates of GaN-barrier and InxGa1-xN-well were evaluated and confirmed with the triple quantum wells. Based on the growth rates and 28o-angle geometric shape, one can control the finite size of InGaN/GaN microdisks by plasma-assisted molecular beam epitaxy.

Localization of current-induced degradation effects in (InAlGa)N-based UV-B LEDs

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Journal of Applied Physics
https://doi.org/10.1063/1.5028047

The degradation behavior of ultraviolet-B light emitting diodes (UV-B LEDs) emitting near 310 nm has been investigated and a method to localize the degradation effects is presented. Measurements of the electro-optical characteristics of UV-B LEDs, during a 200 h constant-current degradation study, showed an initial fast decrease in the optical power accompanied by a decrease in the drive voltage and an increase in the capacitance. Furthermore, by using a specially designed contact geometry, it was possible to separate the degradation of the electrical properties of the p-layers and p-contacts from the degradation of the active region and n-side of the LED heterostructure. Our investigations show that the initial changes in capacitance and voltage can be attributed to changes in the p-side and at the p-contact of the LED, which can be explained by an activation of Mg dopants.

Gate tunable surface plasmon resonance enhanced graphene/Ag nanoparticles-polymethyl methacrylate/graphene/p-GaN heterostructure light-emitting diodes

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Optics Express
https://doi.org/10.1364/OE.26.025257

By combining the surface plasmon enhancement technique with gating effect, a tunable blue lighting emitting diode (LED) based on graphene/Ag nanoparticles (NPs)-polymethyl methacrylate (PMMA)/graphene/p-GaN heterostructure has been achieved. The surface plasmon enhancement is introduced through spin-coating Ag nanoparticles on graphene/p-GaN heterostructure while the gating effect is demonstrated through a graphene/PMMA/graphene sandwich structure, where the top graphene layer acts as the gate electrode. Compared with initial graphene/p-GaN heterostructure LEDs, the electroluminescence (EL) emission intensity of Ag NPs/graphene/p-GaN heterostructure LEDs has been largely enhanced, attributing to the surface plasmon resonance (SPR) of Ag nanoparticles. The EL emission intensity of graphene/Ag NPs-PMMA/graphene/p-GaN heterostructure LEDs can further be gate-tunable effectively through exerting a static voltage between the sandwich structure, which tunes the Fermi level of graphene contacting with p-GaN. These results indicate that through sophisticated design, graphene/Ag NPs-PMMA/graphene/p-GaN heterostructure LEDs can be a potential candidate for many essential electronic and optoelectronic applications.

GaN/AlGaN multiple quantum wells grown on transparent and conductive (-201)-oriented β-Ga2O3 substrate for UV vertical light emitting devices

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Applied Physics Letters
https://doi.org/10.1063/1.5025178

GaN/AlGaN multiple quantum wells (MQWs) are grown on a (2—01)-oriented β-Ga2O3 substrate. The optical and structural characteristics of the MQW structure are compared with those of a similar structure grown on sapphire. Scanning transmission electron microscopy and atomic force microscopy images show that the MQW structure exhibits higher crystalline quality of well-defined quantum wells

when compared to a similar structure grown on sapphire. X-ray diffraction rocking curve and photoluminescence excitation analyses confirm the lower density of dislocation defects in the sample grown on a β-Ga2O3 substrate. A detailed analysis of time-integrated and time-resolved photoluminescence measurements shows that the MQWs grown on a β-Ga2O3 substrate are of higher optical quality. Our work indicates that the (2—01)-oriented β-Ga2O3 substrate can be a potential candidate for UV vertical emitting devices.

High-power blue superluminescent diode for high CRI lighting and high-speed visible light communication

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Optics Express
https://doi.org/10.1364/OE.26.026355

We demonstrated a high-power (474 mW) blue superluminescent diode (SLD) on c-plane GaN-substrate for speckle-free solid-state lighting (SSL), and high-speed visible light communication (VLC) link. The device, emitting at 442 nm, showed a large spectral bandwidth of 6.5 nm at an optical power of 105 mW. By integrating a YAG-phosphor-plate to the SLD, a CRI of 85.1 and CCT of 3392 K were measured, thus suitable for solid-state lighting. The SLD shows a relatively large 3-dB modulation bandwidth of >400 MHz, while a record high data rate of 1.45 Gigabit-per-second (Gbps) link has been achieved below forward-error correction (FEC) limit under non-return-to-zero on-off keying (NRZ-OOK) modulation scheme. Our results suggest that SLD is a promising alternative for simultaneous speckle-free white lighting and Gbps data communication dual functionalities.

Hybrid Cyan Nitride/Red Phosphors White Light-emitting Diodes with Micro-hole structures

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IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2018.2872035

Hybrid white light emitting diodes (LEDs) has been developed utilizing micro-LEDs radiatively pumping down-conversion phosphor materials. The cyan InGaN/GaN multiple quantum wells (MQWs) LEDs with 95 μm in square are fabricated into 4×4 pixels as one unit in 4 inch wafer by photolithography and inductively coupled plasma (ICP) etching techniques. The relatively low turn on voltage and low leakage of cyan micro-LEDs indicate good electrical performance. A significant reduction in the efficiency droop characteristics of cyan micro-LED has been observed in comparison with that of standard green LED. Finally, based on a systemic optimization for white emission indexes, high quality hybrid white light emission has been demonstrated by the combination of blue and cyan micro-LEDs with two types of phosphors, which have a high color rendering index up to 87 at the correlated color temperatures of 6500 K. It also demonstrates a way to adjust the color component by modifying the output power of cyan micro-LED in hybrid LED, showing a promising candidate in a large range of applications including micro-displays, bioinstrumentation, photolithography and lab-on-chip systems in the future.

In Operando Micro-Raman Three-Dimensional Thermometry with Diffraction-Limit Spatial Resolution for GaN-based Light-Emitting Diodes

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PHYSICAL REVIEW APPLIED
http://dx.doi.org/10.1103/PhysRevApplied.10.034049

Confocal micro-Raman microscopy performed in the transparent spectral region of a semiconductor can,

in principle, be used for operando three-dimensional (3D) thermometry with optical diffraction-limit spatial resolution. However, when applied to high-power GaN-based light-emitting diodes (LEDs), the applicability is hindered by the often strong secondary electroluminescence in the visible spectral region that overwhelms the Raman signal. We develop a "split-time-window" scheme that can mimic the continuous wave operation but without the interference of the secondary emission, which allows us to carry out noninvasive 3D temperature profiling and comprehensive thermal analyses of the whole device at any operation current. The technique is applied to an InxGa1−x)N/GaN LED to extract its 3D temperature distribution when operated at 350 mA with µm-scale resolution when using a 532-nm laser. We show that although a conventional technique can yield a reliable average temperature difference between the heat sink and the LED junction (a few degrees), the spatial fluctuations are much larger than the average difference. Furthermore, we show that using the anti-Stokes to Stokes Raman intensity ratio as a metric can yield more reliable and accurate results than using the Raman frequency shift.

High-performance vertical GaN-based near-ultraviolet light-emitting diodes on Si substrates

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Journal of Materials Chemistry C
http://dx.doi.org/10.1039/C8TC04477E

High-performance vertical GaN-based near-ultraviolet (UV) light-emitting diodes (LEDs) on Si substrates with an electroluminescence emission wavelength of 395 nm have been fabricated by designing the epitaxial structures to reduce the dislocation density and enhance the electron confinement and the hole injection. By designing the epitaxial structures with a continuously Al-composition-graded AlGaN interlayer between Al0.30Ga0.70N layer and Al0.15Ga0.85N layer, the dislocation density in epitaxial films has been greatly reduced, and high-quality GaN epitaxial films grown on Si substrates with full-width at half-maximums for GaN(0002) and GaN(10-12) X-ray rocking curves of 260 and 280 arcsec, respectively, have been obtained. Furthermore, by applying an electron blocking layer with 8 periods of AlInGaN/GaN superlattices, both electron confinement and hole injection have been enhanced accordingly. High-performance vertical GaN-based 395 nm UV LED chips with a high light output power of 535 mW and a low forward voltage of 3.10 V at a current of 350 mA, corresponding to a high wall-plug efficiency of 49.3%, which are the best values for the GaN-based 395 nm UV LEDs ever reported. These high-performance near-UV LED chips shed light on the application of medical curing, lighting, etc.

Failure limits and electro-optical characteristics of GaN-based LEDs under electrical overstress

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Microelectronics Reliability
https://doi.org/10.1016/j.microrel.2018.06.054

This work presents the analysis of the degradation mechanisms and of the electro-optical characteristics of light emitting diodes (LEDs) submitted to electrical overstress. The analysis was carried out by a custom-setup, that allows us to measure the current-voltage (I-V) and electroluminescence curves of the devices while pulsing the devices with increasing voltages, up to failure. We investigated a wide span of electrical over-stress (EOS) time durations (from 1 ms to 10 s). The results provide information on (i) the dependence of failure voltage/power level on pulse duration; (ii) on the temperature-dependence of the pulsed I-V characteristics; and (iii) on the changes in electrical and optical properties reached at extremely high current densities. The results presented within this paper provide relevant (and so far unpublished) information on the characteristics of the devices in this extremely high stress regime.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowma

High-fidelity cavity soliton generation in crystalline AlN micro-ring resonators

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Optics Letters
https://doi.org/10.1364/OL.43.004366

Chip-scale mode-locked dissipative Kerr solitons have been realized on various materials platforms, making it possible to achieve a miniature, highly coherent frequency comb source with high repetition rates. Aluminum nitride (AlN), an appealing nonlinear optical material having both Kerr ($\chi 3$), and Pockels ($\chi 2$) effects, has immerse potential for comb self-referencing without the need for external harmonic generators. However, cavity soliton states have not yet been achieved in AlN microresonators. Here, we demonstrate mode-locked Kerr cavity soliton generation in a crystalline AlN microring resonator. By utilizing ultrafast tuning of the pump frequency through single-sideband modulation, in combination with an optimized wavelength scan and pump power-ramp patterns, we can deterministically elongate a ~400 ns short-lived soliton to a time span as long as we wish to hold it.

Green Vertical-Cavity Surface-Emitting Lasers Based on Combination of Blue-Emitting Quantum Wells and Cavity-Enhanced Recombination

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2866406

We fabricated green vertical-cavity surface-emitting lasers by employing $In_xGa_{1-x}N$/GaN quantum wells (QWs) active layers. The In fraction of the QW is 0.18 and the electroluminescence emission peak is around 445 nm, dominantly in the blue. With such QWs embedded in a microcavity, however, lasing was achieved at the emission edge (~ $493 nm), approaching to the green region. Such phenomenon is attributed to the cavity-enhanced recombination, where the cavity effect and photon-electron interactions or the gain enhancement factor play important roles.

Influence of waveguide strain and surface morphology on AlGaN-based deep UV laser characteristics

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Journal of Physics D: Applied Physics
https://doi.org/10.1088/1361-6463/aadb84

The waveguide strain and the surface morphologies of AlGaN-based laser heterostructures emitting in the deep UV spectral range have been investigated. In particular, the impact of the AlGaN heterostructure design on the strain relaxation as well as the effect of the growth temperature on the surface morphology were explored. We found strain-induced plastic relaxation for laser heterostructures with 130 nm thick Al0.45Ga0.55N waveguide layers, whereas pseudomorphic growth was obtained for laser heterostructures with Al0.70Ga0.30N waveguide layers. Optically pumped lasing near 280 nm was demonstrated for the coherently grown laser heterostructures. A strong correlation of the surface morphology with the waveguide growth conditions was also observed. Low growth temperatures of 900 °C lead to a high density of V-pits originating from dislocations. By increasing the growth temperatures to 1070 °C the V-pit density significantly decreases,

resulting in a more than two-fold reduction of the threshold power density of optically pumped lasers.

Improvement of single photon emission from InGaN QDs embedded in porous micropillars

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Applied Physics Letters
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In many InGaN/GaN single photon emitting structures, significant contamination of the single photon stream by background emission is observed. Here, utilizing InGaN/GaN quantum dots incorporated in mesoporous distributed Bragg reflectors (DBRs) within micropillars, we demonstrate methods for the reduction of this contamination. Using the resulting devices, autocorrelation measurements were performed using a Hanbury Brown and Twiss set-up, and thus, we report a working quantum dot device in the III-nitride system utilizing mesoporous DBRs. Uncorrected g(2)(0) autocorrelation values are shown to be significantly improved when excited with a laser at longer wavelengths and lower powers. Through this optimization, we report a g(2)(0) value from a blue-emitting InGaN/GaN quantum dot of 0.126 ± 0.003 without any form of background correction.

Thermal analysis of GaN-based laser diode mini-array

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Chinese Physics B
https://doi.org/10.1088/1674-1056/27/9/094208

Thermal characteristics of multiple laser stripes integrated into one chip is investigated theoretically in this paper. The temperature pattern of the laser diode mini-array packaged in a TO-can is analyzed and optimized to achieve a uniform temperature distribution among the laser stripes and along the cavity direction. The temperature among the laser stripes varies by more than 5 K if the stripes are equally arranged, and can be reduced to less than 0.4 K if proper arrangement is designed. For conventional submount structure, the temperature variation along the cavity direction is as high as 7 K, while for an optimized trapezoid submount structure, the temperature varies only within 0.5 K.

Enhancing the performance of GaN based LDs by using low In content InGaN instead of GaN as lower waveguide laye

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Optics & Laser Technology
https://doi.org/10.1016/j.optlastec.2018.09.021

Performance of InGaN based blue laser diodes (LDs) with different In content of (In)GaN lower waveguide (LWG) layers are investigated by simulation and experimental methods. It is found from the simulation results that the threshold current decreases and slope efficiency increases when the In content of InGaN LWG layer increases from 0% to 6%. However, when the In content is too high, the optical confinement factor of MQWs decreases, recombination rate in LWG layer increases and the surface morphology becomes roughness, all of these result in the deterioration of the performance of LDs with high In content InGaN LWG layer, the output power decreases from 97 to 83 mW at the injection current of 100 mA. It agrees well with the experiment results that the performance of LDs can be improved by using a low In content InGaN instead of GaN as lower waveguide layer.

Design of Room Temperature Electrically Pumped Visible Semiconductor Nanolasers

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IEEE Journal of Quantum Electronics
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This paper presents a comprehensive theoretical study of the optical and thermal properties of an electrically pumped semiconductor nanolaser (SNL) having an GaN/(InGaN/GaN MQWs)/GaN core shell structure. Numerical results show that the lasing whispering-gallery mode (WGM) has a threshold gain of 413 cm-1. Furthermore, it is shown that when it is operated well-above threshold, the device temperature increases by only 22 K above an ambient temperature of 300 K. These promising results are attributed to the strong mode confinement in the active region and the good thermal properties of the material system of the proposed structure. The results presented in this paper offer guidelines for fabrication of electrically pumped room temperature continuous wave SNL operating in the visible spectral region.

Optimization of cubic GaN/AlGaN quantum cascade structures for negative refraction in the THz spectral range

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Optical and Quantum Electronics
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In this work we theoretically investigate a possibility to use cubic nitride based multi-layer periodic nanostructure as a semiconductor metamaterial. The structure design is based on an active region of a quantum cascade laser optimized to achieve optical gain in the Terahertz (THz) spectral range. In particular, we test the GaN/AlGaN quantum well configurations, which should exhibit important advantages compared to GaAs-based structures, namely room temperature operation without the assistance of magnetic field and lower doping densities. Our numerical rate-equations model is solved self-consistently and it takes into account electron-longitudinal optical phonon scattering between all the relevant states among the adjacent periods of the structure. A global optimization routine, specifically genetic algorithm is then used to generate new gain-optimized structures. This work confirms the advantages of cubic GaN designs over GaAs ones, namely feasibility of negative refraction at room temperature without the assistance of magnetic field while keeping the doping densities of the same order of magnitude.

17 000%/W second-harmonic conversion efficiency in single-crystalline aluminum nitride microresonators

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Applied Physics Letters
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High quality factor optical microcavities have been employed in a variety of material systems to enhance nonlinear optical interactions. While single-crystalline aluminum nitride microresonators have recently emerged as a low loss platform for integrated nonlinear optics such as four wave mixing and Raman lasing, few studies have investigated this material for second-harmonic generation. In this letter, we demonstrate an optimized fabrication of dually resonant phase-matched ring resonators from epitaxial aluminum nitride thin films. An unprecendented second-harmonic generation efficiency of 17 000%/W is obtained in the low power regime, and pump depletion is observed at a relatively low input power of 3.5 mW. This poses epitaxial aluminum nitride as the highest efficiency second-harmonic generator among current integrated platforms.

Impact of dislocations on DLTS spectra and degradation of InGaN-based laser diodes

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Microelectronics Reliability
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The aim of this paper is to illustrate the dependence of DLTS characteristics and degradation of InGaN-based laser diodes (LDs) on the density of dislocations. Three groups of multi-quantum well LDs with different dislocation densities were submitted to constant current stress, at room temperature: the analysis is based on combined electrical-optical measurements and Deep-Level Transient Spectroscopy (DLTS) investigation was made before and after stress. DLTS results show the presence of a hole trap in all the samples, whose intensity is related to the dislocation density. Constant current stress induces a significant decrease in the optical power (subthreshold regime), not related exclusively to the dislocation density, and the appearance of a new deep level for electrons (point defect generated after stress).

Structure Optimization of 266 nm Al0.53GaN/Al0.75GaN SQW DUV-LD

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Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2018.09.038

A hypothetical design and investigation regarding an optimization of 266 nm DUV LD for Al0.53GaN/Al0.75GaN single quantum well had been reported. Where, an optical confining problem due to low refractive indexes of QW and QB that has a direct effect on the LD performance has been enhanced, via a narrow auxiliary optical confining layer. This hypothetical report pays attention to some insufficient and fully investigated parameters, thus our report represents valuable findings for future fabrication purposes.

GROUP 3 - Power Electronics

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Simulation Design of High Baliga's Figure of Merit Normally-off P-GaN gate AlGaN/GaN Heterostructure Field Effect Transistors with Junction Field Plates

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Superlattices and Microstructures
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In this paper, we conducted a numerical analysis on novel Normally-off P-GaN gate AlGaN/GaN heterostructure field effect transistors with junction field plates (JFP-HFET). The breakdown voltage (BV) was significantly improved with the introduction of the junction field plate (JFP), which can make a rectangular distribution of the electric field in the GaN channel between the gate and the drain. The highest BV of 1340 V of JFP-HFET could be achieved with the gate to the drain distance Lgd=6 µm, the length of the P-type region of the JFP Lp=5.8 µm, the thickness of the JFP Tj= 500 nm, the doping concentration of P-type region of the JFP Np=1×1017 cm-3, and the Al fraction of the AlGaN JFP xAl=0.25. The optimum parameters of the JFP-HFET were achieved by considering both the principle of charge balance and the practical fabrication of the III-V devices. The highest Baliga's figure of merit (BFOM) 1.2 GW/cm2 was obtained under the conditions of Lgd=6 µm, Lp=5.8 µm, Tj= 100 nm, Np=6×1017 cm-3, and xAl=0.3. C-V, turn-on and turn-off processes revealed that the JFP-HFET showed better switching characteristics than that of the HFET with metal field plate.

High Voltage Vertical GaN p-n Diodes by Epitaxial Lift-Off from Bulk GaN Substrates

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IEEE Electron Device Letters
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High-performance vertical GaN-based p-n junction diodes fabricated using band-gap selective photoelectrochemical (PEC) etching-based epitaxial lift-off (ELO) from bulk GaN substrates are demonstrated. The epitaxial GaN layers and pseudomorphic InGaN release layer were grown by MOCVD on bulk GaN substrates. A comparison study was performed between devices after lift-off processing (after transfer to a Cu substrate) and nominally-identical control devices on GaN substrates without the buried release layer or ELO-related processing. ELO and bonded devices exhibit nearly identical electrical performance, and improved thermal performance, compared to control devices on full-thickness GaN substrates. The breakdown voltage, ideality factor and forward turn-on performance were found to be nearly identical, indicating that the transfer process does not degrade the quality of the p-n junctions. The devices exhibit turn-on voltages of 3.1 V at a current density of 100 A/cm2, with specific on resistance (Ron) of 0.2-0.5 mΩ·cm2 at 5 V and breakdown voltage (Vbr) of 1.3 kV. Both optical and electrical characterization techniques show that the thermal resistance of ELO devices bonded to a Cu carrier is approximately 30% lower than that for control devices on GaN substrates.

Gallium Nitride Integration: Going Where Silicon Power Can't Go

Efficient Power Conversion Corporation

IEEE Power Electronics Magazine
https://doi.org/10.1109/MPEL.2018.2850738

Discusses the challenges that existed in the late 1970s when power engineers working in the field of power metal–oxide–semiconductor field-effect

transistors (MOSFETs) were given the challenge of integrating several power devices to form a monolithic half-bridge that could be used in a variable-speed motor drive. They quickly discovered the difficulty of integrating multiple silicon (Si) power devices into a monolithic component because of the migration of minority carriers from one power device to the next. Solving the problem involved expensive technology. Forty years later, and with the fast developments in gallium nitrideon- Si (GaN-on-Si) technology, multiple power devices can now be monolithically integrated economically. It has been more than eight years since discrete GaN-on-Si power devices hit the off-the-shelf commercial market as replacements for aging Si power MOSFETs. New applications, such as LiDAR and envelope tracking, have benefited from the faster switching speeds and small size of GaN devices.

Enhancement-mode AlGaN/GaN HFET with buried-junction-barrier for breakdown improvement and threshold-voltage modulation

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Superlattices and Microstructures
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A novel AlGaN/GaN heterojunction field-effect transistor (HFET) with buried-junction-barrier (BJB) is proposed in this work. In the BJB-HFET, a thin PGaN layer was inserted in the unintentionally doped GaN channel layer, which introduces a buried PN-junction beneath the gate region. Owing to the presence of the PN-junction, in “OFF-state”, a reverse-biased barrier for electrons is formed along the channel in GaN buffer, which effectively reduces the buffer leakage current of the device. Moreover, the BJB also facilitates to obtain a uniform electric-field (E-field) distribution in the depletion region that dictates breakdown voltage (BV) improvement. For a AlGaN/GaN BJB-HFET with a gate-drain distance of 5 µm, a BV as high as 1190 V at leakage current of 10 µA/mm is achieved with a low specific on-resistance (Ron,sp) of 0.54 mΩ cm2, which yields a significantly high Baliga's Figure-of-Merit (FOM) of 2.83 GW/cm2. Besides, benefiting from the energy-band modulation capability of the BJB structure, a higher threshold-voltage (Vth) can be simultaneously obtained in the BJB-HFET compared with the conventional heterojunction field-effect transistor (Conv. HFET). The proposed BJB structure is of great potential for high performance AlGaN/GaN power transistors.

High-Performance LPCVD-SiNx/InAlGaN/GaN MIS-HEMTs with 850-V 0.98-mΩ·cm2 for Power Device Applications

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IEEE Journal of the Electron Devices Society
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We demonstrate the electrical performances of the quaternary InAlGaN/GaN MIS-HEMTs with high quality SiNx gate dielectric and surface passivation layer deposited by low pressure chemical vapor deposition (LPCVD) at 780 ∘C. Excellent LPCVD-SiNx/InAlGaN interface and SiNx film quality were obtained, resulting in very high output current density, a very small threshold voltage hysteresis and steep subthreshold slope. The LPCVD-SiNx/InAlGaN/GaN MIS-HEMT device exhibited high ON/OFF current ratio, large gate voltage swing, high breakdown voltage, and very low dynamic ON-resistance (RON) degradation, meaning effective current collapse suppression compared to the plasma enhanced chemical vapor deposition (PECVD)-SiNx/InAlGaN/GaN MIS-HEMTs. The corresponding specific ON-resistance (RON,sp) for LPCVD-SiNx device was as low as 0.98 mΩ·cm2, yielding a high figure of merit (FOM) of 737 MW/cm2. These results demonstrate a great potential of the LPCVD-SiNx/InAlGaN/GaN MIS-HEMTs for high-power switching applications.

A Novel Enhancement-Mode GaN Vertical MOSFET with Double Hetero-Junction for Threshold Voltage Modulation

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Superlattices and Microstructures
https://doi.org/10.1016/j.spmi.2018.09.010

A novel Enhancement-mode (E-mode) GaN vertical power MOS transistor (VMOS) with GaN/AlGaN/GaN double heterojunction (DH) is proposed in this work. The polarization effect of the top GaN/AlGaN hetero-junction can be engineered by tailoring the top GaN layer thickness, which enables flexibly modulate the threshold voltage (Vth) of the DH-VMOS. Meanwhile, the two-dimensional electron gas (2-DEG) at the lower AlGaN/GaN hetero-interface performs as part of the conduction channel of the device which is beneficial for device on-resistance (Ron) reduction. By increasing the top GaN layer thickness from 5 to 40 nm the Vth of the DH-VMOS can be shifted from +2.9 to +4 V. The demonstrated device structure presents a novel and controllable approach to modulate the Vth of E-mode GaN vertical power devices, which is of great interests for GaN power device for over kilo-volt applications.

AlGaN/GaN MIS-HEMT With AlN Interface Protection Layer and Trench Termination Structure

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IEEE Transactions on Electron Devices
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In this brief, an AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistor (MIS-HEMT) with pulsed laser deposited AlN interface protection layer (IPL) and trench termination (T^2) structure is experimentally and theoretically investigated. The AlN IPL could effectively improve the interface quality and reduce the interface trap density, which is verified by frequency-dependent C-V measurement and conductance method. The T^2 structure extends the depletion region and increases the average electric field (E-field) strength between the gate and drain, achieving an enhanced breakdown voltage (BV). The measured BV and saturated output current density are 412 V and 505 mA/mm for the device at LG/LGS/LGD/WG= sf1.5/1.5/5/10 µm, respectively. Compared with the MIS-HEMT without T^2 structure, the proposed device increases the BV by 63%.

Influence of channel/back-barrier thickness on the breakdown of AlGaN/GaN MIS-HEMTs

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Journal of Semiconductors
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The leakage current and breakdown voltage of AlGaN/GaN/AlGaN high electron mobility transistors on silicon with different GaN channel thicknesses were investigated. The results showed that a thin GaN channel was beneficial for obtaining a high breakdown voltage, based on the leakage current path and the acceptor traps in the AlGaN back-barrier. The breakdown voltage of the device with an 800 nm-thick GaN channel was 926 V @ 1 mA/mm, and the leakage current increased slowly between 300 and 800 V. Besides, the raising conduction band edge of the GaN channel by the AlGaN back-barrier lead to little degradation for sheet 2-D electron gas density, especially, in the thin GaN channel. The transfer and output characteristics were not obviously deteriorated for the samples with different GaN channel thickness. Through optimizing the GaN channel thickness and designing the AlGaN back-barrier, the lower leakage current and higher breakdown voltage would be possible.

High-performance quasi-vertical GaN Schottky diode with low turn-on voltage

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Superlattices and Microstructures
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In this letter, we demonstrate high performance GaN vertical Schottky diode on sapphire substrate. With optimized device structure and adopting low dislocation patterned sapphire substrate (PSS), a high DC performance with low turn-on voltage of 0.45 V, on-resistance of 0.084 mΩ cm2 and breakdown voltage above 100 V is achieved at a 6 × 100 μm2 anode size. Meanwhile, two types of GaN Schottky barrier diode (SBD) with different anode area were fabricated to investigate its influence on device characteristics. We have observed a larger current density and smaller leakage current with reducing the anode size, contributing to a more compact design for cost reduction.

Fabrication of High-Uniformity and High-Reliability Si_3N_4/AlGaN/GaN MIS-HEMTs With Self-Terminating Dielectric Etching Process in a 150-mm Si Foundry

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IEEE Transactions on Electron Devices
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A novel early gate dielectric AlGaN/GaN metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) process is reported. With the high-quality Si_3N_4 dielectric by low-pressure chemical vapor deposition and damage free, self-terminating passivation layer etching at the gate area, the MIS-HEMTs on 150-mm Si substrate demonstrate excellent output performance and good uniformity. The interface trap density between the gate insulator and the barrier layer is as low as 2 x 10^{12} $cm^{-2} \cdot eV^{-1}$ extracted by the conductance method. The MIS-HEMT fabricated on the wafer delivers an extremely small gate leakage current of 10^{-9} mA/mm and a high Ion/Ioff ratio of 10^{11}. The subthreshold swing (SS) is around 80 mV/dec, and the saturated output current density is 750 mA/mm. The dynamic on-resistance increases about 42% at a quiescent drain bias of 600 V. The Vth shift is -0.63 and -0.89 V at a high temperature of 200 °C and negative gate-bias stress of -25 V, respectively, indicating a comparable stability with the state-of-the-art MIS-HEMTs. An excellent threshold voltage and SS uniformity (1 - σ /μ) with the value of 94.5% and 95.2% are achieved on the 150-mm wafer.

Reduction of leakage current at the SiNx/GaN interface in GaN Schottky diodes

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Journal of Materials Science: Materials in Electronics
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The breakdown characteristics for a GaN wraproud field plate diode are compared to those of a planar diode and a mesa diode to determine the improvement due to the field plate geometry. Mesa diodes exhibit a higher breakdown voltage compared to planar diodes, in agreement with simulation models. Wraparound field plate diodes, however, show high leakage current resulting in lower breakdown values than predicted. It is found that the extra leakage is caused by damage from the plasma enhanced chemical vapor deposition of the SiNx used to form the field plate. To mitigate the leakage current, atomic layer deposition was used to put down a protective Al2O3 prior to SiNx deposition. This significantly reduced the leakage current and raised the breakdown voltage of the wraparound Schottky diodes.

Impact of carbon impurities on the initial leakage current of AlGaN/GaN high electron mobility transistors

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Microelectronics Reliability
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We have systematically studied the origin of high gate-leakage currents in AlGaN/GaN high electron mobility transistors (HEMTs). Devices that initially had a low gate-leakage current (good devices) are compared with ones that had a high gate-leakage current (bad devices). The apparent zero-bias Schottky barrier height of bad devices ($0.4 < \varphi B0 < 0.62$ eV) was found to be lower than that of the good devices ($\varphi B0 = 0.79$ eV). From transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS) analysis, we found that this difference is due to the presence of carbon impurities in the nickel layer in the gate region.

Degradation of GaN-on-GaN vertical diodes submitted to high current stress

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Microelectronics Reliability
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GaN-on-GaN vertical devices are expected to find wide application in power electronics, thanks to the high current densities, the low on-resistance and the high breakdown voltage. So far, only few papers on the reliability of GaN-on-GaN vertical devices have been published in the literature. This paper investigates the degradation of GaN-on-GaN pn diodes submitted to stress at high current density. The study was carried out by means of electrical characterization and electroluminescence (EL) measurements. We demonstrate that: (i) when submitted to stress at high current density, the devices show significant changes in the electrical characteristics: an increase in on-resistance/turn-on voltage, an increase in the generation/recombination components, the creation of shunt-paths. (ii) the increase in on-resistance is strongly correlated to the decrease in the EL signal emitted by the diodes. (iii) the degradation kinetics have a square-root dependence on time, indicative of a diffusion process. The results are interpreted by considering that stress induces a diffusion of hydrogen from the highly-p-type doped surface towards the pn junction. This results in a decrease in hole concentration, due to the creation of MgH bonds, and in a lower hole injection. As a consequence, on-resistance increases while EL signal shows a correlated decrease.

A new electro-optical transmission-line measurement-method revealing a possible contribution of source and drain contact resistances to GaN HEMT dynamic on-resistance

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Microelectronics Reliability
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Despite their potential in the field of power electronics, many reliability issues still affect the electrical performance of Gallium Nitride HEMT power devices and require an effort of analysis and understanding. The characterization of the on-state resistance of this transistor is necessary to understand the dynamics of some phenomena such as trapping. The degradation of this resistance has always been related to traps in the 2DEG channel, without taking into consideration possible contributions from the source and drain contacts (metal/semiconductor). In this work, resistance measurements, with and without ultra-violet illumination, are performed on three different technological options to highlight the effect of illumination on contact resistances.

Effect of power cycling tests on traps under the gate of Al2O3/AlGaN/GaN normally-ON devices

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Microelectronics Reliability
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GaN-based power components are known to exhibit reversible instabilities in their electrical characteristics, particularly in the threshold voltage and in the on-state resistance. This is due to trap effects in the structure. Works presented in this paper attempt to answer the question of how are these traps affected during aging by power cycling and especially if there is irreversible degradation. For this purpose, power cycling tests were performed using 80 K of junction temperature swing on Normally-ON Al2O3/AlGaN/GaN MOS-HEMTs power chips reported on a direct copper bonding (DCB) substrate. The aging has been regularly interrupted in order to perform characterization of several aging indicators. Furthermore, trap characterizations, based on the analyses of transient current measurements, have been carried out during the aging process. The results show that irreversible degradation affects threshold voltage with drift to negative values for all tested samples. These drifts were mainly attributed to cumulative trapping with power cycles, probably induced by hot electrons, in a progressive and non-recoverable way.

Effect of HTRB lifetest on AlGaN/GaN HEMTs under different voltages and temperatures stresses

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Microelectronics Reliability
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Space and transport industries are facing a strong global competition which is setting economic constraints on the entire supply chain. In order to address decreasing development costs and to propose new features, components-off-the-shelf (COTS) have become a very attractive solution. This paper investigates the degradation of AlGaN/GaN HEMTs COTS submitted to HTRB lifetest. Temperature and voltage step stresses were applied to untangle the effect of each stressor. The main aim is to establish a lifetime model, taking into account several degradation mechanisms, over a large range of temperatures and voltages. The experimental outcomes highlight the activation of different failure mechanisms occurring during the stress tests, and which depend from the different temperature and voltage working ranges. In this work, experimental analysis has been performed in order to characterize the root cause behind the activation of these multiple failure mechanisms and estimate the operative range where they may superimpose.

Impact of sidewall etching on the dynamic performance of GaN-on-Si E-mode transistors

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Microelectronics Reliability
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The aim of this paper is to investigate the role of the etching of the sidewalls of p-GaN on the dynamic performance of normally-off GaN HEMTs with p-type gate. We analyze two wafers having identical epitaxy but with different recipes for the sidewall etching, referred to as “Etch A” (non-optimized) and “Etch B” (optimized). We demonstrate the following relevant results: (i) the devices with non-optimized etching (Etch A), when submitted to positive gate bias, show a negative threshold voltage shift and a decrease in Ron, which are ascribed to hole injection under the gate and/or in the access regions; (ii) transient characterization indicates the existence of two trap states, with activation energies of 0.84 eV (CN defects) and 0.30 eV. The latter (with time-constants in the ms range) is indicative of the hole de-trapping process, possibly related to trap states in the AlGaN barrier or at the passivation/AlGaN interface; (iii) by optimizing the p-GaN sidewall etching (for the same epitaxy) it is possible to completely eliminate the threshold voltage shift. This indicates that hole injection mostly takes place along the sidewalls.

Failure analysis of 650 V enhancement mode GaN HEMT after short circuit tests

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Microelectronics Reliability
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The paper presents the results of a post failure analysis performed on commercial 650 V GaN power HEMT after short circuit destructive tests. The used experiment set up includes a protection circuit able to avoid the explosion of the sample during the test. Moreover, it limits the energy involved in the failure and facilitates the identification of the areas where the failure is initiated. The post failure analysis confirms that DUTs exhibit two kinds of failures. In the first failure mode, for which large energies are dissipated in the device before the failure, the damaged area of the chip is quite large and is located close to external drain contacts. In this area, very likely, the temperature exceeds the melting temperature of the metallization. The second failure mode is observed for higher values of the drain voltage and involves lower energies dissipated in the DUT during SC before the failure. In this case, the damaged area is very small and is located below the source field plate at gate edge on the drain side. 2D finite element simulations show that in this region the dissipated power density becomes very high and can cause the local temperature to exceed the temperature limit of GaN/AlGaN structure.

Radiation robustness of normally-off GaN/HEMT power transistors (COTS)

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Microelectronics Reliability
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This work aims to characterize the sensitivity to cosmic radiation of GaN Normally-off commercial technologies used in switching power conversion. It is necessary for the Space, Aeronautics and Automotive industries to characterize the radiation robustness of these new Commercial Off-The-Shelf (COTS) components in the operational and environmental conditions of their applications. Electrical behaviour of normally-off GaN power transistors under heavy ion test campaign is presented to define the cross section, determine the safe operating area (SOA) and analysis the mechanism of Single Event Effects (SEE) in these devices.

Degradation of vertical GaN-on-GaN fin transistors: Step-stress and constant voltage experiments

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Microelectronics Reliability
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We present an extensive analysis of the degradation of GaN-on-GaN fin-vertical transistors submitted to stress under positive gate voltage and off-state conditions. By analysing the degradation kinetics we demonstrate the existence of different processes: (i) trapping of electrons in the gate insulator under positive gate bias, (ii) time-dependent breakdown of the gate MOS structure under forward gate voltage; (iii) catastrophic failure for off-state voltages higher than 280 V. 2D simulations are used to identify the physical location of the failed region, and to investigate the dependence of electric field on fin width (values between 70 nm, 195 nm and 280 nm).

Evolution of C-V and I-V characteristics for a commercial 600 V GaN GIT power device under repetitive short-circuit tests

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Microelectronics Reliability
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In this article, a repetitive and non-destructive short-circuit aging test is developed to characterize the electrical parameters evolutions of a 600 V GaN Gate Injection Transistor (GIT). The evolutions of C-V and I-V characteristics during the repetitive short-circuit tests with a relatively low bias voltage and long pulse duration are presented and summarized. The capacitance CGD at on-state mode and the gate

current at relative high gate voltage show significant degradations before and after test.

On the impact of substrate electron injection on dynamic Ron in GaN-on-Si HEMTs

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Microelectronics Reliability
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The impact of electron injection from the substrate on the dynamic Ron of GaN-on-Si High Electron Mobility Transistors (HEMTs) has been investigated by means of back-bias transient and vertical leakage measurements and TCAD simulations. A strong correlation between electrons injected from the substrate and on-state drain current transients is demonstrated. Moreover, the contribution of the electron-type traps in the buffer layer as opposed to the usually studied hole-like traps to the dynamic Ron is discussed. In particular, the impact of electron-like traps for different levels of substrate leakage current is studied. A TCAD model has been developed and calibrated by taking into account both off-state vertical leakage and on-state drain current transient experimental results. The proposed charge dynamic has also been assessed against state-of-the-art theories. This analysis contributes to a deeper understanding of the complex scenario of different types of traps in the buffer layer of GaN-on-Si devices and highlights the impact that trap-states can have on the on-state and off-state currents.

Impact of the substrate and buffer design on the performance of GaN on Si power HEMTs

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Microelectronics Reliability
https://doi.org/10.1016/j.microrel.2018.06.036

This paper presents an extensive analysis of the impact of substrate and buffer properties on the performance and breakdown voltage of E-mode power HEMTs. We investigated the impact of buffer thickness, substrate resistivity and substrate miscut angle, by characterizing several wafers by means of DC and pulsed measurement.
The results demonstrate that: (i) the resistivity of the silicon substrate strongly impacts on the breakdown voltage and vertical leakage current. In fact, highly resistive substrates may partly deplete under high vertical bias, thus limiting the total potential drop on the epitaxial layers. As a consequence, the vertical IV plots show a “plateau”, that limits the vertical leakage. (ii) the depletion of the substrate may worsen the dynamic performance of the devices, due to an enhancement of buffer trapping. (iii) Larger buffer thickness results in an increased robustness of the vertical stack, due to the thicker insulating region. (iv) the miscut angle (0°, 0.5°, and 1°) can significantly impact on both threshold voltage and the 2DEG density; devices with miscut substrate have higher current density. On the other hand, the dynamic on-resistance variation is comparable in the three cases.

GROUP 4 - Advanced Electronics and RF

Group leader: Jean-Claude Dejaeger (IEMN)

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

Comparative study on calculated terahertz absorption spectra of different heterostructure materials with external magnetic field

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Journal of Physics Communications
https://doi.org/10.1088/2399-6528/aadbba

Room temperature operation and frequency tunability are attractive advantages of terahertz (THz) detectors based on the two-dimensional electron gas (2DEG) in the heterostructure material with external magnetic field. This work compared absorption spectra of four typical heterostructure materials (AlGaN/GaN, InAlN/GaN, AlGaAs/GaAs and SiGe/Si) with the nonlocal magnetoconductivity model at ambient and cryogenic temperatures in the frequency range 0–5 THz. The GaN based materials have the highest absorption amplitude, while the AlGaAs/GaAs material owns the largest frequency shift as the magnetic field increases up to 10 tesla, although superconducting magnets at cryogenic temperature are usually employed to provide that high magnetic field. The numerical results showed that the absorption properties (amplitude and frequency) could be further optimized by other parameters, such as the period and filling factor of the grating coupler, and the barrier thickness.

Investigations of Active Antenna Doherty Power Amplifier Modules Under Beam-Steering Mismatch

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IEEE Microwave and Wireless Components Letters
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This letter investigates the performance of a Doherty power amplifier (DPA) in an 8x1 active antenna transmitter module under an average voltage-standing-wave ratio of 4:1 induced by the array 1-D beam steering and mutual coupling. The GaN-based DPA and a 2x1 segment of the array are verified via measurements at the operating frequency of 3.5 GHz. The co-design and co-simulation of both the antenna array and the behavioral model of the DPA show that the inherent back-off efficiency benefit--when compared to traditionally used class-AB and -B amplifiers in base stations--can be maintained when restricting the beam-steering angle, in this case $\theta \in [-45°,45°]$, and operational bandwidth of the combined system.

Effect of proton irradiation energy on SiNx/AlGaN/GaN metal-insulator semiconductor high electron mobility transistors

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Journal of Vacuum Science & Technology B
https://doi.org/10.1116/1.5049596

The effects of proton irradiation energy on the electrical properties of SiNx/AlGaN/GaN metal-insulator semiconductor high electron mobility transistors (MISHEMTs) using in situ grown silicon nitride as the gate dielectric were studied. The SiNx/AlGaN/GaN MISHEMT devices were irradiated with protons at energies of 5, 10, or 15 MeV at a fixed fluence of 2.5×1014 cm−2. The largest amount of device degradation was shown in the samples irradiated with the lowest irradiation energy of 5 MeV. The DC saturation current was reduced by 10.4%, 3.2%, and 0.5% for MISHEMTs irradiated with proton energies of 5, 10, and 15 MeV, respectively. Device performance degradation was more pronounced in the irradiated samples under high-frequency operation. At a frequency of 100 kHz, the

percent saturation drain current reduction at a gate voltage of 3 V was 40%, 19%, and 17% after proton irradiation at 5, 10, and 15 MeV, respectively. The carrier removal rates for the MISHEMT devices were in the range of 21–144 cm−1 for the proton irradiation energies studied. The measured DC degradation and carrier removal rates are lower than the values reported for AlGaN/GaN metal-gate high electron mobility transistor devices irradiated at similar conditions, which can be attributed to the SiNx insulating layer reducing the total damage on the AlGaN surface.

Comparison of unit cell coupling for grating-gate and high electron mobility transistor array THz resonant absorbers

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Journal of Applied Physics
https://doi.org/10.1063/1.5032102

We report experimental studies on the excitation of synchronized plasmon resonances in AlGaN/GaN High Electron Mobility Transistor (HEMT) arrays. In contrast to the commonly employed grating-gate configurations, the analyzed structure contains periodically patterned ohmic contacts to the two-dimensional electron gas, which are laid-out parallel to the gate fingers. In this structure, the terahertz to plasmon coupling mechanism is fundamentally different from that in grating-gate configurations. Whereas the grating-gate configuration constitutes a coupled resonant system in which the resonance frequency depends on the grating periodicity, when periodical ohmic contacts are incorporated, the system behaves as a synchronized resonant system in which each unit cell is effectively independent. As a result, in a HEMT-array, the resonance is no longer set by the periodicity but rather by the gate and the ungated region length. Experimental results of fabricated samples compare well with numerical simulations and theoretical expectations. Our work demonstrates that the proposed approach allows: (i) more efficient excitation of high order plasmon modes and (ii) superior overall terahertz to plasmon coupling, even in configurations having less number of devices per unit area. From this perspective, our results reveal a simple way to enhance the terahertz to plasmon coupling and thus improve the performance of electron plasma wave-based devices; this effect can be exploited, for example, to improve the response of HEMT-based terahertz detectors.

Coeffect of trapping behaviors on the performance of GaN-based devices

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Journal of Semiconductors
https://doi.org/10.1088/1674-4926/39/9/094007

Trap-induced current collapse has become one of the critical issues hindering the improvement of GaN-based microwave power devices. It is difficult to study the behavior of each trapping effect separately with the experimental measurement. Transient simulation is a useful technique for analyzing the mechanism of current collapse. In this paper, the coeffect of surface- and bulk-trapping behaviors on the performance of AlGaN/GaN HEMTs is investigated based on the two-dimensional (2D) transient simulation. In addition, the mechanism of trapping effects is analyzed from the aspect of device physics. Two simulation models with different types of traps are used for comparison, and the simulated results reproduced the experimental measured data. It is found that the final steady-state current decreases when both the surface and bulk traps are taken into account in the model. However, contrary to the expectation, the total current collapse is dramatically reduced (e.g. from 18% to 4% for the 90 nm gate-length device). The results suggest that the surface-related current collapse of GaN-based HEMTs may be mitigated in some degree due to the participation of bulk traps with short time constant. The work in this paper will be helpful for further optimization design of material and device structures.

Effect of SiN:H x passivation layer on the reverse gate leakage current in GaN HEMTs

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Chinese Physics B
https://doi.org/10.1088/1674-1056/27/9/097309

This paper concentrates on the impact of SiN passivation layer deposited by plasma-enhanced chemical vapor deposition (PECVD) on the Schottky characteristics in GaN high electron mobility transistors (HEMTs). Three types of SiN layers with different deposition conditions were deposited on GaN HEMTs. Atomic force microscope (AFM), capacitance–voltage (C–V), and Fourier transform infrared (FTIR) measurement were used to analyze the surface morphology, the electrical characterization, and the chemical bonding of SiN thin films, respectively. The better surface morphology was achieved from the device with lower gate leakage current. The fixed positive charge Q f was extracted from C–V curves of Al/SiN/Si structures and quite different density of trap states (in the order of magnitude of 1011–1012 cm−2) was observed. It was found that the least trap states were in accordance with the lowest gate leakage current. Furthermore, the chemical bonds and the %H in Si–H and N–H were figured from FTIR measurement, demonstrating an increase in the density of Q f with the increasing %H in N–H. It reveals that the effect of SiN passivation can be improved in GaN-based HEMTs by modulating %H in Si–H and N–H, thus achieving a better Schottky characteristics.

High Performance InAlN/GaN/Si High Electron Mobility Transistor Using Microwave Ohmic Annealing Technique

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ECS Journal of Solid State Science and Technology,
http://dx.doi.org/10.1149/2.0071810jss

In this study, a high-performance InAlN/GaN high electron mobility transistor (HEMT) was fabricated using low-temperature microwave annealing (MWA) as the ohmic metal alloy process for the first time. Ni–Al alloy aggregation is significant for InAlN devices because of the high Al fraction in InAlN layer. Furthermore, the indium segregation and out-diffusion of the InAlN barrier layer resulted in lower drain current and the formation of extra trap centers. Compared with traditional rapid thermal annealing with a high-temperature process window, MWA results in simultaneously superior ohmic contact and wafer sheet resistances because of the superior surface morphology of the ohmic metal alloy in the MWA device. Moreover, the heterostructure interfacial quality of two-dimensional electron gas density can be maintained through low-temperature MWA, as indicated by reciprocal space map measurements. Furthermore, Baliga's figure-of-merit calculation indicated that the MWA-InAlN HEMT had superior DC characteristics, providing improved device radiofrequency bandwidth and output power density performance.

Accurate Measurement of Channel Temperature for AlGaN/GaN HEMTs

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2868807

This paper proposes a novel electrical method for the determination of channel temperature in AlGaN/GaN high-electron mobility transistors. A test structure combining various device geometries has been utilized to achieve the temperature dependence of the channel resistance and then applied to detect the channel temperature under the gate instead of that at the gate edge on the drain side. A 2-D electrothermal model has been built, and the model demonstrates excellent agreement with the

experimental data. Compared with gate resistance thermometry and micro-Raman spectroscopy, our method has advantages of high accuracy, easy positioning, and immunity to the gate head geometry. This facilitates its potential for temperature extraction, especially for short channel devices. Finally, we apply this method to different device structures to demonstrate its scalability, and the uncertainty caused by current collapse is also discussed.

Resistive nickel temperature sensor integrated into short-gate length AlGaN/GaN HEMT dedicated to RF applications

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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2018.2864643

This paper describes a new method to extract the operating temperature in short-gate length AlGaN/GaN High Electron Mobility Transistors (HEMTs) dedicated to RF applications. For this goal, a nickel resistive sensor is integrated into the HEMT active area close to the hot thermal spot thanks to a well-suited technological process. Operating temperature of the HEMT is extracted showing the capabilities of this method to monitor the thermal behavior of the device. Furthermore, it is shown that DC and RF characteristics are not degraded by additional parasitic capacitance and/or sensor biasing.

Assessing GaN FET Performance Degradation in Power Amplifiers for Pulsed Radar Systems

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IEEE Microwave and Wireless Components Letters
https://doi.org/10.1109/LMWC.2018.2867732

GaN FETs have achieved superior performance in the design of microwave power circuits. Nevertheless, the amount of dispersion related to this technology poses severe issues for the correct modeling and characterization of these devices. In this letter, the effects of GaN FET dispersion on the design of power amplifiers (PAs) with dynamic power supply, largely adopted in state-of-the-art high-efficiency pulsed radar transmitters, are discussed. In particular, we propose a technique for evaluating GaN device performance degradation in new-generation PAs that represents an effective alternative to pulsed-RF multiharmonic source/load-pull microwave setups.

TCAD Simulation for Nonresonant Terahertz Detector Based on Double-Channel GaN/AlGaN High-Electron-Mobility Transistor

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2869291

We propose a nonresonant terahertz (THz) detector based on double-channel (DC) GaN/AlGaN high-electron-mobility transistor (HEMT) utilizing a technology computer-aided design platform. The hydrodynamic model is simplified as the drift-diffusion model for nonresonant THz detection simulation. Dependence of THz photoresponse on various structure parameters of the detector is analyzed by simulation. The two typical metrics, responsivity and noise equivalent power (NEP), are theoretically calculated for the optimization of the structure parameters. The optimized responsivity and NEP reach 5.8 kV/W and 50 pW/Hz0.5 at the same gate voltage, respectively, and a minimum NEP of 20 pW/Hz0.5 is obtained. The comparison between our simulation results and the experiment data of single-channel HEMT detector proves that the DC HEMT detector shows an excellent THz detection performance.

Low-Loss Coplanar Waveguides on GaN-on-Si Substrates

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IEEE Microwave and Wireless Components Letters
https://doi.org/10.1109/LMWC.2018.2867084

Low-loss coplanar waveguides (CPWs) on AlGaN/GaN HEMT heterostructures grown on high-resistivity Si substrates (GaN-on-Si) are demonstrated. Performance has been evaluated from 0.1 to 20 GHz, and loss as low as 0.27 dB/mm at 20 GHz is achieved. The performance of CPWs fabricated with ion implant- and mesa etching-based processes are compared, and finite element simulations are used to analyze the CPW loss mechanisms. In this frequency range, the dielectric loss associated with the GaN-on-Si substrate is below 0.065 dB/mm, compared to approximately 0.01 dB/mm for reference GaN-on-SiC CPW lines. The extra loss in the GaN-on-Si CPWs is due to a parasitic conductive layer with a sheet resistance of $2x10^4$ Ω/□. The low loss obtained, combined with the economic and integration advantages of GaN-on-Si substrates, makes them promising for GaN monolithic microwave integrated circuits.

Al_2O_3-Dielectric InAlN/AlN/GaN Γ-Gate MOS-HFETs with Composite Al_2O_3/TiO_2 Passivation Oxides

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IEEE Journal of the Electron Devices Society
https://doi.org/10.1109/JEDS.2018.2870844

Novel Al_2O_3-dielectric InAlN/AlN/GaN Γ-Gate metal-oxide-semiconductor heterostructure field-effect transistors (MOS-HFETs) with composite Al_2O_3/TiO_2 passivation oxides formed by using ultrasonic spray pyrolysis deposition (USPD)/RF sputtering, respectively, are investigated. The Γ-gate includes a 1-μm long active gate on the Al_2O_3 dielectric and a 1-μm long field-plate (FP) on the composite Al_2O_3/TiO_2 oxides. The present Γ-Gate MOS-HFET has demonstrated excellent on/off current ratio (Ion/Ioff) of 8.2×10^{10}, subthreshold swing (SS) of 102.3 mV/dec, maximum extrinsic transconductance of (gm, max) of 210.1 mS/mm, maximum drain-source saturation current density (IDS, max) of 868.3 mA/mm, two-terminal off-state gate-drain breakdown voltage (BVGD) of -311.2 V, three-terminal drain-source breakdown voltage (BVDS) of 237 V at VGS = -10 V, and power-added efficiency (P.A.E.) of 39.9% at 2.4 GHz. A conventional Schottky-gate HFET and TiO_2-dielectric MOS-HFET were also prepared in comparison. The present design has shown superior DC/RF device performance. It is suitable for high-power RF circuit applications.

Stability and robustness of InAlGaN/GaN HEMT in short-term DC tests for different passivation schemes

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Microelectronics Reliability
https://doi.org/10.1016/j.microrel.2018.07.142

On-wafer short term step-stress tests were carried out to evaluate InAlGaN/GaN HEMT devices. Three types of transistor were studied, each one having a specific two dielectric layer passivation. The results of these tests demonstrate that the upper layer of the passivation has a strong impact on the ageing of the devices. When the upper layer is an Al2O3 Atomic Layer Deposited one, the transistors show a better stability of their electrical parameters than those passivated with the other stacks.

ASM GaN: Industry Standard Model for GaN RF and Power Devices--Part-II: Modeling of Charge Trapping

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2868261

Because of charge trapping in GaN HEMTs, dc characteristics of these devices are not representative of high-frequency operation. The advanced spice model GaN model presented in Part I of this paper is combined with a Shockley-Reed-Hall-based trap model, yielding a comprehensive FET

model for GaN HEMTs which can accurately model GaN devices exhibiting trapping-related dispersion effects. Measurement results of the dc and pulsed output and transfer characteristics of a commercially available GaN HEMT are presented, trapping in the device is modeled, and excellent fit to the measured data is shown. This paper presents an accurate model of trapping which is validated for eight different quiescent bias points of pulse measurements, with quiescent drain voltage ranging from 5 to 20 V and quiescent gate voltage ranging from -2.8 to -3.8 V, and a large range of gate and drain voltages to which the device was pulsed in the pulse measurements and at which the device was measured in the dc measurements, with gate voltage ranging from -4 to 0.4 V and drain voltage ranging from 0 to 40 V. This paper also presents high-frequency (10 GHz) large-signal RF validation of the model for optimal complex load condition.

Comparison of reliability of 100 nm AlGaN/GaN HEMTs with T-gate and SAG-gate technology

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Microelectronics Reliability
https://doi.org/10.1016/j.microrel.2018.06.042

The effect of gate technology and semiconductor passivation on the switching speed and device reliability has been investigated. By reducing the parasitic capacitances and reducing the passivation induced surface charge density a median lifetime of around 106 h at a channel temperature of 125 °C and a current-gain cut-off frequency of 74 GHz for a T-gate technology has been achieved. By electroluminescence and TEM cross-sectioning of a stressed device a local inhomogeneous pit formation process was found as the major degradation mechanism for the decrease of the saturation current.

Computational study of Fermi kinetics transport applied to large-signal RF device simulations

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Journal of Computational Electronics
https://doi.org/10.1007/s10825-018-1242-5

A detailed description and analysis of the Fermi kinetics transport (FKT) equations for simulating charge transport in semiconductor devices is presented. The fully coupled nonlinear discrete FKT equations are elaborated, as well as solution methods and work-flow for the simulation of RF electronic devices under large-signal conditions. The importance of full-wave electromagnetics is discussed in the context of high-speed device simulation, and the meshing requirements to integrate the full-wave solver with the transport equations are given in detail. The method includes full semiconductor band structure effects to capture the scattering details for the Boltzmann transport equation. The method is applied to high-speed gallium nitride devices. Finally, numerical convergence and stability examples provide insight into the mesh convergence behavior of the deterministic solver.

HiSIM_GaN: Compact Model for GaN-HEMT With Accurate Dynamic Current-Collapse Reproduction

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2868284

The compact model of HIroshima-University Starc Igfet Model (HiSIM)_GaN for GaN-HEMT devices is reported, which solves the Poisson equation iteratively, in a similar way as the industry-standard compact HiSIM models for other semiconductor devices. The model considers all possible charges induced within the device, including the dynamically varying trap density. It is verified that the model can reproduce the 2-D-device simulation results accurately. In particular, the operation frequency

dependence of the current collapse can also be captured correctly based on the trap time constant.

On-wafer RF stress and trapping kinetics of Fe-doped AlGaN/GaN HEMTs

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Microelectronics Reliability
https://doi.org/10.1016/j.microrel.2018.07.122

In this paper, we investigate the trapping effects, of iron doped AlGaN/GaN HEMTs, before and after on-wafer 24 hour RF stress test. First, we study the trap centers responsible of the current collapse at different on-state bias and temperature conditions. Second, we investigate 24 hour RF stress effect on the trapping kinetics.
By filling traps under off-state condition with high drain-source voltage, we have identified two prominent traps labelled E1 and E2 with activation energies of 0.7 eV and 0.6 eV under the conduction band, respectively. An increase of the amplitude of the trap centers E1 and E2 by 22.9% and 15.8% respectively is noticed during the RF stress. This result suggests that the degradation observed during RF stress might have induced a density increase of the traps involved in the E1 and E2 trap signatures responsible on the current collapse.

An improved DRBL AlGaN/GaN HEMT with high power added efficiency

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Materials Science in Semiconductor Processing
https://doi.org/10.1016/j.mssp.2018.09.013

An improved DRBL AlGaN/GaN HEMT (IDRBL HEMT) with high power added efficiency is proposed and its mechanism is studied by co-simulation of ADS and TCAD software. The barrier layer on both sides of the gate of the new structure has a recessed layer. The simulation results show that the optimized IDRBL HEMT has a large breakdown voltage, a small gate-source capacitance and a large power added efficiency. The maximum PAE obtained from IDRBL HEMT was 53.30%, while the PAE of DRBL HEMT was 36.02%. Therefore, the HEMT of the IDRBL structure has great application prospects in the microwave and radio frequency fields.

Direct wafer bonding of GaN-SiC for high power GaN-on-SiC devices

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Materialia
https://doi.org/10.1016/j.mtla.2018.09.027

GaN-on-SiC has been very attractive for high-power GaN device owing to the high thermal conductivity of SiC substrate. However, the transition layer with a low-thermal-conductivity for epitaxial growth of GaN layers cause a high thermal barrier resistance at the interface between GaN and SiC. This work employed surface activated bonding (SAB) method to fabricate GaN-on-SiC structure without a conventional transition layer via direct wafer bonding at room temperature. The interfaces bonded at room temperature was investigated to confirm the structure. Also, the interface annealed at 200 °C was inspected to confirm the possible changes at a working temperature.

GROUP 5 – MEMS and Sensors

Group leader: Marc Faucher (IEMN)

Information selected by Marc Faucher

Comparison of Silicon, Germanium, Gallium Nitride, and Diamond for using as a Detector Material in Experimental High Energy Physics

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Results in Physics
https://doi.org/10.1016/j.rinp.2018.08.045

Semiconductor detectors with Silicon as the sensor material are widely used in High Energy Physics (HEP) experiments for high precision tracking and determination of primary and secondary vertices with good spatial resolution. They are close to the interaction point, so they are prone radiation damage due to the high fluence of produced particles. The choice of semiconductor material is based on the the signal to noise ratio, multiple scattering, pulse timing and radiation hardness. In this paper, we compare the suitability of Silicon (Si), Germanium (Ge), Gallium Nitride (GaN), and Diamond for high energy and high luminosity experiments. In addition, we also show the results on the growth of diamond films and their characterizations.

Piezoelectric-on-silicon Lorentz force magnetometers based on radial contour mode disk resonators

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Sensors and Actuators A: Physical
https://doi.org/10.1016/j.sna.2018.09.009

In this paper, we realize two unique design topologies for Lorentz force magnetometers (LFMs) based on radial contour (RC) mode piezoelectric-on-silicon disk resonators for the detection of out-of-plane magnetic fields (i.e. normal to the plane of fabrication). The proposed topologies take advantage of the strong electromechanical coupling from the piezoelectric Aluminum Nitride (AlN) layer to enhance the sensitivity of the devices while operating under ambient pressure, thus avoiding the need for vacuum encapsulation. Compared to previously reported modes, we show that RC mode provides a higher coupling efficiency. This ultimately leads to higher responsivity (defined here as the ratio of the pre-amplified output resonant current to the external magnetic field strength, normalized over the excitation current applied) compared to other modes previously reported. Having shown the advantages of the disk LFM, we then extend the advantages of a single disk LFM by mechanically coupling two disk resonators to increase the responsivity. We show that the quality (Q) factor, which determines the responsivity at resonance, does not degrade substantially by mechanically coupling the disks. The responsivity of our coupled disk LFM (21.20 ppm/mT) is 8 times higher compared to a state of art vacuum sealed LFM based on capacitive readout, but without the contraint of requiring vacuum.

Disposable Gate AlGaN/GaN High Electron Mobility Sensor for Trace-Level Biological Detection

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IEEE Electron Device Letters
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In this report, we propose a highly reliable biosensor based on the disposable gate (DG) AlGaN/GaN high electron mobility transistor (HEMT) sensor. The greatest advantage of this device is that the HEMT structure and the sensing structure containing the

sensitive membrane are separate, overcoming the drawback of being easily contaminated in a biochemical environment. The DG structure HEMT sensor exhibited stable and rapid response to the addition of different concentrations of the prostate-specific antigen (PSA), and the achieved limit of PSA detection was as low as 100 fg/mL. It was also found that the DG AlGaN/GaN HEMT sensor shows good linearity and specificity. These results demonstrate the DG HEMT sensor can be considered to be a promising biosensor platform for practical application in disease diagnosis.

Numerical simulation study of a high efficient AlGaN-based ultraviolet photodetector

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Superlattices and Microstructures
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In this paper, a two-dimensional (2D) numerical simulation study of a p+-n-n+ AlGaN-based ultraviolet (UV) photodetector, which is designed to achieve true solar blindness with a cutoff wavelength of 0.31 µm, is presented. The device performance is evaluated by investigating both the current density-voltage characteristics and the spectral response (SR). The proposed structure is optimized in terms of the fundamental geometrical and doping parameters. During the simulations, it was found that the detector is sensitive to the UV rays in the 0.155–0.37 µm wavelength range and the spectral response can reach 0.156 A W-1 under a light intensity of 1 Wcm−2 at zero-bias voltage and room temperature. This SR peak value increases further under reverse bias conditions. The temperature effect on the detector SR and the impact of an explicit trap concentration located into the p+ and n-region are also investigated. The spectral response decreases for a temperature exceeding 420 K. At the same time, the SR reference values begin to be affected only for acceptor and donor trap densities that are much higher than the local (total) doping concentration.

High-quantum-efficiency ultraviolet solar-blind AlGaN photocathode detector with a sharp spectral sensitivity threshold at 300 nm

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Applied Optics
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At present, most of the existing practical ultraviolet (UV) solar-blind detectors are based on Te–Cs photocathode image intensifiers. However, limited by their photoemission characteristics, it is difficult for the Te–Cs-based photocathodes to achieve both high quantum efficiency in the application band and high cutoff ratio in the non-applied band simultaneously. In this paper, a high-quantum-efficiency UV solar-blind detector based on AlGaN photocathodes with a sharp spectral sensitivity threshold at 300 nm is reported. The proposed AlGaN photocathode has extremely high quantum efficiency (i.e., 20%) in the 210–275 nm band, while the efficiency curve steeply reduces to 2% at 300 nm, showing obviously superior performance than the existing Te–Cs photocathodes.

Analytical Modeling and Simulation Based Investigation of AlGaN/AlN/GaN Bio-HEMT Sensor for C-erbB-2 Detection

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IEEE Sensors Journal
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Resolution of HEMT sensors needs to be improved to make feasible the precise detection of antigens from body fluids like saliva instead of blood. For enhancing sensitivity and long term stability a systematical study of the device becomes mandatory which is impossible without the aid of an analytical model. Presented through this work is a mathematical model developed for high frequency AlGaN/AlN/GaN HEMT with focus on its sensing performance. The HEMT application as a bio transistor for detection of c-erbB-

2 protein, the breast cancer biomarker is being focused and the sensitivity analysis is done. The model developed has been compared and verified with simulation using Silvaco ATLAS TCAD. The analytical model for the device has been developed by the rigorous induction and expansion of Poisson's equation. Numerical model for charge equivalent in c-erbB-2 also have been developed and device sensing is analyzed for varying quantities of c-erbB-2 in both saliva and serum. Enhanced sensing potentials over the existing bio-HEMT sensors have been observed in the device incorporating the AlN interlayer and modification of epitaxial design. The impact of gate length on sensitivity has also been analyzed and devices of gate length 1µm and 5µm yields sensitivity of 2.5mA/mgL-1 and 0.72mA/mgL-1 respectively.

In-situ fabrication of PtSe2/GaN heterojunction for self-powered deep ultraviolet photodetector with ultrahigh current on/off ratio and detectivity

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Nano Research
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The research of ultraviolet photodetectors (UV PDs) have been attracting extensive attention, due to their important applications in many areas. In this study, PtSe2/GaN heterojunction is in-situ fabricated by synthesis of large-area vertically standing two-dimensional (2D) PtSe2 film on n-GaN substrate. The PtSe2/GaN heterojunction device demonstrates excellent photoresponse properties under illumination by deep UV light of 265 nm at zero bias voltage. Further analysis reveals that a high responsivity of 193 mA·W–1, an ultrahigh specific detectivity of 3.8 × 1014 Jones, linear dynamic range of 155 dB and current on/off ratio of ~ 108, as well as fast response speeds of 45/102 µs were obtained at zero bias voltage. Moreover, this device response quickly to the pulse laser of 266 nm with a rise time of 172 ns. Such high-performance PtSe2/GaN heterojunction UV PD demonstrated in this work is far superior to previously reported results, suggesting that it has great potential for deep UV detection.

Negative-capacitance and bulk photovoltaic phenomena in gallium nitride nanorods network

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RSC Advances
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An enhanced self-powered near-ultraviolet photodetection phenomenon was observed in epitaxial gallium nitride (GaN) nanorods network grown on an intermediate layer of N:GaN on a nitridated HfO2(N:HfO2)/SiO2/p-Si substrate. The fabricated Au/GaN/N:GaN/N:HfO2/Ag heterostructure exhibited a giant change (OFF/ON ratio > 50 without applying any external electrical field) in its conductance when illuminated by a very weak (25 mW cm−2) near-UV monochromatic light with a low dark current (nearly 20 nA). The presented near-UV photodetector offers photoresponsivity of ∼2.4 mA W−1 at an applied voltage of 1 V. We observed an optically generated internal open circuit voltage of ∼155 mV and short circuit current ∼430 nA, which can be attributed to the quantum confinement of free charge carriers in the nanorod matrix. Interestingly, it also shows a negative capacitance after near-UV illumination. It has great potential as a self-powered UV photodetector and in metamaterial applications.

Polarization engineered N-polar Cs-free GaN photocathodes

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Journal of Applied Physics
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We report on holistic and systemic approach of development of Cs-free GaN photocathode structures which utilize polarization band engineering in order to allow for air stable operation and eliminate the

need for cesium-based surface treatments. Physics-based simulation of band structure and Monte Carlo simulation of electron transport and emission were used to guide experimental development of photocathode structures. By using an N-polar device, the polarization charge allows for the creation of large surface band bending without the need for δ-doped capping layers. The insertion of a thin AlN interlayer allows for the creation of a quasi-band offset and additional beneficial polarization charge to create a desirable band profile. Samples of both polarities were grown and subjected to chemical surface treatments in order to account for differences in native oxide formation on Ga- and N-polar surfaces. Measured photoemission spectra show quantum efficiencies as high as 23% for a HCl-treated Cs-free N-polar photocathode, which is comparable to cesiated devices.

Hybrid graphene/unintentionally doped GaN ultraviolet photodetector with high responsivity and speed

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Applied Physics Letters
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Ultraviolet (UV) photodetectors with high responsivity and speed are highly desirable for imaging and remote sensing applications. Limited by the crystalline quality of a GaN-based material, which is ideal for UV photodetection, the further improvement of the performance is minimal. A hybrid graphene/unintentionally doped (UID) GaN UV photodetector with both high responsivity and high speed is reported. Holes in graphene, which are induced by the photogenerated electrons trapped at the graphene/UID GaN interface according to the capacitive effect, have a long lifetime owing to the electron-hole pair separation in space. Graphene acts as a carrier transport channel and greatly increases the charge collection efficiency under an external bias voltage. The responsivity of a hybrid graphene/UID GaN photodetector with a photosensitive area of 2 mm2 reaches 5.83 A/W at −10 V with a specific detectivity of ∼1011 Jones. The response time is ∼5 ms, which is faster than that of traditional GaN photodetectors. These results will provide a feasible route to UV detection with high performance.

AlGaN ultraviolet Avalanche photodiodes based on a triple-mesa structure

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A high-performance Al0.1Ga0.9N ultraviolet (UV) avalanche photodiode (APD) with a separate absorption and multiplication structure grown on AlN templates is fabricated by employing a triple-mesa structure. The fabricated AlGaN UV-APD exhibits a maximum gain up to 2.3 × 104 at the reverse bias of 67 V and a low avalanche breakdown voltage (<70 V). The triple-mesa structure is confirmed to significantly lower the avalanche breakdown voltage and reduce the sidewall leakage current in comparison with the conventional double-mesa one. These improvements are explained by the simulation of the electric field which shows a significant improvement in the distribution uniformity in the active regions and enhancement in the intensity in the multiplication region. In addition, the scaling effects of various anodes and mesas are investigated, and the dark current is found to decrease with a decrease in the mesa size thanks to the reduced amount in the high-conductivity threading dislocation that crosses the multiplication region.

Peculiarities of the current-voltage and capacitance-voltage characteristics of plasma etched GaN and their relevance to n-GaN Schottky photodetectors

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The impact of reactive ion etching (RIE) induced damage on the optoelectronic properties of GaN epitaxial layers and the photoresponse of Schottky detectors is investigated. Plasma induced surface damage in epitaxial layers is noticed which leads to a significant reduction of the intensity of the photoluminescence signal and also the photoresponse of detector devices post dry etching process. Electrical characterization of Au/Ni/GaN Schottky diodes along with secondary ion mass spectroscopy results indicate that the ion bombardment induced damage is mostly confined close to the surface of the GaN layer. It is found that the current-voltage characteristics of Schottky contacts on pristine n-GaN layers can be understood by considering a model based on the thermionic emission of carriers across the junction. However, the same is not possible in the case of plasma etched samples where the involvement of the thermionic field emission of carriers is essential. It is proposed that the RIE process leads to the generation of nitrogen vacancies in strongly localized domains near the surface. Such vacancies act as shallow donors shifting the Fermi level into the conduction band, thus enabling the tunnelling of carriers across the junction. However, this is not evident in capacitance-voltage characteristics since the damage is much prior to the depletion edge and is confined to extremely small domains. A method for the recovery of dry etch induced damage through O2 plasma treatment is demonstrated which is found to be very effective in improving the post-etch surface morphology and also the optoelectronic properties of etched GaN epitaxial layers. The spectral response of the Schottky photodetector is seen to degrade by 90% due to the plasma etching process. However, the same can be recovered along with an enhancement of the deep ultraviolet response of the detector after O2 plasma treatment of etched layers within the RIE chamber. The understanding developed here is crucial for the optimization of the RIE process and is found to be very helpful in recovery of damage caused by the dry etching process.

High Efficiency Si Photocathode Protected by Multifunctional GaN Nanostructures

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Photoelectrochemical water splitting is a clean and environmentally friendly method for solar hydrogen generation. Its practical application, however, has been limited by the poor stability of semiconductor photoelectrodes. In this work, we demonstrate the use of GaN nanostructures as a multifunctional protection layer for an otherwise unstable, low-performance photocathode. The direct integration of GaN nanostructures on n+–p Si wafer not only protects Si surface from corrosion but also significantly reduces the charge carrier transfer resistance at the semiconductor/liquid junction, leading to long-term stability (>100 h) at a large current density (>35 mA/cm2) under 1 sun illumination. The measured applied bias photon-to-current efficiency of 10.5% is among the highest values ever reported for a Si photocathode. Given that both Si and GaN are already widely produced in

industry, our studies offer a viable path for achieving high-efficiency and highly stable semiconductor photoelectrodes for solar water splitting with proven manufacturability and scalability.

Hydrogen sensing performance of a Pd/HfO2/GaOx/GaN based metal-oxide-semiconductor type Schottky diode

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An interesting hydrogen sensor based on a Pd/HfO2/GaOx/GaN metal-oxide-semiconductor (MOS) structure is fabricated and demonstrated. The HfO2 and GaOx layers are prepared using a sputtering approach and hydrogen peroxide (H2O2) treatment. The hydrogen sensing characteristics of the studied device are comprehensively studied. Experimentally, good hydrogen sensing characteristics, including a high sensing response of 8.47 × 105, a low detection level of 5 ppm H2/air, and reversible, short response and recovery times upon exposure to different hydrogen concentrations and temperatures are obtained. The influence of humidity on hydrogen sensing performance is also studied. The exothermic action of the hydrogen adsorption process leads to a decreased hydrogen sensing response at higher temperatures. Consequently, the studied Pd/HfO2/GaOx/GaN MOS diode is promising for high-performance hydrogen sensing applications and integration with other GaN-based high-speed devices on a chip.

GROUP 6 - Photovoltaics and Energy harvesting

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Information selected by Knowmade

Simulation and optimization of a tandem solar cell based on InGaN

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Mathematics and Computers in Simulation
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The present paper indicates a numerical simulation to optimize the photovoltaic characteristics of an InGaN tandem solar cell. The cell is composed of two sub-cells p-InGaN/i-InGaN/n-InGaN with indium fraction (x) of 0.05 and 0.15, using sun AM1.5 illumination and SILVACO software for the simulation. The results show that there is an increase in the conversion efficiency compared to that of single-junction p-InGaN/i-InGaN/n-InGaN cells. We have also simulated the effect of p-doping in the top-cell, the indium composition, and the intrinsic layer thickness; on the characteristics of the tandem solar cell. We have reached a conversion efficiency of 3.71% for an intrinsic layers thickness of 0.1 um and p-doping of 1018 cm−3 in the top cell.

Visualizing light-to-electricity conversion process in InGaN/GaN multi-quantum wells with a p–n junction

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Chinese Physics B
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Absorption and carrier transport behavior plays an important role in the light-to-electricity conversion process, which is difficult to characterize. Here we develop a method to visualize such a conversion process in the InGaN/GaN multi-quantum wells embedded in a p–n junction. Under non-resonant absorption conditions, a photocurrent was generated and the photoluminescence intensity decayed by more than 70% when the p–n junction out-circuit was switched from open to short. However, when the excitation photon energy decreased to the resonant absorption edge, the photocurrent dropped drastically and the photoluminescence under open and short circuit conditions showed similar intensity. These results indicate that the escaping of the photo-generated carriers from the quantum wells is closely related to the excitation photon energy.

Facile growth of high aspect ratio c-axis GaN nanowires and their application as flexible p-n NiO/GaN piezoelectric nanogenerators

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Acta Materialia
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Piezoelectric nanogenerators (PNGs) have attracted great interest as energy sources to power-up smart clothing, micro/nano systems, and portable electronic gadgets. Due to non-centrosymmetric crystal structure, bio-compatibility, and mechanical robustness of GaN, it is a promising candidate to fabricate PNGs. In this study, c-axis GaN nanowires were grown by MOCVD, then were embedded inside polydimethylsiloxane and flipped on to the flexible substrate, followed by the deposition of p-type NiO to form heterojunction. The fabrication of GaN nanowires based heterojunction PNG on flexible substrate is the first report to the best of our knowledge. The piezoelectric properties of PNGs were investigated as a function of the GaN nanowire length. A maximum piezoelectric output potential of 20.8 V and current of 253 nA were measured. The stability of the device was also evaluated and found stable even after 20,000 cycles. This high piezoelectric output was attributed to the

suppression of free carrier screening and junction screening. Moreover, the underlying reasons for the high stability are the malleability of the device and high aspect ratio of the GaN nanowires. The design and stability of our device make it a promising candidate for applications in self-powered systems for environment monitoring and low power electronics.

Impact of the Periphery Electrostatic Field on the Photovoltaic Effect in Metal–Semiconductor Contacts with a Schottky Barrier

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Semiconductors
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Studies of an electrostatic system of flat metal–semiconductor contacts with a Schottky barrier reveals a nontrivial dependence of their current and voltage photosensitivity (the photovoltaic effect) on the contact shape. The specific features of using the photovoltaic effect in such contacts are determined, to a great extent, by the built-in periphery electrostatic field with an absolute value that depends on the contact perimeter and area. Thus, to increase the efficiency of light-to-electrical energy conversion by Schottky contacts, it is necessary to use optimization techniques based on the concepts of the proposed physical model of an electrostatic system of flat Schottky contacts with regard to periphery electrostatic fields. The “hot electron resonance” effect, which enhances the external quantum efficiency of photodiodes with a Schottky barrier, can be explained by enhancement of the field emission of electrons by the periphery electrostatic field.

Flexible Piezoelectric Energy Harvesting Exploiting Biocompatible AlN Thin Films Grown onto Spin Coated Polyimide Layers

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The increasing demand of piezoelectric energy harvesters for wearable and implantable applications requires biocompatible materials and careful structural device design, paying special attention to the conformability characteristics, properly tailored to scavenge continuously electrical energy even from the tiniest body movements. The paper provides a comprehensive study on a flexible and biocompatible Aluminum Nitride (AlN) energy harvester based on a new alternative fabrication approach, exploiting a thin polyimide (PI) substrate, prepared by spin coating of precursors solution. This strategy allows manufacturing substrates with adjustable thickness to meet conformability requirements. The device is based on a piezoelectric AlN thin film, sputtered directly onto the soft PI substrate, without poling/annealing processes and patterned by simple and low cost microfabrication technologies. AlN active layer, grown on soft substrate, exhibits good morphological and structural properties with roughness of 6.35 nm, columnar texture and (002) c-axis orientation. Additionally, piezoelectric characterization has been performed and the extracted piezoelectric coefficient d33eff value of AlN thin film resulted to be 4.93 ± 0.09 pm/V. The fabricated flexible AlN energy harvester provides an output peak-to-peak voltage of ~1.4 V and a peak-to-peak current up to 1.6 µA, under periodical deformation, corresponding to a current density of 2.1 µA/cm2, and providing instantaneous power of 1.57 µW under optimal resistive load. Furthermore, the AlN energy harvester exhibits high elasticity and resistance to mechanical fatigue. High quality AlN piezoelectric layers on elastic substrates with tunable thicknesses pave the way for the development of a straightforward technological platform for wearable/implantable energy harvesters and biomechanical sensors.

Gallium nitride nanowire as a linker of molybdenum sulfides and silicon for photoelectrocatalytic water splitting

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The combination of earth-abundant catalysts and semiconductors, for example, molybdenum sulfides and planar silicon, presents a promising avenue for the large-scale conversion of solar energy to hydrogen. The inferior interface between molybdenum sulfides and planar silicon, however, severely suppresses charge carrier extraction, thus limiting the performance. Here, we demonstrate that defect-free gallium nitride nanowire is ideally used as a linker of planar silicon and molybdenum sulfides to produce a high-quality shell-core heterostructure. Theoretical calculations revealed that the unique electronic interaction and the excellent geometric-matching structure between gallium nitride and molybdenum sulfides enabled an ideal electron-migration channel for high charge carrier extraction efficiency, leading to outstanding performance. A benchmarking current density of 40 ± 1 mA cm−2 at 0 V vs. reversible hydrogen electrode, the highest value ever reported for a planar silicon electrode without noble metals, and a large onset potential of +0.4 V were achieved under standard one-sun illumination.

GROUP 7 - Materials, Technology and Fundamental

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Deep-UV Emission from Highly-Ordered AlGaN/AlN Core-Shell Nanorods

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3D core-shell nanostructures could resolve key problems existing in conventional planar deep-UV LED technology due to their high structural quality, high-quality non-polar growth leading to a reduced quantum-confined Stark effect, and their ability to improve light extraction. Currently, a major hurdle to their implementation in UV-LEDs is the difficulty of growing such nanostructures from AlxGa1-xN materials with a bottom-up approach. In this paper, we report the successful fabrication of an AlN/AlxGa1-xN/AlN core-shell structure using an original hybrid top-down/bottom-up approach, thus representing a breakthrough in applying core-shell architecture to deep-UV emission. Various AlN/AlxGa1-xN/AlN core-shell structures were grown on optimized AlN nanorod arrays. These were created using Displacement Talbot Lithography, a two-step dry-wet etching process, and optimised AlN MOVPE regrowth conditions to achieve the facet recovery of straight and smooth AlN non-polar facets, a necessary requirement for subsequent growth. Cathodoluminescence hyperspectral imaging of the emission characteristics revealed that a 229 nm deep-UV emission was achieved from the highly uniform array of core-shell AlN/AlxGa1 xN/AlN structures, which represents the shortest wavelength achieved so far with a core-shell architecture. This hybrid top-down/bottom-up approach represents a major advance for the fabrication of deep-UV LEDs based on core-shell nanostructures.

AlGaN Nanowires: Path to Electrically Injected Semiconductor Deep Ultraviolet Lasers

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IEEE Journal of Quantum Electronics
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In this paper, we review the recent progress of AlGaN nanowire heterostructures and the demonstration of electrically pumped semiconductor deep ultraviolet (UV) lasers with such nanowires. Future prospects and challenges for nanowire deep UV lasers are also presented.

Circumventing the miscibility gap in InGaN nanowires emitting from blue to red

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Nanotechnology
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Widegap III-nitride alloys have enabled new classes of optoelectronic devices including light emitting diodes, lasers and solar cells, but it is admittedly challenging to extend their operating wavelength to the yellow–red band. This requires an increased In content x in In x Ga1−x N, prevented by the indium segregation within the miscibility gap. Beyond the known advantage of dislocation-free growth on dissimilar substrates, nanowires may help to extend

the compositional range of InGaN. However, the necessary control over the material homogeneity is still lacking. Here, we present In x Ga1−x N nanowires grown by hydride vapor phase epitaxy on silicon substrates, showing rather homogeneous compositions and emitting from blue to red. The InN fraction in nanowires is tuned from x = 0.17 up to x = 0.7 by changing the growth temperature between 630 °C and 680 °C and adjusting some additional parameters. A dedicated model is presented, which attributes the wide compositional range of nanowires to the purely kinetic growth regime of self-catalyzed InGaN nanowires without macroscopic nucleation. These results may pave a new way for the controlled synthesis of indium-rich InGaN structures for optoelectronic applications in the extended spectral range.

Imaging the scattering field of a single GaN nanowire

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Journal of Optics
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In this work, a single gallium nitride (GaN) nanowire has been examined by our previously reported technique parametric indirect microscopic imaging (PIMI). Mapping of the nanoscale scattering signals from GaN nanowire has been achieved with PIMI system. A comparison with classical far field microscopy and FDTD simulations is included to show the relevant differences and the strength of this technique. In PIMI, highly defined modulated illumination, far field variation quantification, and filtering process resolve the nanoscale scattering field distribution in the form of polarization parameters. We believe that our system provides us a platform to understand the physics of these nanoscale scattering fields from optical nanoantennas.

An optical Bragg scattering readout for nano-mechanical resonances of GaN nanowire arrays

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Applied Physics Letters
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We report the use of optical Bragg scattering and homodyne interferometry to simultaneously measure all the first order cantilever-mode mechanical resonance frequencies and quality factors (Q) of gallium nitride nanowires (GaN NWs) in periodic selected-area growth arrays. Hexagonal 2D arrays of GaN NWs with pitch spacings of 350–1100 nm were designed and prepared to allow optical Bragg scattering of 632.8 nm laser light. The NWs studied have diameters ranging from 100 to 300 nm, lengths from 3 to 10 µm, resonance frequencies between 1 and 10 MHz, Q-values near 10 000 at 300 K, and Young's modulus of 310 ± 45 GPa. The optical system can detect the thermally induced Brownian mechanical motion of the NWs and driven NW motion and allows the simultaneous monitoring of hundreds of mechanical resonators with a single laser beam. The read-out system allows large arrays of NWs to be characterized and, upon mapping the resonance frequencies to individual array elements, to be applied as, e.g., spatially resolved temperature and mass sensors.

NON/SEMI POLAR

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Imaging basal plane stacking faults and dislocations in (11-22) GaN using electron channelling contrast imaging

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Taking advantage of electron diffraction based measurements, in a scanning electron microscope, can deliver non-destructive and quantitative information on extended defects in semiconductor thin films. In this work, we have studied a (11-22) semi-polar GaN thin film overgrown on regularly arrayed GaN micro-rod array templates grown by metal organic vapour phase epitaxy. We were able to optimise the diffraction conditions to image and quantify basal plane stacking faults (BSFs) and threading dislocations (TDs) using electron channelling contrast imaging (ECCI). Clusters of BSFs and TDs were observed with the same periodicity as the underlying micro-rod array template. The average BSF and TD densities were estimated to be ≈4 × 104 cm−1 and ≈5 × 108 cm−2, respectively. The contrast seen for BSFs in ECCI is similar to that observed for plan-view transmission electron microscopy images, with the only difference being the former acquiring the backscattered electrons and the latter collecting the transmitted electrons. Our present work shows the capability of ECCI for quantifying extended defects in semi-polar nitrides and represents a real step forward for optimising the growth conditions in these materials.

Phosphor-free white emission from InGaN quantum wells grown on in situ formed submicron-scale multifaceted GaN stripes

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Journal of Alloys and Compounds
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We demonstrate in situ self-organization of multifaceted GaN stripes on m-sapphire substrates. The GaN stripes aligned along <> with submicron-scale {112}, {10}, {20}, {11}, and {0001} facets are identified and employed as growth templates of InGaN quantum wells (QWs). Under identical growth conditions the emission spectrum of the InGaN QWs is determined by the GaN stripe shaping and atomic structures of the stripe surface. For instance, the growth rate (thickness) of the InGaN QWs is proportional to the layer spacing and dangling bond density of specific growth face and plays a key role in emission wavelength. Accordingly, using the stripe templates the InGaN QWs on different stripe facets have different emission wavelengths. Broad photoluminescence peak covering ultraviolet, blue, green, yellow, amber, and red emissions is observed for the InGaN QWs grown on various sidewall facets of the stripe templates. The chromaticity diagram indicates a cool-daylight white emission with a correlated color temperature of 5997 K.

Metal organic chemical vapor deposition of m-plane GaN epi-layer using a three-step approach towards enhanced surface morphology

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Thin Solid Films
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Specular m-plane (100) gallium nitride (m-GaN) epi-layer are grown on m-plane (100) sapphire substrates by metal organic chemical vapor deposition using a three-step approach. A two-step approach was used to grow m-GaN buffer layer (BL), while a three-step approach was applied to

improve the surface morphology of the top m-GaN epi-layer at high temperature. The three-step approach started with growing m-aluminum nitride nucleation layer with an optimized ammonia flux during the growth of aluminum nitride. Then the temperature was ramped up during the recrystallization step before the m-GaN BL deposition at low-temperature and the growth of m-GaN layer at high-temperature for the final step. Unexpectedly, when ammonia flow was intentionally halted during the recrystallization step, the surface morphology of the BL drastically changed from three- to two- dimensional with an abrupt cross-sectional structure. This in turn facilitated the complete coalescence of the m-GaN layer as revealed by field emission scanning electron microscopy. The three-step technique was found to affect the quality of m-GaN epi-layer as the samples exhibit improved crystallinity with X-ray diffraction rocking curves widths of 4680 and 1980 arcsec along the azimuth, perpendicular and parallel to [100] directions, respectively.

MATERIAL / CHARACTERIZATION / EQUIPMENT / NUMERICAL SIMULATION

Information selected by
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Valence band tomography of wurtzite GaN by spectroscopic ellipsometry

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Applied Physics Express
https://doi.org/10.7567/APEX.11.101001

The effective hole masses of wurtzite GaN are determined experimentally by an all-optical method. Therefore, we measure interband transitions as a function of the degenerate free-electron density and analyze the different many-body contributions arising from the Burstein–Moss effect and band-gap renormalization. When the known anisotropic effective electron mass is taken into account, the shape of the valence band can be reconstructed. Here, nonpolar (11-20) GaN thin films doped with germanium or silicon at $9 \times 1018 \leq n \leq 1.5 \times 1020$ cm−3 are investigated. Effective hole masses of $m^*_h(k_y) = 1.82m_0$, $m^*_h(k_z) = 1.95m_0$, for the A valence band and $m^*h(ky) = 1.64m_0$ for the B valence band are found (for 0.3 nm−1 < |k| < 2 nm−1) .

Growth kinetics of basic ammonothermal gallium nitride crystals

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Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2018.08.028

The ammonothermal method has been extensively studied for the last two decades because of its potential to produce high-quality bulk gallium nitride (GaN) boules at low cost. Currently, the ammonothermal literature lacks in situ, internal fluid temperature measurements during the crystal growth process. This study reports on internal fluid temperature measured simultaneously in the dissolution and growth zones for twelve basic ammonothermal GaN growth experiments (pressure range = 180–261 MPa; molar NH3:Na fill ratio = 20:1) on {0 0 0 1} and {1 0 0}-orientation GaN seeds. Knowledge of the fluid temperature combined with mass-change measurements of the polycrystalline source and seed crystals has enabled the distinction of three growth regimes: a mass transport-limited regime at internal fluid density differences below 1.2 mol/L between dissolution and growth zones; a surface reaction-limited regime above the aforementioned critical fluid density difference and below growth zone fluid temperatures of ~570 °C; and an apparent loss of solvent-limited regime above growth zone fluid temperatures of ~570 °C. Analysis of growth in [0 0 0 1], [0 0 0], and [1 0 0] has enabled the determination of activation energies of each respective GaN crystallographic orientation in the surface reaction-limited regime.

Influence of in-situ NH3 plasma passivation on the electrical characteristics of Ga-face n-GaN MOS capacitor with atomic layer deposited HfO2

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Solid-State Electronics
https://doi.org/10.1016/j.sse.2018.08.009

The effects of in-situ NH3 plasma passivation on the interface between atomic layer deposited HfO2 and Ga-face n-GaN substrate in metal-oxidesemiconductor (MOS) devices were investigated by varying plasma power and exposure time and compared with GaN MOS device without plasma passivation. ALD HfO2-GaN device with in-situ NH3 plasma treatment shows improved electrical characteristics including negligible frequency dispersion at the near flat-band voltage region, lower hysteresis (~10 mV), suppressed oxide capacitance dispersion in the accumulation (2.2%), lower leakage current density (5.21 × 10−2 A/cm2 at 1 V), and low interface state density (Dit) of ~6.77 × 1011 eV−1 cm−2 at Ec-Et = 0.3 eV using an optimized plasma passivation exposure time of 10 min and power of 50 W. These results are attributed that NH3 plasma treatment could eliminate carbon species and detrimental sub-GaOx as well as passivate the surface and bulk defects on GaN caused by Ga-N dissociation.

Improvement mechanism of sputtered AlN films by high-temperature annealing

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Journal of Crystal Growth
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The improvement mechanism of sputtered AlN films by high temperature annealing in nitrogen ambient has been investigated. Sputtered AlN films were annealed at 1100–1700 °C and their microstructures were observed by scanning transmission electron microscopy. A two-layer structure consisting of columnar domains with different sizes was observed in the as-grown sputtered AlN films. The first layer with 10 nm thickness located at the AlN/sapphire interface, comprised columnar domains with diameters of nm order and was compressively strained owing to the lattice mismatch between AlN and sapphire. The diameter of columnar domains in the other layer was approximately 25 nm. The columnar domains split into irregularly shaped and coalesced at an elevated annealing temperature, resulting in improved crystal quality. When the annealing temperature was 1700 °C, the domain boundaries in AlN films were almost annihilated and the full width at half maximum of the (0002)- and (10-12)-plane X-ray rocking curves were improved to as low as 49 and 310 arcsec, respectively. The polarity switched from N-polar to Al-polar after about 4–10 AlN layers in the growth direction. The oxygen element content slightly increased at the polarity inversion boundary, which may have caused the polarity to switch.

Method for controlling stress gradients in PVD aluminum nitride

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Journal of Micromechanics and Microengineering
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In this paper we describe a method for controlling both the residual stress and the through-thickness stress gradient of aluminum nitride (AlN) thin films using a multi-step deposition process that varies the applied radio frequency (RF) substrate bias. The relationship between the applied RF substrate bias and the AlN residual stress is characterized using AlN films grown on oxidized silicon substrates is determined using 100 nm–1.5 µm thick blanket AlN films that are deposited with 60–100 W applied RF biases; the stress-bias relationship is found to be well described using a power law relationship. Using this relationship, we develop a model for varying the RF bias in a series of discrete deposition steps such that each deposition step has zero average

stress. The applied RF bias power in these steps is tailored to produce AlN films that have minimized both the residual stress and the film stress gradient. AlN cantilevers were patterned from films deposited using this technique, which show reduced curvature compared to those deposited using a single RF bias setting, indicating a reduction of the stress gradient in the films.

Operation Mechanism of GaN-based Transistors Elucidated by Element-Specific X-ray Nanospectroscopy

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Scientific Reports
https://doi.org/10.1038/s41598-018-31485-4

With the rapid depletion of communication-frequency resources, mainly due to the explosive spread of information communication devices for the internet of things, GaN-based high-frequency high-power transistors (GaN-HEMTs) have attracted considerable interest as one of the key devices that can operate in the high-frequency millimeter-wave band. However, GaN-HEMT operation is destabilized by current collapse phenomena arising from surface electron trapping (SET), which has not been fully understood thus far. Here, we conduct quantitative mechanistic studies on SET in GaN-HEMTs by applying element- and site-specific photoelectron nanospectroscopy to a GaN-HEMT device under operation. Our study reveals that SET is induced by a large local electric field. Furthermore, surface passivation using a SiN thin film is demonstrated to play a dual role: electric-field weakening and giving rise to chemical interactions that suppress SET. Our findings can contribute to the realization of high-capacity wireless communication systems based on GaN-HEMTs.

MOVPE growth and high-temperature annealing of (100) AlN layers on (100) sapphire

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Journal of Crystal Growth
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Heteroepitaxial growth of AlN layers on (100) m-plane sapphire substrates was investigated by metalorganic vapour phase epitaxy. Different nucleation temperatures were used to achieve single phase (100) AlN layers. The crystallinity of the layers further increased with increasing annealing temperature and annealing time. The full-width at half maximum of the symmetric (100) X-ray rocking curves decreased from about 2900/1940 arcsec to 1030/800 arcsec along [0001]/[110]AlN. The density of basal stacking faults of the annealed layers was found to decrease from 2.8×105 to 1.5×104 cm−1. The annealed layers had a larger effective optical bandgap energy of 6.15 eV than 6.04 eV of the as-grown layers due to their better crystallinity and structural order.

Above bandgap thermoreflectance for non-invasive thermal characterization of GaN-based wafers

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Applied Physics Letters
https://doi.org/10.1063/1.5040100

GaN devices integrated with dissimilar substrates have transformed electronic and optoelectronic applications. However, an effective thermal resistance (TBReff) exists between the GaN layer and the dissimilar substrates typically, which can potentially cause a major heat transport bottleneck. A non-invasive method for monitoring the TBReff of bare wafers is a key enabler for process monitoring and for the reduction of TBReff through design optimization. The existing TBReff measurement techniques require metal deposition on the sample surface. Here, we demonstrate a generic non-

invasive transient thermoreflectance technique which does not require modification of the GaN surface and can be applied to any GaN-based wafers, regardless of the substrate material. Above-bandgap pump and probe lasers are used to avoid any interference caused by sub-surface reflections, ensuring that this technique strictly follows the fundamental principle of thermoreflectance-based methods. Several GaN wafers on common substrates (SiC, Si, diamond, and sapphire) are measured to assess the validity of this technique.

Theoretical Evaluation of the Effects of Isolation-Feature Size and Geometry on the Built-In Strain and 2-D Electron Gas Density of AlGaN/GaN Heterostructures

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2018.2869024

Using a commercial self-consistent Poisson-Schrödinger solver with the built-in possibility of allowing elastic energy minimization, the strain and the sheet charge density induced at the pseudomorphically grown Ga-face Wurtzite AlGaN/GaN heterojunctions are evaluated in the context of 3-D simulation of heterostructure field-effect transistor (HFET) epilayers etched into a variety of isolation-feature sizes and geometries. Through these studies and in the presence of surface states, the extent of the relevance of strain minimization in the vicinity of the unconstrained boundaries of isolation features of different degrees of roundness and perimeter-to-area ratio to threshold-voltage engineering is assessed. Although it is demonstrated that threshold-voltage shift caused by this induced strain minimization is smaller than the amount of shift levied by the depleting effect of the negatively charged states on the sidewall facets, it is shown that the reduction of the isolation-feature size is capable of substantially reducing the average trace of the stress tensor across such heterointerfaces. Considering the importance of this factor to the long-term reliability of AlGaN/GaN HFETs, especially when undergoing self-heating at high-power levels, use of alternative isolation features such as small islands of a lateral area less than 1000 nm^2 is proposed as a solution.

Growth of III-N / graphene heterostructures in single vapor phase epitaxial process

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Journal of Crystal Growth
https://doi.org/10.1016/j.jcrysgro.2018.09.017

We investigated the growth of III-N / graphene heterostructures as a single process in a MOVPE reactor. Raman spectra revealed that graphene can be successfully deposited on sapphire substrate by propane pyrolysis if temperature exceeds 1060 oC and hydrogen is used as a carrier gas. GaN epitaxial layers and heterostructures on such graphene using both high-temperature AlN buffer layer and low-temperature GaN nucleation layer was demonstrated. Analysis of surface morphology and X-Ray diffraction curves indicate that GaN quality depends on graphene thickness. Use of copper electroplated Ni-based contact layer combined with thermal shock allows exfoliation of large-area III-N LED structures from sapphire.

Influence of surface step width of 4H-SiC substrates on the GaN crystal quality

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Journal of Crystal Growth
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In this work GaN films are grown on 4H-SiC substrates with different surface terrace step width and the influence of the step width on the crystal quality of GaN is studied using X-ray diffraction (XRD) method. The results prove that the different surface terrace step width has a big impact on the (002) and (102) full width at half maximum (FWHM) of GaN films. It is mainly because the nucleation and coalescence mechanism of AlN is closely related with the surface step width, resulting in

different densities of threading dislocations in the subsequent grown GaN films.

N-polar AlN buffer growth by metal–organic vapor phase epitaxy for transistor applications

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Applied Physics Express
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We present the electrical characterization of N-polar AlN layers grown by metal–organic vapor phase epitaxy and the demonstration of N-polar AlN-channel metal–semiconductor field-effect transistors (MESFETs). A high concentration of silicon is unintentionally incorporated during the high-temperature growth of N-polar AlN, causing a high buffer leakage current. The silicon concentration decreases from 2 × 1018 to 9 × 1015 cm−3 with decreasing growth temperature, reducing the buffer leakage current to 5.6 nA/mm at a 100 V bias. The N-polar AlN MESFET exhibits an off-state drain current of 0.27 nA/mm and a transistor on/off ratio of 4.6 × 104 owing to the low leakage of AlN buffer layers.

Two charge states of the CN acceptor in GaN: Evidence from photoluminescence

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PHYSICAL REVIEW B
https://doi.org/10.1103/PhysRevB.98.125207

We have found a photoluminescence (PL) band with unusual properties in GaN. The blue band, termed as the BLC band, has a maximum at about 2.9 eV and an extremely short lifetime (shorter than 1 ns for a free-electron concentration of about 1018cm−3). The electron- and hole-capture coefficients for this defect-related band are estimated as 10−9 and 10−10cm3/s, respectively. The BLC band is observed only in GaN samples with relatively high concentration of carbon impurity, where the yellow luminescence (the YL1 band) with a maximum at 2.2 eV is the dominant defect-related PL. Both the YL1 and BLC bands likely originate from the CN defect, namely, from electron transitions via the −/0and 0/+ thermodynamic transition levels of the CN. The BLC band appears only at high excitation intensities in n-type GaN samples codoped with Si and C, and it can be found in a wide range of excitation intensities in semi-insulating (presumably p-type) GaN samples doped with C. The properties and behavior of the YL1 and BLC bands can be explained using phenomenological models and first-principles calculations.

Epitaxial growth and interfacial property of monolayer MoS2 on gallium nitride

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RSC Advances
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Two-dimensional (2D) transition-metal dichalcogenides (TMDCs) on semiconductor substrates are important for next-generation electronics and optoelectronics. In this study, we demonstrate the growth of monolayer MoS2 on a lattice-matched gallium nitride (GaN) semiconductor substrate by chemical vapor deposition (CVD). The monolayer MoS2 triangles exhibit optical properties similar to that of typical single-crystal MoS2 sheets, as verified by the Raman, photoluminescence, and morphological characterizations. The Raman and PL features and their intensity mappings suggest that the as-grown MoS2 on GaN substrate can achieve high quality and uniformity, demonstrating that GaN substrate is favorable for 2D MoS2 growth. Moreover, the

interfacial property and stacking structure were investigated by first-principles density functional theory (DFT) calculations to confirm the interlayer interactions of monolayer MoS2 on GaN. Accordingly, the ability to grow high quality monolayer MoS2 on semiconductor GaN substrate would open a new route toward the synthesis of hetero and composite structures for promising electronic and optoelectronic device applications.

Crystal engineering by tuning the growth kinetics of GaN 3-D microstructures in SAG-HVPE

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CrystEngComm
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The growth of GaN 3-D microstructures is investigated by SAG-HVPE. Capitalizing on the properties of this kinetically-controlled process, the main experimental parameters and physical mechanisms that control the shaping of 3D GaN prisms and pyramids in SAG-HVPE are highlighted. Growth experiments performed on N-polar AlN/Si(100) and Ga-polar GaN/Si(111) substrates also provide insight into how to switch from a pyramid to a prismatic shape for a given substrate polarity. The aspect ratio of GaN rods could be tuned by playing with the HCl partial pressure additionally introduced during growth. The influence of both mass transport and surface kinetics is discussed, as the crystal growth rate varies with increasing surface area as time goes by. Ammonia treatment prior to the growth, aimed at blocking the r planes thanks to H2 passivation, is proposed to tune the morphology of the GaN rods. Raman spectroscopy performed on individual GaN rods shows no relevant strain field and no structural differences between the rods and state-of-the-art bulk GaN.

Crystal quality evolution of AlN films via high-temperature annealing under ambient N2

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The crystal quality evolution of AlN films via high-temperature (HT) annealing under nitrogen is investigated. It is found that the best crystal quality can be realized using an optimized combination of the annealing temperature at 1700 °C and AlN thickness of 540 nm, respectively. It is thus achieved the X-ray diffraction ω-scan full width at half maximum (FWHM) values of 59 and 284 arcsec for (0002) and (101 @#x0305;2) diffractions, respectively. It is verified that the significant reduction in the threading dislocation density (TDD) via HT annealing starts from the interface zone between AlN and sapphire anterior to the zone far from the interface, which is caused by less energy being required to decrease the larger twist angle among the columns in the interface zone. Benefiting from the low-TDD annealed AlN template, the internal quantum efficiency of the 282-nm AlGaN-based multiple quantum wells reached 57 % at 300 K.

A thermodynamic supersaturation model for the growth of aluminum gallium nitride by metalorganic chemical vapor deposition

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Journal of Applied Physics
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A thermodynamic supersaturation model for growth of AlGaN by metalorganic chemical vapor deposition was developed for experimentally accessible growth parameters. The derived non-linear relationships enabled us to estimate Ga and Al supersaturation during AlGaN growth for given

growth conditions. Calculations revealed that the GaN phase was close to chemical equilibrium, while the Al supersaturation was as high as 1010 for typical growth conditions. Such a disparity in the supersaturation of reaction species plays a significant role in the stability of the growth of the resulting ternary alloy. The agreement between experiment and simulation suggests that the parasitic gas phase reactions between trimethylaluminum and NH3 were not significant at low NH3 flow rates/partial pressures, indicating that, under these conditions, the AlGaN growth was thermodynamically limited.

GaN surface as the source of non-radiative defects in InGaN/GaN quantum wells

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Applied Physics Letters
https://doi.org/10.1063/1.5048010

Blue light-emitting diodes based on III-nitride semiconductors are nowadays widely used for solid-state lighting. They exhibit impressive figures of merit like an internal quantum efficiency close to 100%. This value is intriguing when considering the high dislocation density running throughout the InGaN/GaN quantum well (QW) active region. This striking feature is currently ascribed to carrier localization occurring in the InGaN alloy, which hinders their diffusion toward dislocations. However, it was recently reported that another source of defects, disconnected from dislocations, dramatically decreases the radiative efficiency of InGaN/GaN QWs. Those defects, present at the surface, are usually trapped in an InGaN underlayer (UL), which is grown before the QW active region. To get insight into the trapping mechanism, we varied the UL thickness, In content, and materials system (InGaN or InAlN) and studied the photoluminescence decay time at 300 K of a single InGaN/GaN QW. Our data demonstrate that defects are incorporated proportionally to the indium content in the UL. In addition, we show that those defects are created during the high-temperature growth of GaN and that they segregate at the surface even at low-temperature. Eventually, we propose an intrinsic origin for these surface defects.

Influence of nitride buffer layers on superconducting properties of niobium nitride

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Journal of Vacuum Science & Technology A
https://doi.org/10.1116/1.5044276

Niobium nitride thin films were deposited using reactive magnetron sputtering simultaneously on sapphire substrates with TiN, VN, and AlN buffer layers. Deposition temperature was varied from 400 to 840 °C. It was found that the crystal structure, surface roughness, and transition temperatures of the resulting NbN films depend strongly on both the growth temperature and the type of the buffer layer. The use of VN and TiN buffer layers for growing NbN at 400 °C improved transition temperatures compared to NbN grown at 840 °C on sapphire. While increasing the temperature improved the superconducting performance of films grown directly on sapphire, it caused hexagonal δ′-NbN and ε-NbN phases to emerge on the buffered films. A highly oriented hexagonal ε-NbN film was achieved by using a TiN buffer and an 840 °C deposition temperature. The ability to deposit high performance NbN at a lower temperature will improve and simplify the fabrication of advanced superconducting devices such as superconducting single photon detectors.

Intentional polarity conversion of AlN epitaxial layers by oxygen

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Scientific Reports
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Nitride materials (AlN, GaN, InN and their alloys) are commonly used in optoelectronics, high-power and high-frequency electronics. Polarity is the essential characteristic of these materials: when grown along c-direction, the films may exhibit either N- or metal-polar surface, which strongly influences their physical properties. The possibility to manipulate the polarity during growth allows to establish unique polarity in nitride thin films and nanowires for existing applications but also opens up new opportunities for device applications, e.g., in non-linear optics. In this work, we show that the polarity of an AlN film can intentionally be inverted by applying an oxygen plasma. We anneal an initially mixed-polar AlN film, grown on sapphire substrate by metal-organic vapor phase epitaxy (MOVPE), with an oxygen plasma in a molecular beam epitaxy (MBE) chamber; then, back in MOVPE, we deposit a 200 nm thick AlN film on top of the oxygen-treated surface. Analysis by high-resolution probe-corrected scanning transmission electron microscopy (STEM) imaging and electron energy-loss spectroscopy (EELS) evidences a switch of the N-polar domains to metal polarity. The polarity inversion is mediated through the formation of a thin AlxOyNz layer on the surface of the initial mixed polar film, induced by the oxygen annealing.

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

Activating buried p-type gallium nitride for power electronics

SemiconductorToday

Cornell University, IQE RF LLC and Qorvo Inc in the USA have been working out ways to better activate buried p-type layers of gallium nitride (p-GaN) [Wenshen Li et al, Appl. Phys. Lett., vol113, p062105, p2018]. In most GaN/III-N growth processes the p-type layers are left until last because of the difficulty of activation, which usually involves heating the sample in an attempt to drive out hydrogen that passivates the magnesium doping used to create mobile hole charge carriers.

This p-GaN-last constraint limits the sort of structures that can be explored for power electronics and other applications. Examples of buried-structure devices include heterojunction bipolar transistors (HBTs), trench metal-oxide-semiconductor field-effect transistors (MOSFETs), current-aperture vertical electron transistors (CAVETs), and laterally diffused MOSFETs (LDMOSFETs).

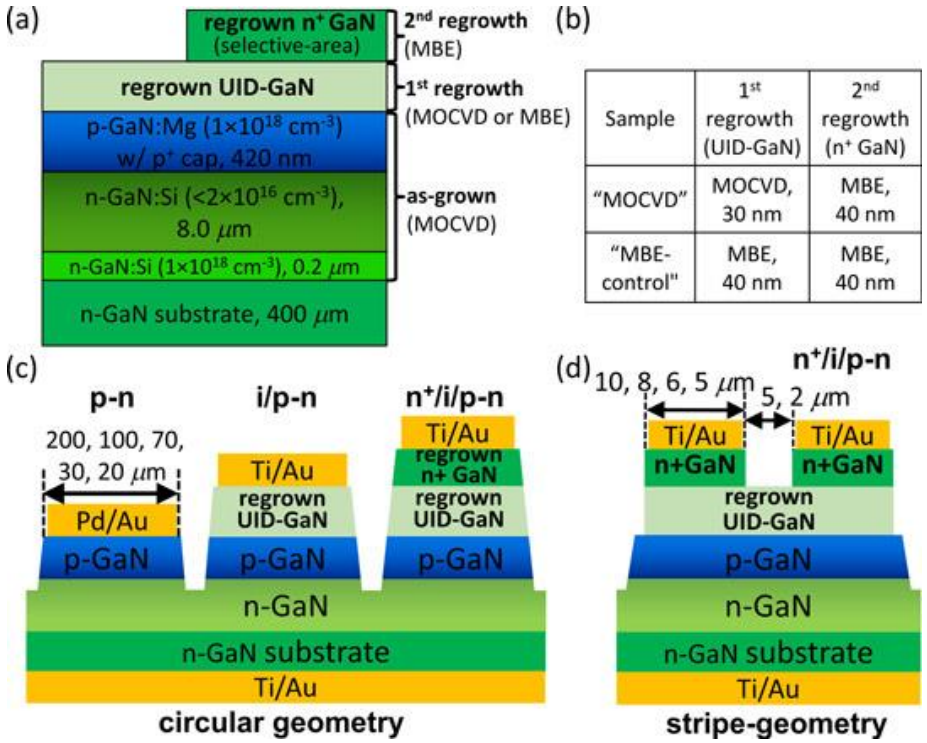


Figure 1: (a) Schematic layer structure of as-grown in-situ activated p-n diode structure and two re-grown layers. (b) Information on two re-grown layers on MOCVD and MBE control samples. (c) Schematic cross sections of three types of circular diode: p-n, i/p-n and n+/i/p-n diodes fabricated on both samples. (d) Schematic cross section of n+/i/p-n diodes with stripe geometry. Stripes all have a finger length of 50µm.

The team used the reverse breakdown measurements for assessing p-GaN activation as "a sensitive probe pertinent to power electronic applications".

Metal-organic chemical vapor deposition (MOCVD) produced epitaxial layers on bulk GaN (Figure 1). The top p-GaN layers were activated in-situ. The researchers report that the contact resistance (~4x10-5Ω-cm2) and Hall measurement (hole density ~7% magnesium concentration, mobility 24cm2/V-s) results for this material with a top p-GaN layer were “among the best in the literature”.

The p-GaN was then buried using re-growth via blanket MOCVD or molecular beam epitaxy (MBE) of undoped GaN. For the MOCVD sample, the p-GaN was passivated with 900°C annealing in ammonia for 30 minutes in the reaction chamber. The MOCVD sample was also prepared by ultraviolet-ozone and hydrofluoric acid treatments to reduce silicon residues. For the MBE sample, the buried p-GaN was unpassivated. A final n+-GaN layer was grown selectively by MBE on the two samples.

The material was used to create a series of buried p-GaN structures for electrical testing with contacts using various stacks of palladium (Pd), titanium (Ti) and gold (Au). Various dry etch recipes were used to remove the undoped GaN re-grown top layer and for mesa isolation. The buried p-GaN was activated by annealing at 725°C for 30 minutes in dry air, driving hydrogen out through the mesa sidewalls. The metal contacts were applied after annealing.

Probing unmetalized MOCVD-sample structures without buried p-GaN activation showed high leakage currents under reverse bias. The leakage was suppressed by activation.

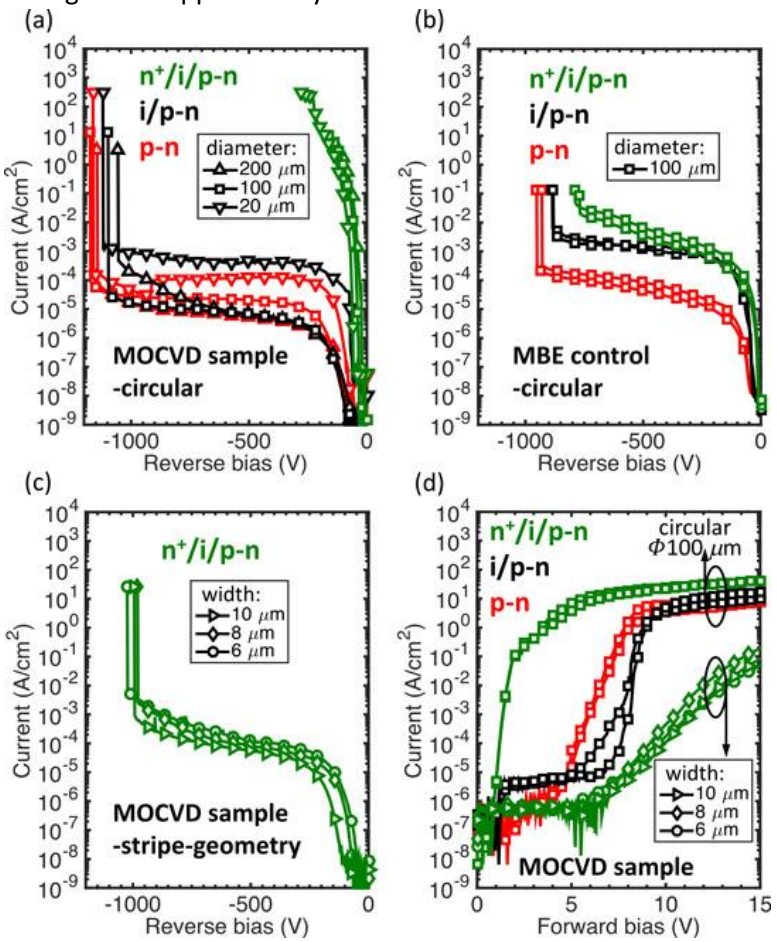


Figure 2: Reverse and forward current density versus voltage characteristics of diodes. (a) Reverse-bias characteristics of circular diodes on MOCVD and (b) on MBE control samples. (c) Reverse-bias characteristics of n+/i/p-n diodes with stripe geometry on MOCVD sample. (d) Forward-bias characteristics of various diodes on MOCVD sample.

The reverse-bias breakdown occurred in the range 1100-1200V for annealed circular p-n and i/p-n diodes, independent of diameter (Figure 2). Breakdown damage was observed as a burnt region at the mesa edge, typical for devices without field plates or other edge termination structure. The researchers estimate more than 28% activation of the magnesium acceptors in the p-GaN layers, as calculated from the field distribution at punch-through. The team sees this as a lower bound on activation as "breakdown is limited by edge field crowding but not punch through".

The n+/i/p-n-diodes had much higher leakage, and current-dependent soft breakdown occurred at 300V. MBE-sample devices had much lower leakage, attributed to the absence of hydrogen in the re-growth.

The high leakage in n+/i/p-n diodes is attributed to the n+-GaN layer blocking the diffusion of hydrogen out of the buried p-GaN layers. For the i/p-n devices, magnesium diffusion into the undoped (UID) GaN cap converts it into a p-GaN layer, allowing hydrogen diffusion upward during activation. Even with 20µm-diameter circular devices, diffusion of hydrogen through the mesa sidewalls is not sufficient for effective p-GaN activation.

Narrower-stripe-geometry devices with widths between 10µm and 5µm reduced the leakage current and enable breakdown to reach comparable values to the circular p-n and i/p-n diodes. The researchers comment: "These data indicate sufficient activation of the buried p-GaN, and thus a lateral hydrogen diffusion length of >5µm (half of the stripe width) under the annealing conditions used in this work. The observed activation should be attributed to the lateral diffusion of hydrogen out of the etched mesa sidewall as well as the exposed UID-GaN surface between fingers."

The forward bias characteristics of the p-n and i/p-n circular devices are similar – the turn-on voltage is rather high, and the on-current low, due to poor ohmic contact with p-type GaN.

The n+/i/p-n devices were back-to-back diodes and hence should not have a high current in the 'forward' bias region. The high current of the circular n+/i/p-n diodes demonstrates high leakage and hence poor p-GaN activation. By contrast, the leakage is suppressed in the stripe devices.

The researchers see 10-20µm as the critical lateral dimension range for effective activation of buried p-GaN through annealing. This range allows the escape of hydrogen out of p-GaN surfaces with a diffusion length of 5-10µm.

The researchers comment: "The reverse breakdown measurement is a much stricter test of the acceptor activation of buried p-GaN than light emission. Any insufficient activation of buried p-GaN leads to drastically higher leakage current due to premature punch-through."

The team also suggests that activation of magnesium near the surface creates an electric field that attracts hydrogen ions (mainly protons), enhancing out-diffusion. However, the effect of concentration gradient and electric field is reduced when the lateral dimension through which the hydrogen is required to diffuse increases.

MACOM launches industrial-temperature-grade 25G lasers for high-volume deployment in 5G LTE wireless front-haul applications

SemiconductorToday

In booth #1A32 at the China International Optoelectronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September) and in booth #579 at the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave

applications) is launching a portfolio of 25G distributed feedback (DFB) lasers designed for use in next-generation 5G LTE wireless front-haul infrastructure. Building on MACOM's legacy in 4G LTE connectivity solutions, the laser portfolio is expected to help wireless operators deploy 25G optical links at commercial scale and cost structures on the path to 5G.

Available in bare die chip format (1xxD-25I-LCT11-50x) and TO-packaging (1xxD-25I-LT5xC-50x) and designed for operation in the -40°C to 85°C temperature range over transmission distances of 2-10km, the new 25G DFB lasers will meet stringent operating requirements while helping to expand wireless infrastructure bandwidth for high-speed 5G connectivity.

The new industrial-temperature-grade 25G laser portfolio leverages MACOM's proprietary etched facet technology (EFT) which, at commercial-scale manufacturing levels, could enable breakthrough cost efficiencies and product uniformity, it is reckoned. MACOM believes that this high-volume production capability distinguishes it as a leading provider of 25G lasers across a host of cloud data-center and wireless infrastructure applications.

"MACOM's new 5G LTE-optimized 25G laser family builds on our comprehensive portfolio of 5G enabling technologies, and again demonstrates the value of EFT for achieving production efficiency that scales to meet industry supply and cost-structure needs," says Dr Fang Wang, VP & business line manager, Lightwave. "For customers transitioning from 10G to 25G wireless front-haul infrastructure, MACOM can provide the 25G lasers, complementary components and application expertise to help accelerate deployment time and reduce costs," he adds.

The industrial-temperature-grade 25G lasers are sampling to customers now, with production availability planned for 2019.

Presto extends test capabilities to 100GHz and beyond

SemiconductorToday

In booth B245 at European Microwave Week (EuMW 2018) in Madrid, Spain (23-28 September), Presto Engineering Inc of San Jose, CA, USA – which provides outsourced operations to semiconductor and Internet of Things (IoT) device firms (including developing industrial solutions for RF, analog, mixed-signal and secured applications, from tape-out to delivery of finished goods) – is highlighting that it can now provide high-volume testing of semiconductor devices up to 100GHz and beyond.

Applications that use GHz frequencies, i.e. millimeter wavelengths (mmW), are increasing rapidly and hence driving the need for high-volume device testing, says the firm, for example for Internet over satellite connections, car ADAS systems, and other high-speed data transfer solutions with a projected volume of more than a billion units by 2020.

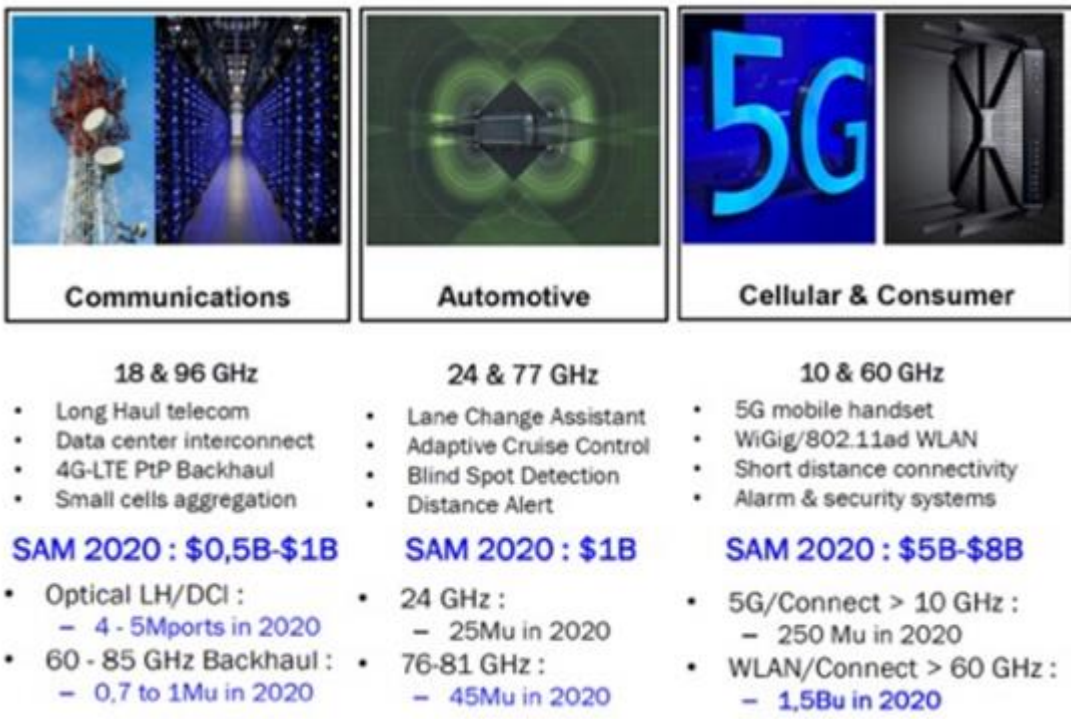
"Commercial test equipment does not test much about 50GHz," says chief operating officer Cédric Mayor. "The current method used by most customers is in-house bench testing by hand, which is slow and expensive. This is because testing equipment above 50GHz becomes increasingly expensive as the frequency increases as it is non-standard," he adds. "To solve this problem, we have created custom interfaces that step the test frequencies down into the range that commercial testers operate in. This enables us to provide a cost-effective testing service for ultra-high-frequency or mmW devices and builds on our existing services for high-frequency device testing."

Another challenge of mmW devices is that the substrate used is often much more brittle than the usual CMOS, such as gallium arsenide (GaAs) or gallium nitride (GaN). The wafers are hence much more susceptible to

breakage in transit and handling. To reduce the possibility of breakage, they are usually cut into quadrants once manufactured. A broken quadrant means fewer damaged parts compared to a whole broken wafer. However, the standard handling and test equipment is designed for circular wafers, so Presto has developed its own quadrant handling adapters for its test equipment.

It is also key to be able to maintain good correlation during the test and during the self-heating of the pulsed test methods, where continuous-wave measurement is normally used. In this case, all the fixturing must be able to control temperature and heat dissipation as well as include RF systematic error compensation for the measurements and maintain the correct reproducibility during production.

Among mmW applications already implemented or under consideration are short-range wireless backhaul, connecting small-cell wireless; data-center interconnect (DCI) for cloud servers; radar (primarily automotive); body scanners for airport security; chip-to-chip communications on printed circuit boards (where even short runs of wires or cables attenuate signals at these frequencies); and wireless communication protocols, such as 5G cellular, WiGig (802.11ad) and Wireless HD.



For convenience, the markets can be considered in three segments: communications, automotive and cellular/consumer, as shown in the table, which includes estimates of the potential served available market (SAM) and unit volumes. The first two of these are in now. Communications, driven by expansion in small-cell backhaul and cloud computing, has annual unit volumes for 2020 projected to be in the millions; and Automotive, driven by assisted driving (with autonomous driving on the horizon), has projected volumes in the tens of millions. The third vertical segment, Cellular & Consumer, driven by WiGig and 5G mobile, is in development now, with 2020 annual unit volumes projected to exceed 1 billion.

For further information, see the white paper ‘Enabling High Volume Test for Millimeter Wave RF Devices’ on Presto’s website.

Advantech Wireless and Alga Microwave presenting GaN-based SSPAs and BUCs for satellite broadcast

SemiconductorToday

Toronto-based wireless technology management company Baylin Technologies Inc (which provides passive and active RF products and services) says that both its subsidies Advantech WirelessTechnologies Inc of Montreal, Canada and Alga Microwave of Kirkland, Quebec, Canada (acquired on 28 June) are presenting satellite solutions for broadcast applications in booth 5.C34 at the IBC 2018 event in Amsterdam, The Netherlands (14-18 September).

Showcasing their Ultra HD-ready satellite solutions, the proprietary gallium nitride (GaN)-based solid-state power amplifiers (SSPAs) and block up-converters (BUCs) from Advantech and Alga deliver solutions for Digital Satellite News Gathering (DSNG) applications.

In an Ultra HD broadcasting environment, additional power is required in order to transmit higher modulation at a lower cost. The new generation of GaN-based SSPAs from Advantech are designed for very high-order modulation transmission of up to 256 APSK in a single compact unit, making ultra HD 4K/8K broadcast over satellite more cost effective.

The GaN-based SSPAs are teleport-grade, designed for 4K/8K Ultra HD transmission and provide elevated linearity while supporting higher-modulation transmissions. The enhanced linearity comes with no increase in size, weight or energy consumption, maximizing efficiency and reducing operational costs.

MACOM showcasing RF and microwave portfolio at EuMW

SemiconductorToday

In booth #271 at European Microwave Week (EuMW 2018) at the IFEMA Feria De Madrid Spain (25-27 September), MACOM Technology Solutions Inc is to showcase its gallium nitride on silicon (GaN-on-Si) portfolio, lightwave antennas and other high-performance MMIC and diode products

Specifically, MACOM will highlight new products optimized for 5G, wireless base-stations, radar, test & measurement, and industrial, scientific & medical RF applications:

Lightwave antenna solutions: combining RF coherent beam-forming and fiber-to-the-element optical transport to deliver wideband performance, low latency and improved spectral efficiency.
Enabling the next generation of wireless base-stations: GaN-on-Si 60W average power Doherty module.
Front-end modules (FEMs): Delivering performance and reliability for wireless networking leveraging proprietary switching technology and integration.
RF Energy: the industry's first GaN-on-Si-based RF energy toolkit.
GaN-on-Si: GaN-on-Si technology in mainstream CMOS factories is expected to enable the scale capacity, cost structure and supply chain economics for mainstream base-stations and RF energy applications at scaled-volume production levels.
High-performance RF components: showcasing MACOM's high-performance MMICs, limiter diode design, cross-reference tools and application-specific solutions.
MACOM experts are also participating in various sessions throughout EuMW, including:

Technical Session: 'Ka-Band P-I-N Diode Based Digital Phase Shifter' (25 September, 13:30, Exhibit Hall) - presenter: Daniel Kramer;
Technical Session: 'Characterization of Bond Wire Interconnects in QFN Packages' (25 September, 13:30, Exhibit Hall) - presenter: Qun Xiao.

EPC launches 100V, 25mΩ eGaN power transistor

SemiconductorToday

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – has launched the EPC2051, a 100V GaN transistor with a maximum RDS(on) of 25mΩ and a 37A pulsed output current for high-efficiency power conversion in a small footprint.

The EPC2051 measures just 1.30mm x 0.85mm (1.1mm2) - 30 times smaller than a comparable silicon MOSFET - so applications demanding higher efficiency and power density no longer have to choose between size and performance, says the firm. Despite the small footprint of the chip-scale package, operating in a 50V–12V buck converter the EPC2051 achieves 97% efficiency at a 4A output while switching at 500kHz. In addition, the low cost of the EPC2051 brings the performance of GaN FETs at a price comparable to silicon MOSFETs.

Applications benefiting from this performance, small size and low cost include 48V input power converters for computing and telecom systems, LiDAR, LED lighting and Class-D audio.

"The ability of eGaN-based power devices to operate efficiently at high frequency widens the performance and cost gap with silicon," says CEO Alex Lidow.

The EPC9091 development board is a 100V maximum-device-voltage half-bridge featuring the EPC2051, and the UP1966A gate driver from uPI Semiconductor. This 2" x 2" (50.8mm x 50.8mm) board is designed for optimal switching performance and contains all critical components for easy evaluation of the 100V EPC2051 eGaN FET.

The EPC2051 eGaN FET is priced at $0.67 each in 1000-unit quantities and $0.37 in 100,000-unit quantities. The EPC9091 development board is priced at $118.75 each. Both products are available for immediate delivery from distributor Digi-Key Corp.

Mission Microwave receives SSPA orders and design wins for SATCOMs

SemiconductorToday

Mission Microwave Technologies LLC of Santa Fe Springs, CA, USA, which manufactures gallium nitride (GaN)-based solid-state power amplifiers (SSPAs) and block up-converters (BUCs), says that it has received substantial orders and design wins from a range of top-tier system integrators in both government and commercial satellite communications markets.

"Since Mission Microwave was founded over four years ago, we have made steady progress winning the confidence and contracts of the leading suppliers of satellite communications (SATCOM) terminals for use in ground, air and maritime services," says president & CEO Francis Auricchio. "We can foresee building on this solid foundation of customer validation to expand the presence and availability of products to more markets segments that benefit from our products' superior performance and remarkable benefits in size, weight and power (SWaP)," he adds.

Major customer wins include applications for Ku-band BUCs across the 25-400W range. These BUCs are used on extremely lightweight fly-away and mobile terminals, including vehicular-mounted terminals that are part of a nationwide first-responder network. Other customer wins include system integrators of innovative flat-panel antennas and lightweight deployable network terminals.

Mission Microwave continues to ship high-power Ka-band BUCs for fixed and mobile applications, with the Dart, Stinger, Javelin and Titan platforms bringing weight savings and performance to terminal designs for power

ranges of 10-200W in both commercial and government bands. Recently, two major suppliers of maritime terminals announced new high-throughput 10W terminals compatible with Inmarsat's Global Xpress network that are based on Mission Microwave products. Other recent Ka-band wins include high-power BUCs for large gateway terminals for use in wideband global satellite networks.

"The satellite terminal market in X, Ku and Ka band increasingly demands the reliability of SSPAs to replace tube amplifiers across the entire range of mobile, fixed and transportable satellite terminals," says Auricchio. "Mission Microwave has proven its technology and ability to deliver and support the ground terminal market as it continues to expand in support of increased in-orbit capacity across a variety of global satellite network architectures."

RF power amplifier market to grow from $3bn by 3.2x, at 12.2% CAGR, through 2028

SemiconductorToday

The approximately $3bn RF power amplifier market is poised to expand at a robust compound annual growth rate (CAGR) of 12.2% over 2018-2028, as the widening expansion of 5G cellular networks will remain the main driver of RF power amplifier market growth, in addition to the continuous penetration of smart devices and connected technology, according to the report 'RF Power Amplifier Market Forecast, Trend Analysis & Competition Tracking - Global Market insights 2018 to 2028' from Fact.MR.

The APEJ region (Asia-Pacific, excluding Japan) currently accounts for a sizable share (<50%) of the RF power amplifier market, whereas North America holds over a quarter of the market.

The North American and European RF power amplifier markets are expected to exhibit high CAGRs, due mainly to the booming consumer electronics sector. However, the strong presence of some of the leading RF power amplifier manufacturers will maintain Asia Pacific (excluding Japan) as the largest market region throughout 2018-2028. With nearly 40% share of the market, APEJ is expected to be driven mainly by the developing telecom, industrial and wireless network sectors.

Burgeoning adoption of energy-efficient equipment, coupled with rapid progress in the semiconductor industry, will further accelerate RF power amplifier market growth in the APEJ region, the report forecasts. In terms of sustainable value generation in the RF power amplifier market, China, South Korea and India are expected to boost high-performance analog semiconductor components, increaing demand. Another strong factor driving growth in the APEJ region is consistently increasing deployment of next-generation wireless networks and LTE networks.

Established and new-entrant semiconductor manufacturers in certain regions, including China, India, Japan and the USA are expected to stimulate the development of new business models among RF power amplifier manufacturers by augmenting demand for advanced consumer electronics and network products – pushing the Internet of Things (IoT) and wireless infrastructure sectors further.

RF power amplifier manufacturers are focusing on increasing investments in technology upgrades, notes the report. The onus has shifted to revamping legacy models in order to improve operational efficiency. Evolving end-user demand has also meant that RF power amplifier manufacturers have to make consistent size/weight reductions while increasing the power density of amplifiers. Investment in R&D on the next generation of multi-mode RF power amplifiers will potentially play a pivotal role in enabling firms to address the challenge of adapting legacy platforms to support modern business operations, unlocking opportunities for RF power amplifier market growth in the near future, it is reckoned.

In March, US-based Cree Inc announced the acquisition of the assets of Radio Frequency (RF) Power business of Germany's Infineon Technologies AG, which should trigger expansion of Cree's existing product portfolio and customer base. Moreover, industry experts expect the acquisition to strengthen Cree's market position, particularly in RF GaN-on-SiC technologies. Also, MACOM has introduced the MAGM series of GaN-on-Si based monolithic microwave integrated circuit (MMIC) power amplifiers, specifically optimized for 5G wireless base-station infrastructure. More recently, NXP Semiconductors announced the launch of its 5G RF front-end portfolio for massive multiple-input-multiple-output (mMIMO) systems (the key ingredient of 5G networks), notes the report.

Magnetic sensing with gallium nitride high-electron-mobility transistors

SemiconductorToday

Magnetic sensing with gallium nitride high-electron-mobility transistors

Researchers at Swansea University in the UK and the University of Nis in Serbia claim the first fabrication of gallium nitride (GaN) magnetic high-electron-mobility transistors (MagHEMTs) [S Faramehr et al, Semicond. Sci. Technol., vol33, p095015, 2018].

The devices featured a split drain (Figure 1) that allowed the deviation of electron paths due to interaction with magnetic fields to be assessed. The relative sensitivity of such devices is given by the current difference between the drain terminals relative to the total drain current over the magnetic field in Teslas (T).

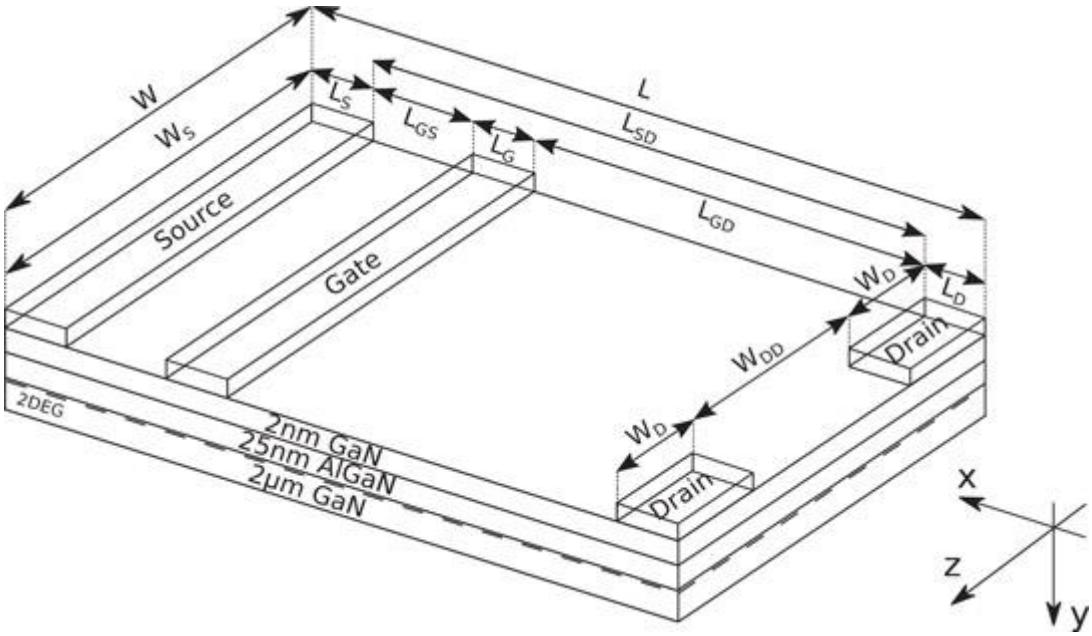


Figure 1: GaN MagHEMT (split-current sensor) schematic showing geometrical parameters used for relative sensitivity optimization.

Magnetic sensors are widely used for control in engineering systems covering aeronautical, automotive and industrial applications.

The devices were fabricated on HEMT heteroepitaxial structures with Al0.25Ga0.75N barrier layer. Step-graded AlGaN was used to transition from the silicon substrate. The length (L) and width (W) of the device were 35μm and 20μm, respectively. The lengths of the source (LS), and drain (LD) were both 5.5μm. The gate length (LG) was 1.0μm. The gate-source distance (L GS) was 1μm. The widths of the two drain contacts (WD) were 7.5μm each. The device was passivated with 10nm silicon nitride.

With the gate at zero and the drain bias at 0.5V, the sensitivity was found to be 11.98%/T – higher than previously reported values for silicon dual-drain split-current magnetic sensors.

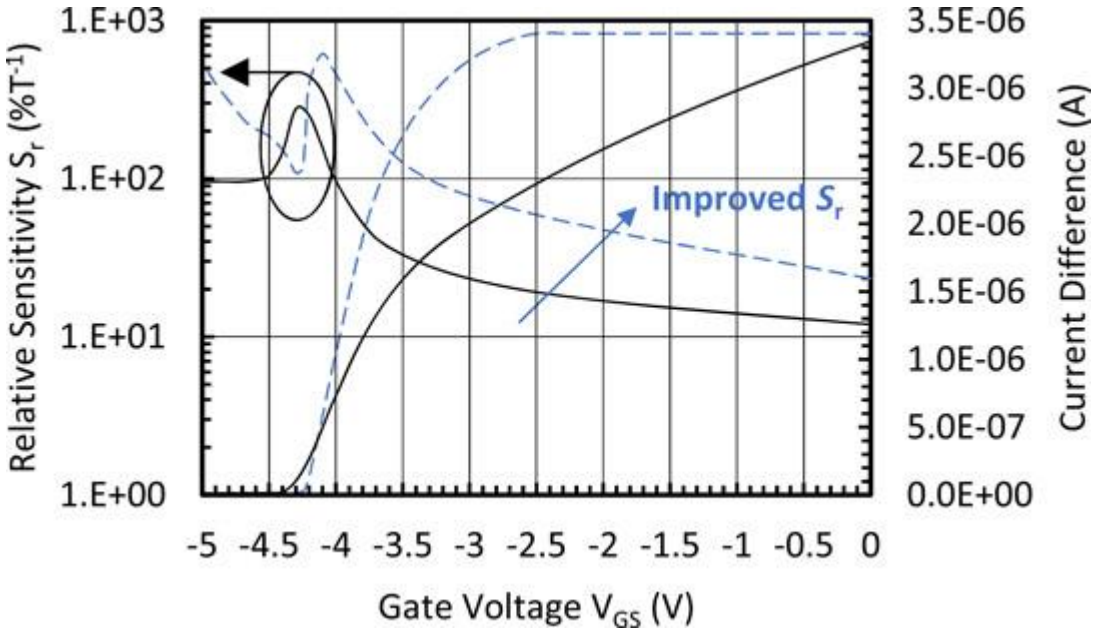


Figure 2: Simulated relative sensitivity (dash) and current difference (dash) of optimized GaN MagHEMT against simulated original GaN MagHEMT.

The researchers used the experimental results to calibrate a series of simulations aimed at optimizing performance. The model suggested that improved sensitivity of 23.29%/T, at zero gate potential and 0.5V drain bias, could be achieved in a device with altered parameters - L=65µm, W=20µm, LS =5.5µm, W S =5.0µm, WDD=5µm, L G =5.0µm and LGD=10µm (Figure 2).

The important changes seem to be a much longer total length of 65µm and reduced source width of 5µm. The reduced source contact decreases the total current flow and increases sensitivity to current deflection effects. The longer length also increases source to drain resistance, again reducing total current. The simulations also suggest an order-of-magnitude enhanced sensitivity at around -4V gate potential.

The researchers further studied the simulations at a raised temperature of up to 500K, showing "promising operation of GaN magnetic sensors under harsh environments". However, there was a decrease in sensitivity to 4.91%/T for the original device structure.

Teledyne e2v HiRel launches highest-voltage 650V/60A bottom-side-cooled GaN FET

SemiconductorToday

Teledyne e2v HiRel Electronics of Milpitas, CA, USA (a a business unit of the Teledyne Defense Electronics Group that provides solutions, sub-systems and components to the space, transportation, defense and industrial markets) has launched a 650V/60A gallium nitride (GaN) field-effect transistor (FET) device dedicated to demanding high-reliability (HiRel) applications. The new 650V/60A enhancement-mode power transistor is claimed to be the highest-voltage GaN FET on the market.

Fabricated in a GaN-on-silicon process, the TDG650E60 is packaged in GaN System's GaNPX package, which enables very low inductance and thermal resistance in a small 11mm x 9mm outline. The package is bottom-side

cooled to offer very low junction-to-case thermal resistance. GaN System's patented 'Island' technology is key to enabling high voltage, current and efficiency.

The plastic-packaged GaN FET is the first 650V product released from the new Teledyne e2v HiRel Enhanced Product (EP) series that addresses the concerns of applications where ceramic packages are not required. In such applications, the cost and earliest availability of newer technologies are the highest priorities for design engineers.

Teledyne e2v HiRel GaN screening, baseline control and a 10 year longevity support program will give reliability and availability assurance for demanding military, space, avionics, and related HiRel applications, says the firm.

"Releasing a HiRel 650V GaN FET is an industry milestone, giving design engineers more margin in the most demanding space and military COTS applications," says Mont Taylor, VP of business development. "The non-ceramic package will allow customers to benefit from the low-weight and efficient GaNPX package for the best performance in these stringent applications."

For demanding high-power applications, GaN power FET technology is the newest, most efficient solution, says the firm. The new 650V FET builds on this by offering additional benefits, including:

- very high switching frequency;
- SWaP (the device is a offered in a very small package);
- high voltage and high current;
- high energy density; and
- modular flexibility (the parts can be used in parallel to increase current).
- Teledyne HiRel Electronics is able to offer samples of the new device available for review. Shipping will begin in November.

US Air Force's GaN technology to be transferred to BAE Systems' Advanced Microwave Products Center

SemiconductorToday

BAE Systems has signed a cooperative agreement with the US Air Force Research Laboratory (AFRL) for Phase 1 of a technical effort to transition gallium nitride (GaN) semiconductor technology developed by the US Air Force to its Advanced Microwave Products (AMP) Center in Nashua, NH, USA.

As part of the effort, BAE Systems will transfer and further enhance the technology, and scale it to 6-inch wafers to slash per-chip costs and improve accessibility of the defense-critical technology.

Since GaN technology provides broad frequency bandwidth, high efficiency and high transmit power in a small footprint, it is suitable for next-generation radar, electronic warfare (EW) and communications systems. Under the agreement, BAE Systems will work with AFRL to establish a 140nm GaN monolithic microwave integrated circuit (MMIC) process that will be qualified for production by 2020, with products available to Department of Defense (DoD) suppliers through an open foundry service.

"Millimeter-wave GaN technologies today are produced in research and development laboratories in low volumes at high associated costs or in captive foundries that are not broadly accessible to defense suppliers," says AMP director Scott Sweetland. "This effort will leverage AFRL's high-performance technology and BAE

Systems' 6-inch manufacturing capability to advance the state of the art in GaN MMIC performance, reliability and affordability while providing broader access to this critical technology."

Work on the project will primarily take place in BAE Systems' 70,000ft2 Microelectronics Center (MEC) in Nashua, NH, where it researches, develops and produces compound semiconductor materials, devices, circuits and modules for a wide range of microwave and millimeter-wave applications. The MEC has been an accredited DoD Category 1A Trusted Supplier since 2008, and fabricates integrated circuits in production quantities for critical DoD programs.

As part of the project, the AMP Center team will work closely with the firm's FAST Labs research organization and MMIC design experts from ENGIN-IC.

5G GaN2 project developing 28GHz, 38GHz and 80GHz demonstrators for 5G cellular network base stations

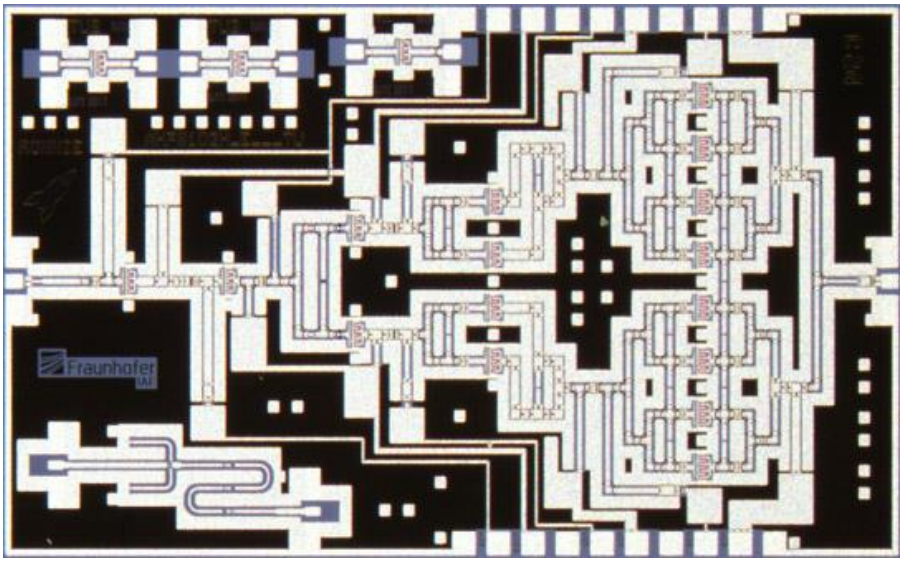
SemiconductorToday

The fifth-generation (5G) cellular network will enable data transmission between humans, devices and machines in real time, but so far no technology exists that allows for a reliable, fast and energy-efficient 5G network. In the European Union (EU) project '5G GaN2', 17 partners from research and industry have joined forces to develop cost-effective and high-performance technologies, based on gallium nitride, for the upcoming mobile communications standard. The consortium, which also includes the Fraunhofer Institute for Applied Solid State Physics (IAF) of Freiburg, Germany, started its work in July.

Besides Fraunhofer IAF, the project consortium partners include the complete value chain of mobile phone technology (wafer suppliers, semiconductor manufacturers and system integrators, together with universities and research institutes).

In the 5G cellular network, cars, devices and production machines will also transmit data in real time via the wireless radio network. In future, these high data rates will be covered by frequency bands in the millimeter-wave range (>24GHz), which provide a ten times higher bandwidth compared with currently available frequency bands (<3GHz) and have now been released internationally to significantly increase the bandwidth range.

The E-band amplifier chip developed at the Fraunhofer IAF measures only 4mm x 2.5mm.



Picture: The E-band amplifier chip developed at the Fraunhofer IAF measures only 4mm x 2.5mm.

However, these new frequency ranges cannot be served efficiently with existing mobile and antenna technology. “Therefore, it is necessary to improve the available output power and energy efficiency of the net infrastructure for these innovative frequency bands, through the use of advanced gallium nitride technology,” says Dr Dirk Schwantuschke, who is managing the project on behalf of Fraunhofer IAF. In the ‘5G GaN2’ project, components, parts and circuits for 5G base stations will be developed based on GaN. “The contribution of the Fraunhofer IAF to the overall project will be the development of power amplifiers in E-band, the frequency range around 80GHz,” explains Schwantuschke.

Lowering cost and improving performance

To meet the demand for data transmission via millimeter-wave frequency bands in the future, base-station technologies need to fulfill two criteria: the output power needs to be improved while simultaneously keeping cost and energy consumption low. To achieve these goals, the ‘5G GaN2’ project partners are counting on GaN-based technology and amplifier circuits. GaN-based electronic components and systems are much more energy efficient than conventional silicon-based components. GaN components can optionally be applied on cost-efficient silicon substrates. Another aspect of the project is the combination of various components in a single module, through innovative approaches regarding packaging technologies, in order to reduce costs.

The project’s aim is to realize demonstrators at 28GHz, 38GHz and 80GHz serving as key technologies for the development of a powerful and energy-efficient 5G cellular network based on GaN. The European Commission initiative ECSEL (Electronic Components and Systems for European Leadership) promotes the three-year joint project, consisting out of 17 project partners from seven countries. ECSEL supports development, research and innovation electronics by bringing various partners from industry, research and public sphere together.

Amplifier development Fraunhofer IAF

Fraunhofer IAF has particular expertise in developing GaN-based amplifiers. “GaN-based devices are especially well suited for powerful high-frequency amplifiers that are required for base stations and the infrastructure of the cellular network, as it allows [us] to provide high frequencies at high power,” says Schwantuschke. “The amplifiers developed at the Fraunhofer IAF are capable of sending more data faster and more energy efficiently through the cellular network.”

Wolfspeed talks 5G and launches new radar technologies at European Microwave Week

SemiconductorToday

At European Microwave Week (EuMW 2018) in Madrid, Spain (25-27 September), Wolfspeed of Durham, NC, USA — a Cree Company that makes silicon carbide (SiC) power products and gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs) — is sharing its view on the upcoming 5G market while unveiling its expanded portfolio of radar and 4G/5G products.

Gerhard Wolf, VP & general manager of Wolfspeed’s RF division, is delivering an industrial keynote on technological challenges posed by the transition to 5G and how the industry can leverage GaN and LDMOS to achieve the greater bandwidth and efficiency that 5G requires. The firm is also featuring its new wideband, two-stage, LDMOS integrated power amplifier (PTNC210604MD) in a live demo at the event.

In addition to showcasing new communications parts, Wolfspeed is unveiling two new 28V GaN MMIC power amplifiers (PAs) for radar applications: the 25W CMPA5259025F and the 50W CMPA5259050F (commercially available now). The C-band MMIC power amplifiers are designed in a compact 0.5” square package with greater

than 30dB small signal and nominally 50% drain efficiency. This combination enables phased-array radar designers to maximize the power per element for C-band radar systems, says the firm.

Both components are also used in linear and compressed amplifier circuits in marine radar, weather monitoring (Doppler weather radar), air traffic control (ATC), maritime vessel traffic control services (VTS), and port security applications. The 50W MMIC PA for C-band radar enables modular system design with increased reliability and lower maintenance costs, making it applicable to a variety of emerging radar applications. For example, the new amplifier is suitable for countries like India and USA as they upgrade radar capabilities at airports across their nations.

STMicroelectronics and Leti to co-develop GaN-on-Si diode and transistor architectures for power conversion applications

SemiconductorToday

STMicroelectronics of Geneva, Switzerland and micro/nanotechnology R&D center CEA-Leti of Grenoble, France are cooperating to develop and industrialize gallium nitride-on-silicon (GaN-on-Si) technologies for power switching devices, whch will enable ST to address high-efficiency, high-power applications, including automotive on-board chargers for hybrid and electric vehicles (HEVs/EVs), wireless charging, and servers.

The collaboration focuses on developing and qualifying power GaN-on-Si diode and transistor architectures on 200mm wafers, a market that research firm IHS Markit forecasts will rise at a compound annual growth rate (CAGR) of more than 20% from 2019 to 2024.

In the framework of Grenoble-based Technological Research Institute Nanoelec (IRT Nanoelec) - an R&D consortium headed by CEA-Leti focused on information and communication technologies (ICT) using micro- and nanoelectronics - ST and Leti are co-developing the process technology on Leti's 200mm R&D line and expect to have validated engineering samples in 2019. In parallel, ST will set up a fully qualified manufacturing line, including GaN/Si hetero-epitaxy, for initial production running in ST's front-end wafer fab in Tours, France, by 2020.

In addition, given the attractiveness of GaN-on-Si technology for power applications, Leti and ST are assessing advanced techniques to improve device packaging for the assembly of high-power-density power modules.

"Recognizing the incredible value of wide-bandgap semiconductors, ST's contributions in power GaN-on-Si manufacturing and packaging technologies with CEA-Leti move to arm us with the industry's most complete portfolio of GaN and SiC products and capabilities, on top of our proven competence to manufacture high-quality, reliable products in volume," says Marco Monti, president of STMicroelectronics' Automotive and Discrete Group.

"Leveraging Leti's 200mm generic platform, Leti's team is fully committed to supporting ST's strategic GaN-on-Si power-electronics roadmap and is ready to transfer the technology onto ST's dedicated GaN-on-Si manufacturing line in Tours," says Leti's CEO Emmanuel Sabonnadiere. "This co-development, involving teams from both sides, leverages the IRT Nanoelec framework program to broaden the required expertise and innovate from the start at device and system levels," he adds.

In February, ST also announced another development of GaN-on-Si for RF applications with MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications), for MACOM's use across a broad range of RF applications and for ST's own use in non-telecom markets. The RF GaN-on-Si is – for now, at least – better suited

to 150mm wafers. Because they produce low switching losses, GaN technologies suit higher-frequency applications.

GaN Systems appoints Arrow Electronics as distributor in EMEA

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) says that distributor Arrow Electronics is now supplying its range of GaN transistors in Europe, Middle East and Africa (EMEA).

GaN Systems says that its 100V and 650V transistor product families offer high efficiency, small sizes and open up opportunities in areas from data centres, electric vehicles and renewable energy to industrial motor drives and consumer electronics.

"This agreement further extends customer access and support to our industry-leading capabilities in power GaN transistors," says Tony Astley, director EMEA sales at GaN Systems. "As the demand for GaN technology grows worldwide, Arrow's extensive power team that combines technical and commercial experience provides the perfect platform for bringing GaN Systems' innovative technology to engineers in EMEA," he adds.

"For some applications, engineers need to look beyond established solutions if they are to create ground-breaking products," comments Matthias Hutter, VP of product management & supplier marketing, EMEA at Arrow Electronics. "GaN technology can deliver significant efficiency savings and GaN Systems offers a range of products to help make this happen."

Delta uses Transphorm's high-voltage GaN FETs to shrink power supply by 25%

SemiconductorToday

Power electronics and thermal management solutions provider Delta Electronics says that its latest 80Plus Platinum 800W power supply unit (PSU) – which now offers a backup lithium-ion battery – benefits from the use of high-voltage (HV) GaN FETs from 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 power conversion applications.

Should a data center lose power, the PSU's battery will keep connected servers running for one minute — long enough to allow for a proper power-down sequence. The use of GaN enabled Delta to reduce the power system size by ~25%, allowing the inclusion of a battery within a CRPS form factor.

The design stems from Delta's experience working with GaN power semiconductors in an effort to equip customers with high-performing power solutions. The decision to use HV GaN devices depended partly on meeting new product reliability and power density objectives. Delta also sought to repurpose its existing PSU design—a standard PFC continuous-conduction mode (CCM) boost converter.

Market analyst firm Yole Développement projects that the use of GaN within server power supplies will grow to about $50m by 2022, comprising the third largest segment of the total GaN power device market (~$450m by 2022), behind broad industrial power supplies.

Thin gallium nitride on silicon carbide high-power and high-frequency electronics

SemiconductorToday

Researchers based in Sweden have developed thinner III-nitride structures on silicon carbide (SiC) with a view to high-power and high-frequency thin high-electron-mobility transistors (T-HEMTs) and other devices [Jr-Tai Chen et al, Appl. Phys. Lett., vol113, p041605, 2018]. Rather than having a ~1-2µm-thick gallium nitride (GaN) buffer layer, the new structure uses a high-quality 60nm grain-boundary-free aluminium nitride (AlN) nucleation layer to avoid extended defects over large areas (Figure 1). The nucleation layer allows high-quality GaN to be grown within 0.2µm.

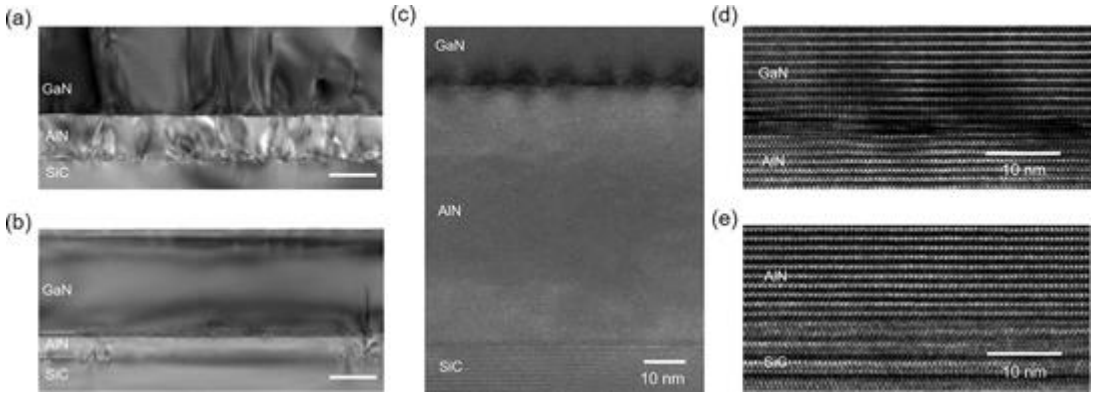


Figure 1: Cross-sectional transmission electron micrograph (TEM) images along the [11-20] direction at the GaN/AlN/SiC interface using (a) conventional and (b) low-TBR AlN nucleation. (c) High-magnification image of GaN/low-TBR AlN NL/SiC. (d) High-resolution image at the interface of the GaN/low-TBR AlN NL. (e) High-resolution image at the interface of the low-TBR AlN NL/SiC. Scale bar is 100nm in (a) and (b).

The normally thick buffer layers are used to transition and reduce defects arising from the 3.5% lattice mismatch between GaN and SiC – the mismatch is much higher for other substrates such as sapphire and silicon. These thick layers create problems for high-power and high-frequency devices. These layers are often doped with carbon or iron to increase resistance with the aim of confining current flow to the channel region, avoiding leakage effects from parasitic conduction. The doping creates charge-trapping states that can cause their own negative impacts on performance such as current collapse in radio-frequency operation.

Thinner devices should also have lower thermal resistance, improving thermal management. The team from SweGaN AB, Chalmers University of Technology, and Linkoping University, comments: “Structural defects like voids and dislocations generated at the interfaces of GaN/AlN/SiC introduce a thermal boundary resistance (TBR) that results in an additional 30-40% channel temperature rise in HEMTs.”

The reduced amount of expensive materials needed is a further attraction of the work. The researchers estimate a 90% reduction in raw materials including precursors and gases, along with reduced processing cost from the decreased growth time needed.

The new AlN nucleation process avoids the usual grain-like morphology that tends to result in column-like growth where defects are carried up into the overlying GaN. The usual graininess is due to the low mobility of aluminium atoms on the growth surface.

The III-nitride material was grown on silicon-face 4H silicon carbide. Hot-wall metal-organic chemical vapor deposition (MOCVD) was used to create epitaxial structures with 60nm AlN nucleation, a 200nm GaN channel, an AlN interlayer of up to 1.5nm, a 10-14nm AlGaN barrier (~30% Al), and a 2nm GaN cap. The 60nm AlN was produced using a low thermal-boundary-resistance (low-TBR) technique enabled by the hot-wall growth.

Despite the thinness of the structure, threading dislocations densities in the low 108/cm2 range was estimated, “two orders of magnitude less than that of the typical GaN layers with the same thickness,” according to the researchers. Contactless Hall measurements on a structure with a 2nm GaN cap and a 14nm Al0.29Ga0.71N barrier gave a 9.8x1012/cm2 two-dimensional electron gas (2DEG) density and a 2050cm2/V-s mobility. The sheet resistance was 315Ω/square.

Test T-HEMTs were produced on material with a 2nm GaN cap, a 10nm Al0.3Ga0.7N barrier and a 1nm AlN interlayer. Tantalum-based contacts were used for the source/drain, giving a contact resistance of 0.3Ω-mm.

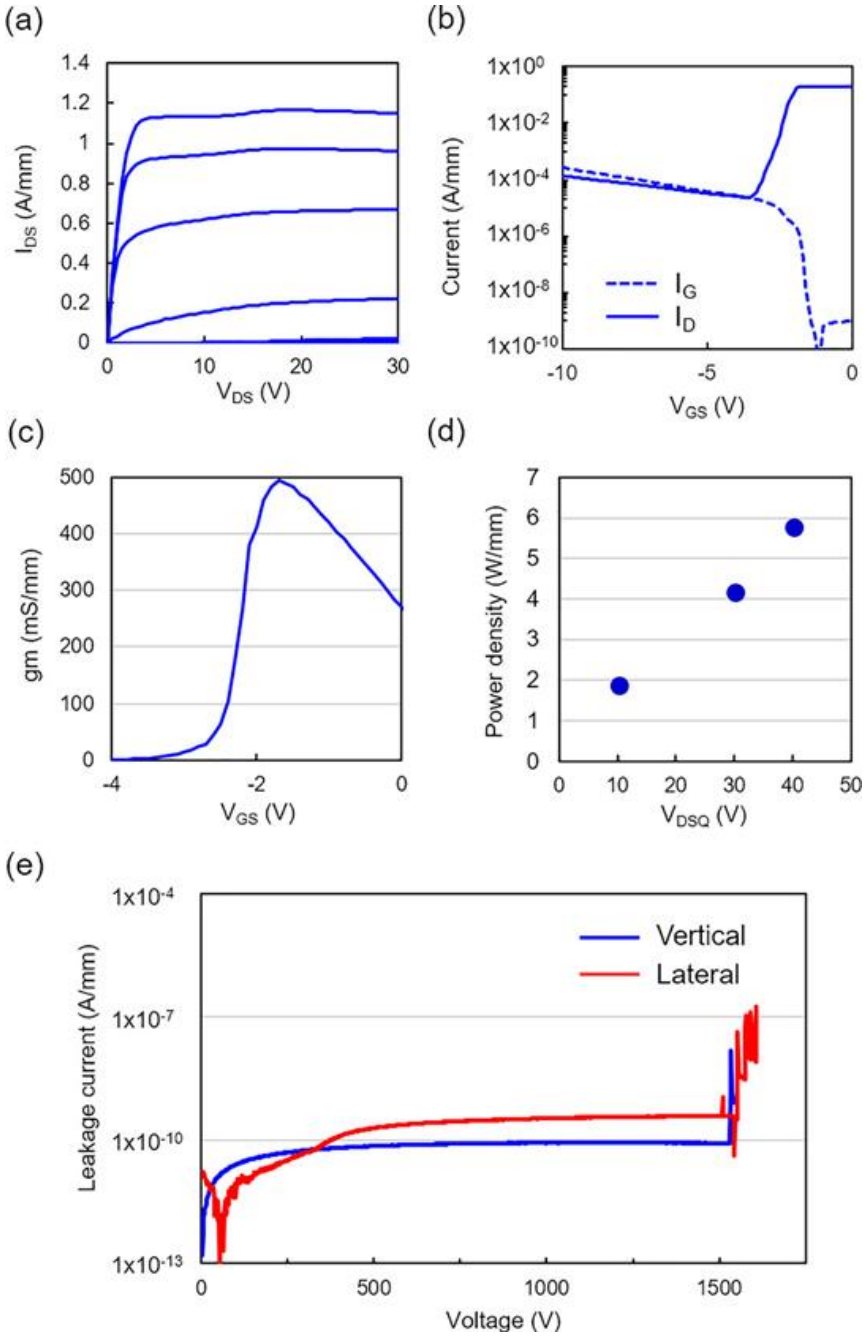


Figure 2: (a) DC drain current-voltage (IDS-VDS) characteristics, (b) transfer characteristics and gate and drain current at 10V drain bias (VDS) as a function of gate voltage (VGS), (c) transconductance (gm) as a function of gate potential, and (d) radio-frequency output power density as a function of VDSQ of T-HEMT. (e) Vertical and lateral breakdown characteristics of heterostructure without top active layers.

The device achieved a high on-current density of 1.1A/mm with low normalized on-resistance of 1.3Ω-mm (Figure 2). The saturation current was maintained up to 30V drain bias. With 10V drain bias, the pinch-off was sharp, with transconductance reaching 500mS/mm. The subthreshold swing depended on gate length: 250mV/decade for 0.1µm and 130mV/decade for 0.2µm. The breakdown voltages were 70V and 140V for the 0.1µm and 0.2µm gates, respectively.

The researchers comment: "The linear relationship between the breakdown voltage and the gate length suggests that the breakdown was taking place laterally due to the limited dimension of the gate length and the gate-to-drain spacing."

The gate-drain spacing was 2µm, far short of the usual 10-20µm normally used in GaN HEMTs aimed at power performance. Also, conventional GaN power HEMTs have micron-scaled gate lengths.

Load-pull measurements at 30GHz gave a peak radio-frequency power density of 5.8W/mm at 40V drain-to-source quiescent bias (VDSQ).

Breakdown measurements on an epitaxial stack without the upper AlN/AlGaN layers gave breakdown voltages up to 1.5kV in both lateral and vertical directions. The team comments: "In both cases, the breakdown was due to the bad delineation of the contacts. Therefore, the real breakdown voltage of the stack is expected to be higher. In other words, the breakdown has been limited by the surface and it confirms that there are no interface carriers."

Space satellite industry expert joins Akash as it files for experimental license with FCC

SemiconductorToday

Akash Systems Inc of San Francisco, CA, USA – which was founded in 2016 by Felix Ejeckam and Ty Mitchell and is focused on developing and supplying small satellites (CubeSats) and the RF power amplifiers that power them – has appointed Brian Holz as chief architect. Holz brings extensive space satellite experience from his work directing the design and construction of satellite constellations for leading commercial organizations.

"With competition becoming fierce in the crowded satellite industry, we recognized the need to bring the best minds to our team," says CEO & gallium nitride (GaN)-on-diamond inventor Felix Ejeckam. "Brian will bolster our systems development as we ramp up efforts to deliver next-generation RF communications links to a world that continues to demand increased connectivity."

Ejeckam invented the GaN-on-diamond technology in 2003 while at Group4 Labs Inc by lifting GaN epitaxy from its original growth substrate (for example, silicon) and transferring it to a synthetic CVD diamond substrate. Group4 Labs' assets were acquired in 2013 by Element Six Technologies (a member of the De Beers Group of Companies). In 2016, Ejeckam, together with Akash co-founder & chief operating officer Ty Mitchell, entered into an agreement with RFHIC Corp of Anyang, South Korea (which designs and makes active RF & microwave high-power components and hybrid modules) to jointly negotiate the repurchase of the GaN-on-diamond intellectual property (IP), with Akash acquiring all patents and other IP rights related to GaN-on-diamond technology for use in satellite communications and related markets.

With extensive experience in space systems engineering, program management and executive leadership, Holz will further Akash's aim to develop the next generation of small satellites and the components that power them. He was previously CEO of OneWeb Satellites, and executive VP & chief technology officer O3b Networks. He has expertise in startup management, global supply chain operations, multi-discipline team leadership and core technology development.

"The satellite industry is massively hindered by bandwidth constraints, and Akash's components will be game-changing for the entire industry," comments Khosla Ventures investor Delian Asparouhov. "Brian is a key component of helping us transform communications in space."

Holz joins Akash just as it has completed its critical FCC (Federal Communications Commission) filing for an experimental license, which grants organizations the ability to conduct scientific and research missions.

OPTOELECTRONICS

Seoul Semiconductor sues TV retailer Fry's Electronics for LED patent infringement

SemiconductorToday

Together with its affiliate Seoul Viosys Co Ltd, South Korean LED maker Seoul Semiconductor Co Ltd has filed a patent infringement lawsuit in the United States District Court for the Eastern District of Texas against consumer electronics retail company Fry's Electronics concerning sales of various LED television products.

With 17 mega-stores in California and 14,000 staff, Fry's is one of the largest big-box retailer of consumer electronics in the USA, offering more than 300 LED TV models featuring 25 different global TV brands.

Seoul asserts that certain LED TV products in Fry's stores infringe 15 of Seoul's LED patents relating to manufacturing processes for LED backlight units. Seoul's patented technologies cover LED TV backlight unit structures, LED backlight lenses for providing uniform illumination of LED lights, UCD technology for high-color-gamut displays, LED packaging, LED chip fabrication, and LED epitaxy. These are said to be significant technologies for improving the color, brightness and duration time of all LCD light sources such as smartphones, laptops, tablet PCs and monitors as well as TVs.

In particular, Seoul says that optical lens technology for offering uniform light distribution on TV or monitor displays is one of the most significant LED backlight technologies that it has developed since the earliest days of LCD backlights.

Seoul says that, to protect that patented technology, it actively enforces its patent rights against suspected infringers. In 2016, it prevailed in US federal court against Japanese lens maker Enplas, with a judgment finding that Enplas willfully infringed one of Seoul's LED backlight lens patents as well as one of its LED backlight system patents. Over the past few years, Seoul has also pursued patent litigation for infringement of LED backlight lens and other components patents against North America TV maker Craig Electronics and Curtis International, obtaining patent royalties from both companies.

UCD technology (KSF) is another of Seoul's core LED backlight technologies that enables improvement in the color gamut of LCD displays such as TVs and smartphones, which has been co-developed with a Japanese corporation for a long time. By enabling green and red light generated with KSF phosphors, UCD technology delivers 92-93% NTSC, which is higher than that of OLED.

Prior to the filing of its most recent litigation, Seoul delivered notices of patent infringement to various global TV brand makers, as well as their suppliers who manufacture TV modules or TV sets in various regions of Asia, including China and Taiwan, through OEM or ODM. Seoul advised these TV makers and manufacturers that they

needed to stop using LEDs and/or other components that likely infringe Seoul's LED backlight lens and UCD technology patents.

"For young entrepreneurs and small business entities to develop innovative products under fair competition culture, it is necessary for market participants to respect other companies' intellectual property rights," says Sam Ryu, Seoul's vice president of IT Business. "To prevent distribution of suspected infringing products, we are thoroughly investigating various global TV brand products that may infringe our patents. If these companies continue to use products that are suspected of infringement, despite our requests to stop, we will take all the necessary legal actions to the end."

K&S and Rohinni launch PIXALUX micro- and mini-LED die placement solution

SemiconductorToday

Singapore-based chip assembly & packaging equipment and materials supplier Kulicke and Soffa Industries Inc (K&S) and Rohinni LLC of Coeur d'Alene, ID, USA (which has developed a proprietary method for transferring semiconductor devices) have launched PIXALUX, K&S's micro- and mini-LED advanced high-speed die placement solution that was developed with Rohinni.

Such next-generation LED technologies have the potential to further enhance performance, improve efficiency and reduce the size of existing lighting technologies, says K&S. High-volume end-markets including automotive, display, consumer electronics and general lighting are expected to drive adoption and benefit from the emerging technology. While micro- and mini-LED benefits are compelling, high-volume placement challenges needed to be addressed prior to widespread market adoption of these emerging lighting solutions, the firm adds.

In May, K&S announced a joint development partnership with Rohinni to directly address this challenge. Rohinni's proprietary robotic process supersedes complex LED manufacture by placing mini- and micro-LEDs directly on virtually any substrate at high speed, in high volumes, and at what is claimed to be greatly reduced cost. With a combination of high-throughput and high-accuracy placement supporting extremely small-die applications, the resultant PIXALUX offers:

- high productivity and yield via its ultrafast placement head design;
- placement accuracy and speed on multiple types of substrates;
- support for placement of LED and IC dies;
- a wafer magazine with 10 wafer carriers; and
- ease of use with one-step automatic wafer loading.

"An example of one of the applications we anticipate PIXALUX initially enabling is the development of 2D LCD display backlighting, which means thinner and lighter display products that will provide better performance, dynamic range (HDR) and efficiency," says Chan Pin Chong, senior VP of Kulicke & Soffa's Wedge Bond & EA/APMR business unit.

"Our partnership with K&S is another big step forward for the Rohinni team and our technology," believes Rohinni's CEO Matt Gerber. "The scale, capabilities and reach of K&S coupled with Rohinni's advanced mini-LED placement technology means customers around the world now have a viable path to develop and manufacture next-generation mini-LED-based products."

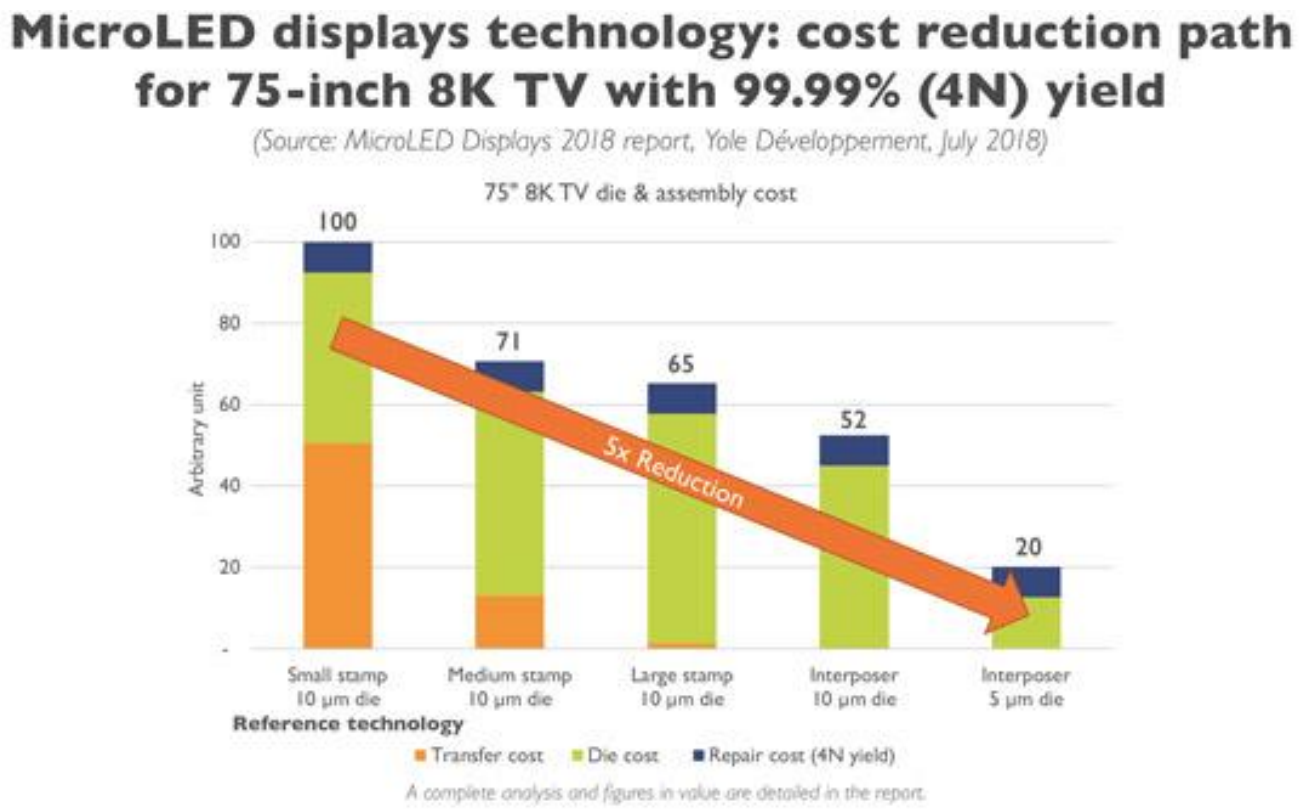
Customer evaluations of the PIXALUX bonder will begin in October.

Technology advances paving way for micro-LED cost reduction in high-volume applications

SemiconductorToday

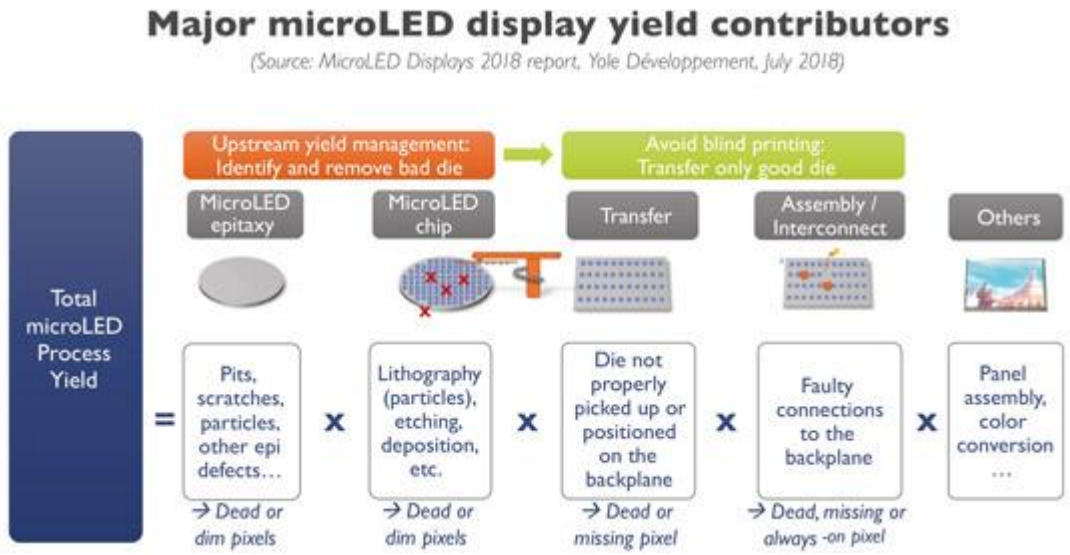
Micro-LED technologies are improving rapidly and new technology paths are emerging at a rapid pace, notes market research and strategy consulting firm Yole Développement in its report 'MicroLED Displays 2018'. The challenge is now focused on cost reduction. What is the feasibility of each solution? Can micro-LED TV or smartphone display manufacturing costs be compatible with these applications? Which cost reduction paths are the most realistic?

"Technology advancements pave the way for various cost-reduction paths toward volume manufacturing, but none are straightforward," comments senior market & technology analyst Dr Eric Virey.



Dozens of technologies are being developed for micro-LED assembly and pixel structures. The cost and complexity range can be staggering. However, there are some fundamentals that anchor all those processes. Alignment dominates assembly cycle times, die size cannot get infinitely small, epitaxy cost has already been through more than 20 years on the cost reduction curve. Cost analysis therefore allows companies to narrow the process parameters down to economically realistic windows and identify efficient cost-reduction strategies.

"Micro-LED companies must understand the cost targets for each application and work backward, making process choices and developing each step so it fits the cost envelope," asserts Virey. "Processes that cannot deliver the right economics will disappear. If none can deliver the right economics, the opportunity will never materialize," he adds. "MicroLED is entering the valley of death between technology development and industrialization and commercialization." Technology solutions should start converging by the end of 2019, it is reckoned.



As the technology improves, there are credible cost-reduction paths for micro-LEDs to compete in the high-end segment of various applications such as TV, augmented reality and virtual reality (AR/VR) and wearables, says Yole. With the right approaches, assembly cost could become a minor contributor. For smartphones, however, approaching the cost of organic light-emitting diodes (OLEDs) implies pushing micro-LEDs toward what is likely to be the limits of the technology in term of die size.

To succeed, micro-LEDs must count on some level of price elasticity, says Yole. They must deliver performance and features that no other display technology can offer and that are perceived by the consumer to be highly differentiating. Micro-displays for AR and head-up displays (HUD) will be the first commercial applications, followed by smartwatches. TVs and smartphones could follow 3-5 years from now, forecasts Yole.

RayVio shipping new XD mid-power and high-power XR Series UV-C LEDs

SemiconductorToday

Health and hygiene company RayVio Corp of Haywood, CA, USA, which is commercializing deep-ultraviolet (UV) LEDs and consumer disinfection solutions, is volume shipping its new 280nm XD mid-power and XR high-power UV-C LEDs, and has established what it clams is industry-leading 10,000 hour benchmarks for lifetime reliability – critical to the success of consumer and medical-grade products. Both the XD and XR Series are available as standard 3535-packaged emitters or mounted on star boards for easy test development and product integration. Both devices are globally available in-stock at distributor Digi-Key Corp.

“We are already stocking both the XD and XR Series and are well equipped to help our customers from a technical standpoint as the demand for UV-C continues to grow,” says Nick Olson, manager, Semiconductor Product Group, at Digi-Key Electronics.

For what is claimed to be the first time in the industry, RayVio is introducing documented lifetime ratings at multiple currents for both the XD and XR devices. This allows designers to engineer solutions for optimum performance, lifetime and reliability characteristics for their particular application.

“These are the most cost-effective UV-C LEDs available and that means more opportunity to develop new solutions,” claims CEO Dr Robert C. Walker. “For applications where cost is the primary driver, the XD mid-power Series is optimum, and when milliwatt-power is the priority our XR Series - with up to 12mW of power - is superior and yet very cost effective on a $/mW basis.”

RayVio says that, regardless of drive current, its UV-C LEDs have demonstrated Sterility Assurance Levels of 10-6 (99.9999%) and can be applied to applications from surface and water disinfection to medical-grade sterilization.

SETi files patent infringement litigation in US court against UV LED sterilizer firm

SemiconductorToday

Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA - which manufactures UV-A, UV-B and UV-C ultraviolet LED products emitting at wavelengths shorter than 365nm - has filed a patent infringement lawsuit in the US District Court for the Northern District of California asserting that both US-based Bolb Inc and Quantum Egg Inc (Q-egg). Bolb and Q-Egg are selling UV LED sterilizer devices that infringe on six of its patents covering fundamental UV LED technology, encompassing UV LED sterilizer structures and drivers, chip fabrication, and epitaxial layer growth.

Since its establishment in 1999, SETi has been dedicated to R&D on patented UV LED technologies. Its expertise has been recognized with government project grants focused on UV LED technology, including for the US Defense Advanced Research Projects Agency (DARPA).

SETi has also collaborated with South Korean UV LED maker Seoul Viosys Co Ltd (SVC), resulting in the development of Violeds technology for UV LED-based disinfection, deodorization, phototherapy and curing. Violeds technology has also been used by the US National Aeronautics and Space Administration (NASA) aboard the International Space Station (ISS).

The UV LED market was estimated to be $223m in 2017 and is projected to grow at more than 33% per year to $1.224bn by 2022. The UV LED appliance market has similarly expanded to many fields, including curing machines, medical devices and purification devices. In particular, the sterilization and purification market is projected to grow significantly over the next few years.

“It is important that such growth is accompanied by fair competition, including respect of intellectual property,” SETi says. “An increasing number of products in the marketplace infringe on SETi’s established patents,” it believes. To protect its intellectual property, SETi has committed to monitoring the market for patent infringement and engaging in enforcement activities.

“SETi strongly opposes the distribution of products in the market that infringe our patents. For this reason, our company will be undertaking enforcement actions against suspected infringers where appropriate and necessary,” the firm concludes.

Plessey and JDC collaborate on tailored backplane for monolithic micro-LED displays

SemiconductorToday

Plessey Semiconductors Ltd of Plymouth, UK has announced a strategic partnership for its own monolithic micro-LED displays – manufactured on its proprietary gallium nitride on silicon (GaN-on-Si) wafers – to be driven by the silicon backplane of Jasper Display Corp (JDC).

Unveiled by JDC at January’s Consumer Electronics Show (CES 2018) in Las Vegas, the eSP70 silicon backplane is tailored for the needs of micro-LED devices. The full-colour-capable active matrix backplane features a resolution of 1920×1080, a pixel pitch of 8µm and offers what is claimed to be excellent current uniformity via a proprietary current-source pixel as well as flexible addressing.

Making displays brighter for portable augmented reality (AR) and virtual reality (VR) battery-powered devices is increasingly challenging, says Plessey. Using existing technologies that require high power output is a serious design limitation as the compact devices have limited space to house on-board power sources. Using JDC's eSP70 backplane will give Plessey the flexibility to utilize its GaN-on-Si platform for micro-LEDs, delivering high brightness with moderate power consumption or run with low power while maintaining daylight-usable brightness levels.

"Plessey's monolithic micro-LED array is a great match to JDC's high-density silicon backplane," believes JDC's VP marketing & product management T.I. Lin. "Our JD27E series demonstrates our ability to deliver what our valuable partner Plessey and the wider industry has been waiting for – silicon that has been designed with their micro-LED needs in mind. Our X-on-Silicon backplane technology for micro-LED can be customized on a per-project basis, allowing us to make specialized silicon suiting needs ranging from low-power AR headsets all the way to automotive headlights," he adds.

"JDC's micro-LED-specific silicon backplane allows Plessey to rapidly bring to market our monolithic full-colour micro-LED array at our entry-level 8µm pixel size," says Plessey's chief technology officer Dr Keith Strickland. "We have overcome the significant challenges involved in accurately aligning and bonding the micro-LED array with the backplane. We are looking forward to partnering with JDC as we continue our development, reducing pixel and display size."

LED market growth in 2018 revised from 11% to 4%

SemiconductorToday

The LED market will grow to $18.796bn in 2018, up just 4% year-on-year (less than the earlier forecast of 11%), according to the report 'LED Industry Demand and Supply Data Base' by LEDinside (a division of TrendForce). The market is slowing down since oversupply is contributing to LED price declines, together with the impacts of escalating trade war on demand in the end market, notes the market research firm.

The massive production capacity expansion of Chinese LED makers has outpaced the growth in demand, triggering oversupply in the market, says LEDinside. The Chinese LED makers originally intend to raise their revenue and profits through production capacity expansion, but the falling average selling prices (ASPs) have made the market situation more difficult. First-half 2018 saw price declines of 20-30% for some LED chips. However, LEDinside does not expect a further sharp drop in prices in the short term, since price levels have almost approached the costs.

Taiwanese LED makers may move packaging facilities out of China

On the demand side, LED makers' export business to North America and other emerging markets has been influenced considerably by the trade war and currency depreciation. With the next wave of tariffs going into effect on 24 September, tariffs of 10% are being imposed on Chinese products, including more than 30 categories of LED lighting-related products. Accounting for around 70% of China's LED lighting exports, the $8bn worth of products will face even higher tariffs of 25% by 1 January 2019.

LEDinside believes that the tariffs may affect Chinese LED packaging companies and lighting product makers, because they may see a large decrease in orders from foreign customers. This will in turn reduce demand for LED chips upstream in the supply chain.

Despite the impacts of the trade war, which may result in a changing landscape in the global LED industry, LEDinside believes that lighting products will still be produced in China in the short term, with little change to

supply chains, because the supply chains of components and electroplating processes are long established in China. Due to the imposed tariffs and cost increase, some US LED lighting manufacturers have already reported price rises for their products in the US market. Meanwhile, to avoid the tax, Taiwanese LED makers that have production facilities in China may move assembly back to Taiwan before exporting to North America. To maintain competitiveness in the long term, LED companies may relocate production to their facilities outside China in order to minimize the impacts of trade issues, concludes LEDinside.

Vertical-cavity resonant near-green lasing of indium gallium nitride

SemiconductorToday

Xiamen University and Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO) in China have developed near-green vertical-cavity surface-emitting lasers (VCSELs) using material that is mainly luminescent in the blue 445nm part of the spectrum [Rongbin Xu et al, IEEE Transactions on Electron Devices, published online 3 September 2018].

The researchers engineered the cavity resonance so that it favored the near-green 493nm-wavelength emissions from indium gallium nitride (InGaN). Efficient green laser diodes are highly desired to plug the 'green gap' for red-green-blue full-color display systems. Presently, green laser light is produced using a combination of a longer-wavelength laser and frequency-doubling, increasing complexity, system sizes, and cost.

Researchers are seeking to plug the gap with InGaN-based devices, but the material suffers from inhomogeneous composition and crystal quality degradation, especially at the higher indium contents needed for green emission.

The active region consisted of a double quantum well of In0.18Ga0.82N, 2.5nm each, separated by 6nm of GaN. Normally such material is expected to emit blue wavelengths around 445nm. The wells were capped with an electron-blocking layer of 20nm of Al0.2Ga0.8N to prevent carrier overflow into the p-type layers. The metal-organic chemical vapor deposition (MOCVD) of III-nitride material was performed on c-plane sapphire.

The epitaxial material was fabricated into a VCSEL (Figure 1) with distributed Bragg reflector (DBR) mirrors defining the cavity and a silicon dioxide (SiO2) current aperture. The DBRs used titanium oxide (Ti3O5) and silicon dioxide dielectric pairs – 13.5 for the bottom mirror and 11.5 for the top. Indium tin oxide (ITO, 30nm) was used for current spreading in the aperture. The p- and n-electrodes were both chromium/gold (Cr/Au). The structure was flipped onto a copper (Cu) heatsink.

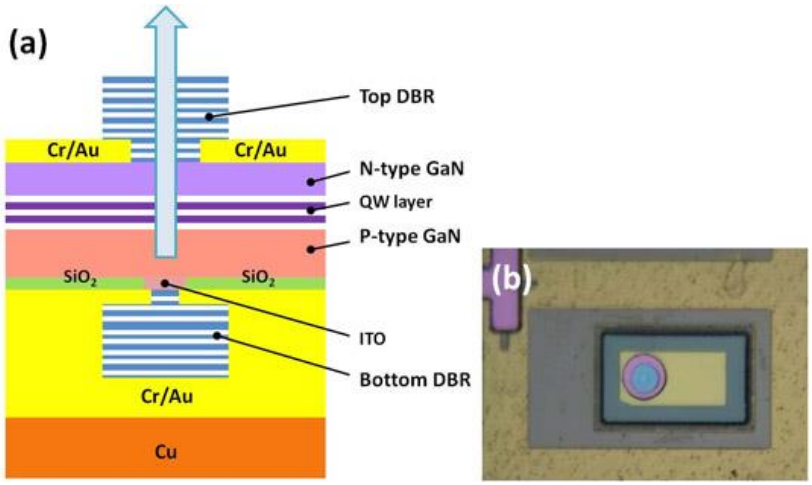


Figure 1: (a) Cross-sectional schematic of VCSEL. (b) Optical image of real device.

At a low 15mA current, the emission centers on the ~440nm blue range of the InGaN quantum well material (Figure 2). As the current increases to the 32mA (~18kA/cm2) threshold, the wavelengths in the cavity resonance region of 493nm become stronger, based on emissions from In-rich localized narrow-gap regions. At higher 45mA current injection, the ~440nm wavelengths are suppressed and a narrow lasing peak emerges with 0.55nm linewidth in the blue-green 493nm region. The output power at 50mA was estimated to be ~178µW. Previously, the researchers report that they produced quantum dot VCSELs in the green region, but with only 10µW light output power. The optical polarization of the emitted light was 71% at 1.09x the threshold current injection.

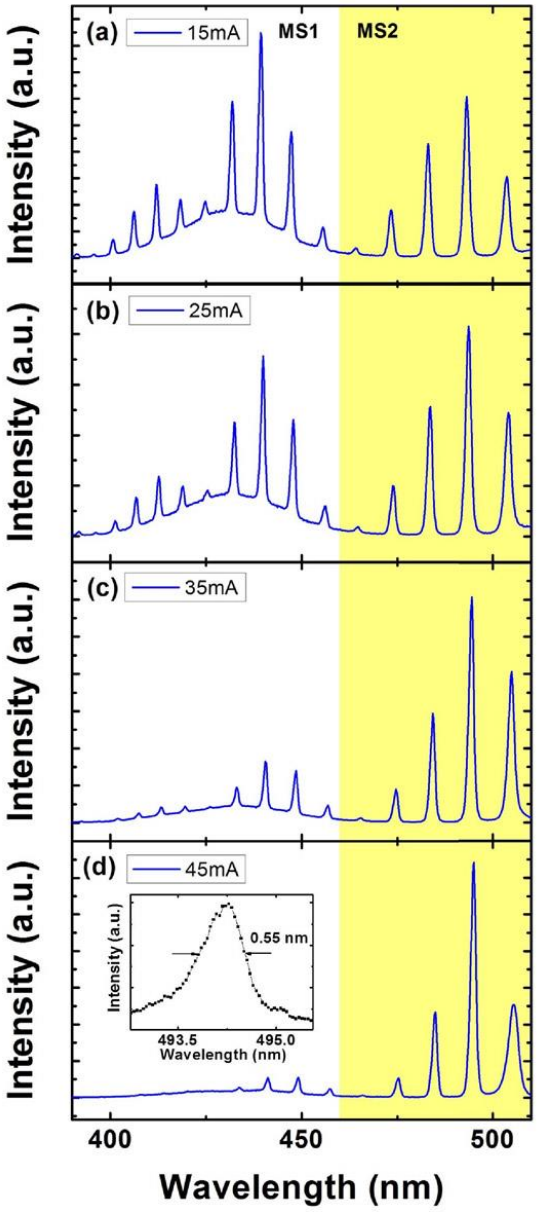


Figure 2: Electroluminescence spectra of the VCSEL measured at four different currents. (a) 15mA, (b) 25mA, (c) 35mA, and (d) 45mA. Inset: linewidth of lasing peak measured with higher resolution

The cavity resonance compensates for the lower density of In-rich localized narrow-gap regions, reducing the lifetime for recombination into photons. The researchers comment: “The short lifetime indicates a high carrier capture efficiency and can compensate the low density of emission centers, resulting in stronger emission intensity.”

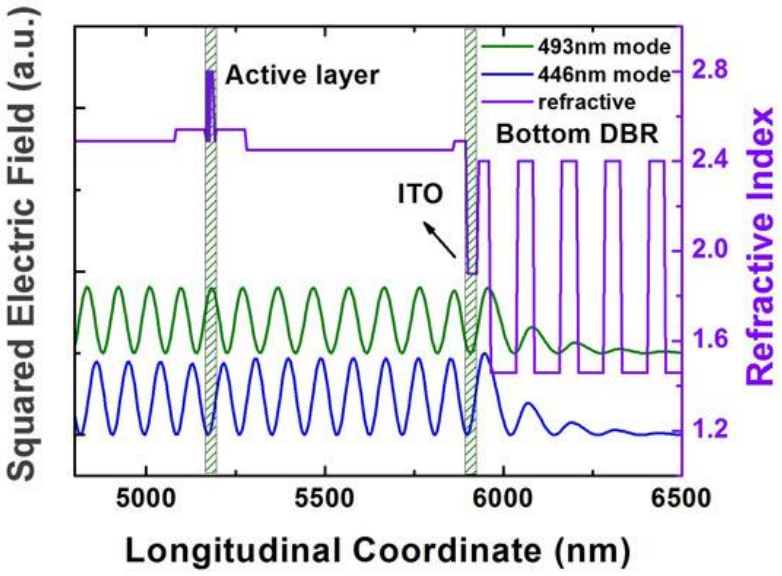


Figure 3: Refractive index and distribution of optical field for 446nm and 493nm cavity modes of VCSEL.

Simulations of the optical field also suggest that the active region lines up with an anti-node (maximum) of the standing-wave pattern for 493nm wavelength emissions. By contrast, the 446nm mode gives a node (minimum) at the active layers. The gain enhancement factor is calculated at 1.82 for 493nm and 0.21 for 446nm. The researcher also point out that the longer lasing wavelength also benefits less absorption loss in the active region.

Plessey orders Aixtron AIX G5+ C MOCVD system for GaN-on-Si monolithic micro-LEDs

SemiconductorToday

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has received an order for an AIX G5+ C Planetary Reactor metal-organic chemical vapor deposition (MOCVD) system from UK-based Plessey Semiconductors to boost its manufacturing capability for gallium nitride on silicon (GaN-on-Si) wafers targeting next-generation micro-LED applications.

With an automatic cassette-to-cassette (C2C) wafer transfer module, the new reactor will be installed and operational during first-quarter 2019 at Plessey's 270,000ft2 fabrication facility in Plymouth, UK. The AIX G5+ C MOCVD system has two separate chamber set-up options, which enables configurations of 8x6-inch or 5x8-inch GaN-on-Si wafers to be automatically loaded and removed from the system in an enclosed cassette environment. The system will be an addition to the firm's existing MOCVD reactors, also supplied by Aixtron, which provide configurations of 7x6-inch or 3x8-inch with manual loading.

Productivity is further enhanced by the new reactor's automated self-cleaning technology, which helps to deliver a very low level of wafer defects by ensuring that the reactor is clean on every run, significantly reducing downtime for maintenance. The new equipment also provides faster ramp and cool down, along with a high susceptor unload temperature to reduce the recipe time.

The AIX G5+ C reactor will support Plessey's extensive production roadmap to increase R&D capacity of its monolithic micro-LEDs based on its proprietary GaN-on-Si technology. Plessey's micro-LEDs are said to offer extremely low power consumption, high brightness and very high pixel density, creating the potential for disruption in many existing application areas that use conventional display technologies such as LCD and OLED.

Plessey is developing illuminators for display engines and full-field emissive micro-LED displays. The complex devices combine very high-density RGB pixel arrays with high-performance CMOS backplanes to produce very high-brightness, low-power and high-frame-rate image sources for head-mounted displays, and wearable electronics devices for augmented reality (AR) and virtual reality (VR) systems.

"Our continued and valuable relationship with Aixtron allows Plessey to rapidly bring to market its monolithic micro-LEDs," says Plessey's chief operating officer Mike Snaith. "To help us achieve this, our latest acquisition of Aixtron's AIX G5+ C planetary system combines outstanding on-wafer uniformity and run-to-run performance at the lowest cost of ownership – aspects that are critical for efficient high-volume GaN-on-Si micro-LED displays," he comments.

"The AIX G5+ C will support Plessey's requirements in the best way possible to address the most stringent requirements for micro-LED production," believes Dr Frank Schulte, VP of Aixtron Europe. "While offering more productive configurations, the tool meets the toughest requirements from the silicon industry in terms of uniformity and particles."

Addressing all of the challenges involved in manufacturing micro-LEDs, including high-volume and cost-effective production capability, Plessey says that it is actively engaging with potential customers to use its production-ready micro-LED technology platform.

Cree launches highest-efficacy 90 CRI chip-on-board LEDs

SemiconductorToday

LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA has launched XLamp eTone LEDs, a set of chip-on-board (COB) LEDs that delivers 90 color rendering index (CRI) light quality at the same efficacy as standard 80 CRI LEDs.

Delivering up to 155 lumens per watt (LPW) at a correclated color temperature (CCT) of 3000K (at 85°C), the new eTone COB LEDs are claimed to provide the highest efficacy available compared with competing COB LEDs of the same size and color. The firm adds that the enhanced performance can transform the output, efficacy and size of LED luminaires in applications that need high-quality light, including retail, museum, high-end commercial and medical.

"Cree is enabling us to create 80 CRI and 90 CRI lights that share the same intensity, beam angle and power consumption with just one product design," comments Massimo Parravicini, R&D director of Reggiani Lighting. "This no-compromise COB solution gives us the industry's top performance, the excellent light quality that our customers require and the LED form factors that will drop right into our existing designs," he adds.

For many indoor lighting applications, the typical guideline for light quality is a minimum CRI of 80. Lower CRI values tend to distort colors and are generally unpleasing, while higher CRI values of 90 mean higher fidelity or accuracy, indicating better light quality, says Cree. LEDs with 90 CRI values are primarily used in settings where color quality is critical, such as retail and museum lighting. LEDs have been available in 90 CRI versions for many years but, until now, this light quality has come at a significant penalty to light output and efficacy compared with lower-light-quality 70 or 80 CRI versions. Cree says that its new eTone LEDs overcome this penalty by delivering an upgrade in LED efficacy of up to 17% over existing 90 CRI LEDs without sacrificing color quality.

"Two years ago, Cree achieved an LED industry first with our lab demonstration of a single high-power LED that hit an extraordinary 134LPW at 1587lm, 85°C and 90 CRI," says Dave Emerson, Cree LEDs executive VP & general manager. "Cree is committed to turning our industry-first R&D results into viable commercial products that offer

customer-ready LED solutions where others do not," he adds. "Today's release of our eTone LEDs that deliver 90 CRI at the same efficacy as 80 CRI means that lighting manufacturers no longer have to sacrifice top-tier efficacy to achieve excellent color quality for indoor lighting applications."

Available in both the ceramic-based XLamp CXA2 Standard Density and the metal-based XLamp CMA & CMT High Current chip-on-board (COB) LED families, all eTone LEDs share the same mechanical and electrical characteristics as the standard versions, so lighting designers will be able to quickly upgrade their designs with minimal redesign effort. Additionally, LM-80 data coverage is available immediately to reduce the time for lighting manufacturers to receive DesignLights Consortium qualifications on their products.

The eTone LEDs will be available in 4000–2700K CCTs at minimum 90 CRI. Product samples of eTone LEDs are available now and production quantities are available with standard lead times.

OTHER

Veeco's president Bill Miller to become CEO as John Peeler transitions to executive chairman; CFO Maheshwari adds COO role

SemiconductorToday

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that chairman & CEO John Peeler will transition to the role of executive chairman, effective 1 October. Current president William J. Miller will become CEO and will join the board of directors, bringing its size to eight. Additionally, Shubham (Sam) Maheshwari will be named chief operating officer and will continue in his role as chief financial officer.

Peeler joined Veeco in 2007 as CEO and became chairman of the board in 2012. As executive chairman, he will work with Miller and the board to ensure an effective transition of management.

"With his impressive background and track record of notable achievements across strategic, product development and operational assignments, there is no one better suited than Bill to take over the helm as Veeco looks forward to its next chapter," believes Peeler.

Over the last 16 years, Miller has held a variety of roles within Veeco. He became president in 2016, overseeing all of Veeco's global business units. Previously, he guided the strategic direction and product development for the MOCVD and Ion Beam product lines and was responsible for the global operations organization. Prior to joining Veeco, Miller held engineering and operations leadership roles with Advanced Energy and Exxon Corp. He holds BS, MS and PhD degrees in mechanical engineering from the University of Pennsylvania.

"I want to thank John for his guidance and building such a strong leadership team," says Miller. "I intend to build on this legacy while discovering new opportunities to leverage the company's outstanding technology and unmatched talent," he adds.

"When John joined the company in 2007, Veeco was considered a data storage and metrology company," notes lead independent director Richard D'Amore. "John's vision and focus on execution transformed Veeco to be on the leading edge of the compound semiconductor and advanced packaging markets… Bill will build upon his progress."

Maheshwari joined Veeco in 2014 with more than 20 years of experience in finance. He previously held senior and executive level positions in the semiconductor industry at KLA-Tencor, Spansion and OnCore. Maheshwari holds BS and MS degrees in chemical engineering and an MBA from the Wharton School of Business. Working side-by-side with Miller, he will be charged with advancing Veeco's operations, customer satisfaction and profitability.

IQE's first-half 2018 revenue growth driven by Photonics segment

SemiconductorToday

For first-half 2018, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported revenue of £73.4m, up 4% on first-half 2017's £70.6m (or up 5.4% on £69.6m from wafer sales, excluding first-half 2017's £0.95m of license income from joint ventures).

Wireless revenue fell slightly from £48.1m to £47.8m. CMOS++ revenue rose from £0.7m to £0.83m. Photonics revenue grew by 24% from £15.2m to £18.9m (rising from 21.9% to 25.8% of wafer sales), remaining IQE's most rapidly growing business segment.

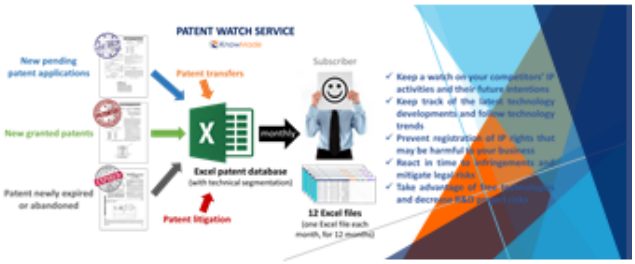
However, overall revenue growth was despite a currency headwind of about 10%, reflecting strong sales growth in each of the firm's main business sectors. On constant-currency basis, Wireless sales were up 11%, InfraRed sales were up 11%, and Photonics sales were up 30%.

Wireless inventory channels, depleted as a consequence of the rapid ramp of VCSELs in second-half 2017, were partially replenished during first-half 2018.

Photonics revenue growth was despite revenue from the largest photonics customer being flat while inventory from the aggressive first mass-market ramp of vertical-cavity surface-emitting laser (VCSEL) epiwafers in second-half 2017 was consumed in the supply chain. Demonstrating the breadth and depth of photonics engagements, revenue from other photonics customers hence rose 40% as photonics capacity was directed to satisfy more than 20 VCSEL chip manufacturer engagements in order to significantly broaden IQE's global reach in the rapidly growing markets for 3D sensing in consumer and other high-growth applications.

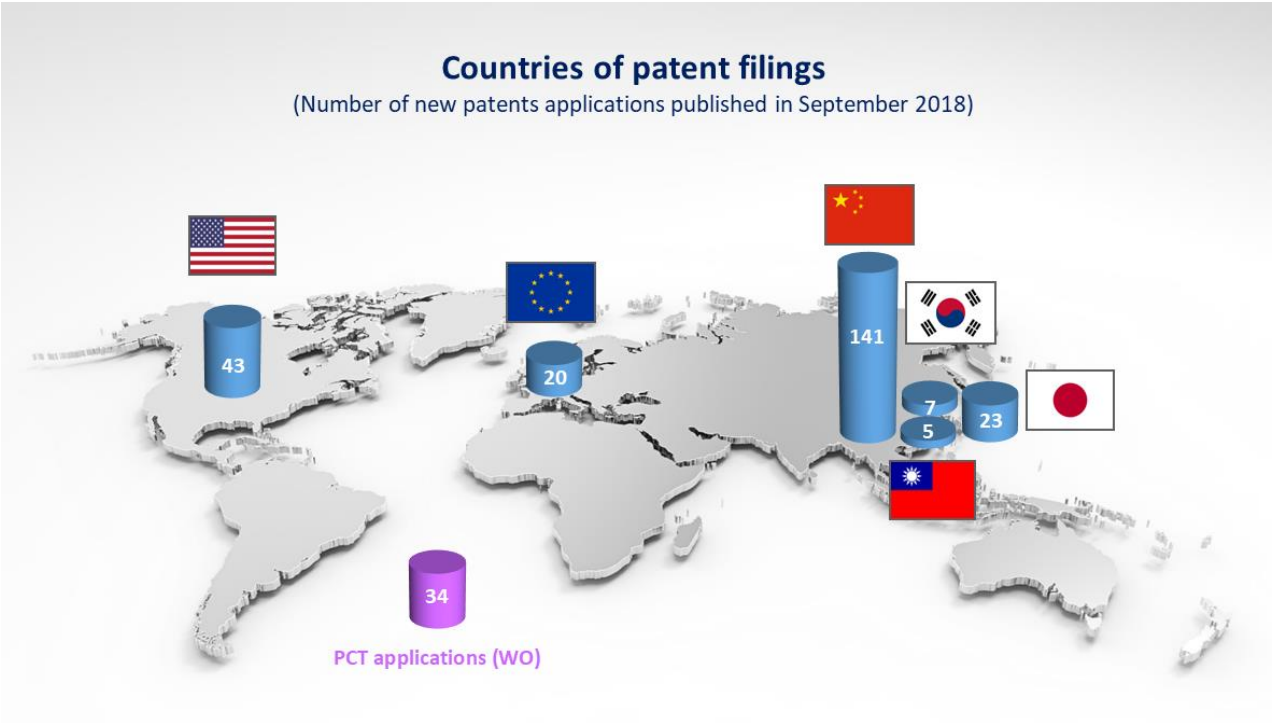
Wafer gross margin contracted from 24.7% to 23.3%. Specifically, Photonics gross margin was adversely impacted by pre-production costs for Newport Foundry of £0.9m (recruitment, increased headcount and training to support 24/7 operation) and low-margin customer-funded product development (primarily new VCSEL customers) reducing photonics margins by a further £0.6m.

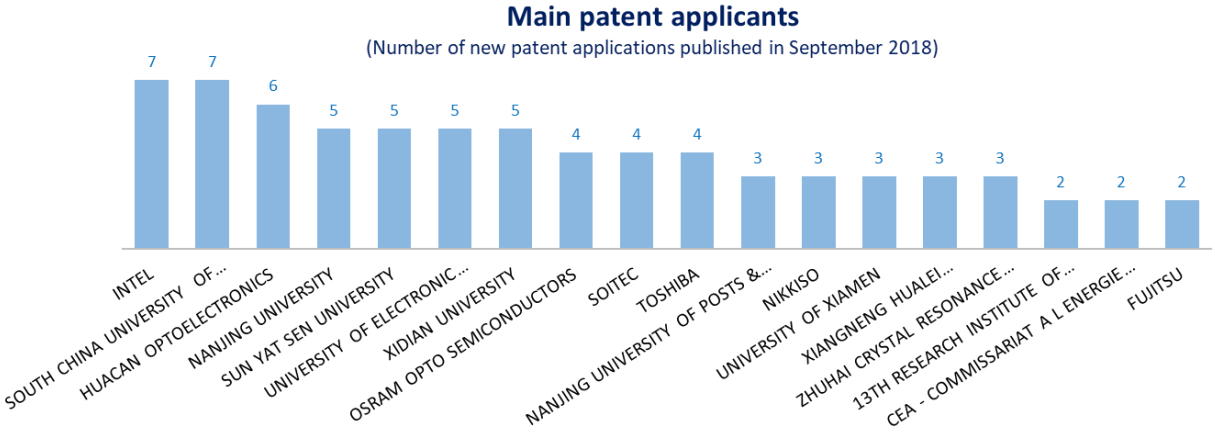
Operating profit (from wafers) has fallen from £9.7m (excluding £1m from license income) to £7.6m, with operating margin falling from 13.8% to 10.4%. Specifically, Wireless operating margin fell from 15.6% to 13.9% due to conversion costs for switching reactors from Photonics to Wireless production during first-half 2018. Photonics operating margin fell from 41.6% to 25.8% due to the high level of low-margin photonics customer qualifications in first-half 2018 and the pre-production costs expensed in relation to the new Newport Foundry. Taking into account the Newport Foundry pre-production costs and the investment in qualification programs for new VCSEL customers, the underlying Photonics operating margin was 33.4%. Photonics margins will return to 35% for H2 2018 as production efficiencies of the ramp in output are realised.



PATENT APPLICATIONS

More than 220 **new patent families (inventions)** were published in **September 2018**.





Other patent applicants: Global Foundries, Guangdong University Of Technology, Haidike Photoelectric Technology, Hebei University Of Technology, Hefei Irico Epilight Technology, IBM, Institute Of Microelectronics Chinese Academy Of Sciences, Mitsubishi Electric, Panasonic, SCIOCS, Seoul Viosys, Shandong Tide China Light Photoelectron, Sumitomo Chemical, Sumitomo Electric Industries, Taiyuan University Of Technology, Toyoda Gosei, University Beijing, Ushio Opto Semiconductors, Zhejiang University, ABB Schweiz, Anke Innovation Technology, Asahi Kasei, Australia Ocean, Beihang University Of Aeronautics & Astronautics, BOE Technology, BOE Technology Group, Bolb, British Nuosaike Technology, Business Foundation Sungkyunkwan University, Chengdu Hiwafer Technology, Chengdu Huaguang Mirco Array Technologies,

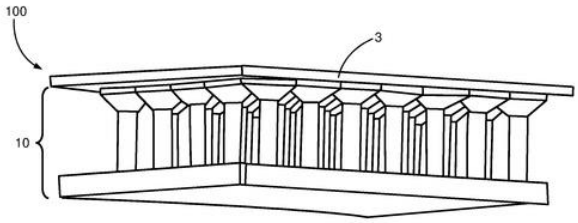
Chipsk, Chongqing BOE Optoelectronics Technology, CSUB Aux For Sponsored Programs Administration, Dalian University Of Technology, Dalian Core Technology, Dalian University For Ntionalities, Disco, Dongguan Zhongjing Semiconductor Technology, Enkris Semiconductor, Everlight Electronics, Fairchild Semiconductor, Fujian Trillion Yuan Photoelectric, Fujifilm, Furukawa, Genesis Photonics, Georgia Tech Research, Glo, Globalwafers, Guangdong Institute Of Semiconductor Industrial Technology, Guangdong Midea Refrigeration Equipment, Guangdong Shengda Electronic, Guangzhou Jianye Electronic Technology, Guizhou Normal University, Han S Laser Technology Industry, Hangzhou Dianzi University, Hantong Feixin Electronic Technology, Harbin Institute Of Technology, Hella & Co, Heyuan Zhongtuo Optoelectronics Technology, Hong Kong Beida Jade Bird Display, HS Elektronik Systeme, Huazhong University Of Science & Technology, Hubei University, Huizhou Byd Industrial, Infineon Technologies Austria, Jian Sheng, Jiangsu Nenghua Microelectronic Technology Development, Kunshan Govisionox Optoelectronics, Kyushu University Institute Of Technology, LG Display, Liming Vocational University, Midea, Nagoya University, Nanchang Huanglv Lighting, Nanchang University, National Chiao Tung University, Nihon Densan, Osaka University, Panasonic Automotive Systems, Panasonic Intellectual Property Management, Petalux.

Notable new patent applications

Nanowire structure and method for producing such a structure

Publication Number: FR3064109, WO2018172281
Patent Applicant: CEA - COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES*

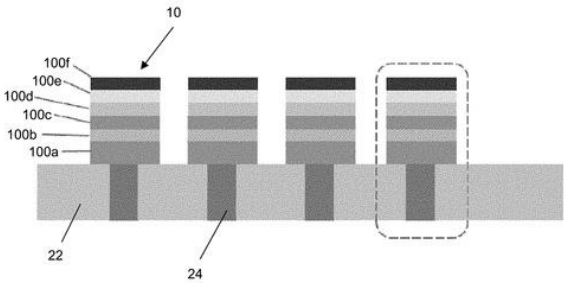
A method for producing a structure (100) comprising a membrane (3) made of a first material, in particular of indium-tin oxide, in contact with receiving ends (13) of a plurality of nanowires (1), the method comprising the following steps: - shaping a nanowire device (10) comprising the receiving ends (13), the receiving ends being shaped so as to form flat surfaces, - placing, in particular by transfer, a membrane device (3; 34) directly on the nanowires at the flat surfaces of the receiving ends of the membrane.



Micro-led display assembly

Publication Number: US20180269191
Patent Applicant: GLOBAL FOUNDRIES

The present disclosure relates to semiconductor structures and, more particularly, to a micro-light emitting diode (LED) display assembly and methods of manufacture. The structure includes an interposer and a plurality of micro-LED arrays each of which include a plurality of through-vias connecting pixels of the plurality of micro-LED arrays to the interposer.

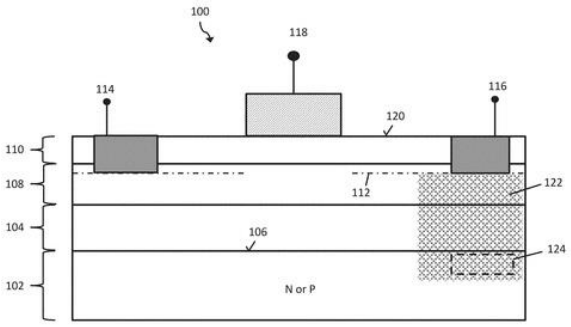


High voltage blocking III-V semiconductor device

Publication Number: US20180269282

Patent Applicant: INFINEON TECHNOLOGIES AUSTRIA

A semiconductor device includes a type IV semiconductor base substrate, a first type III-V semiconductor layer formed on a first surface of the base substrate, and a second type III-V semiconductor layer with a different bandgap as the first type III-V being formed on the first type III-V semiconductor layer. The semiconductor device further includes first and second electrically conductive device terminals each being formed on the second type III-V semiconductor layer and each being in ohmic contact with the two-dimensional charge carrier gas. The base substrate includes a first highly doped island that is disposed directly beneath the second device terminal and extends to the first surface of the base substrate. The first highly-doped island is laterally disposed between portions of semiconductor material having a lower net doping concentration than the first highly-doped island.

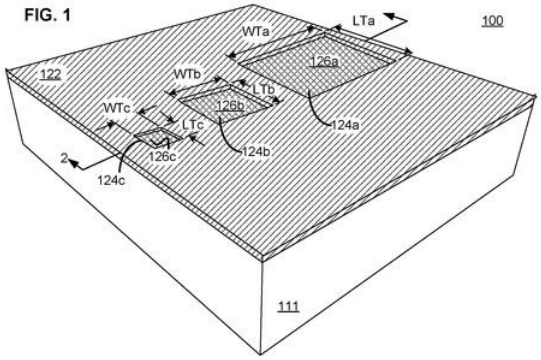


Methods and apparatus for coplanar GaN islands including confined epitaxial layer

Publication Number: WO2018169519

Patent Applicant: INTEL

Methods and apparatus are disclosed for electronic devices including islands of III-V material having differing base width dimensions, but grown by confined epitaxy on island growth areas of an integrated silicon substrate so as to have top surfaces that are substantially coplanar with one another. Transistors of differing sizes can be formed that include the islands of III-V material having differing base width dimensions. The substantially coplanar top surfaces can facilitate electrical interconnection of the transistors of differing sizes formed to include the islands of III-V material. Moreover, a silicon CMOS transistor can be formed in close proximity on the same integrated silicon substrate. The coplanar top surfaces can facilitate interconnecting the silicon CMOS transistor with at least one of the transistors of differing sizes formed to include the islands of III-V material.



Integrated gallium nitride capacitor-transistor structures

Publication Number: WO2018174872
Patent Applicant: INTEL

A switch capacitor bank structure, an integrated circuit die, and a method of fabricating the switch capacitor bank are disclosed. The switch capacitor bank structure includes a plurality of gallium nitride (GaN) transistors on a semiconductor substrate and one or more trench capacitors above the semiconductor substrate. Each of the trench capacitors is located between and is coupled to at least a first corresponding GaN transistor and a second corresponding GaN transistor of the plurality of GaN transistors. The first corresponding GaN transistor and a first trench capacitor of the one or more trench capacitors are coupled to a first interconnect. The second corresponding GaN transistor and the first trench capacitor are coupled to a second interconnect. The first interconnect and the second interconnect are coupled.

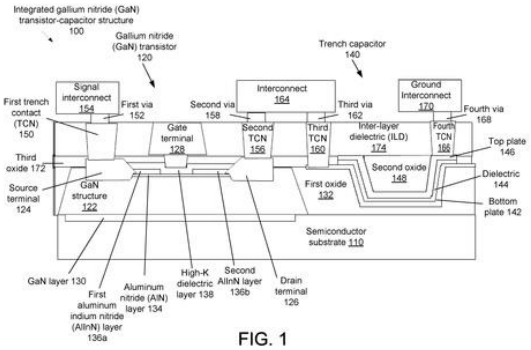
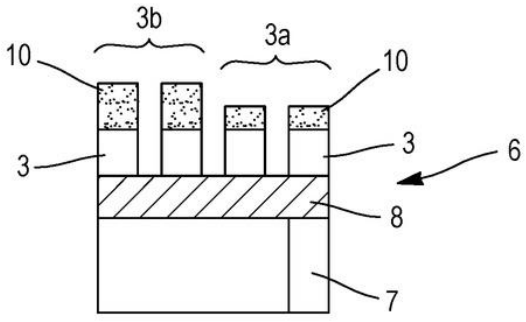


FIG. 1

Growth substrate for forming optoelectronic devices, method for manufacturing such a substrate, and use of the susbstrate, in particular in the field of micro-display screens

Publication Number: US20180269253 FR3064110
Patent Applicant: SOITEC

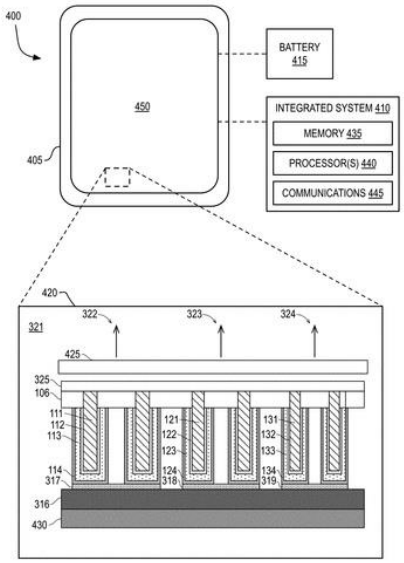
A method for manufacturing a plurality of crystalline semiconductor islands having a variety of lattice parameters comprises providing a substrate including a medium, a flow layer disposed on the medium, and a plurality of strained crystalline semiconductor islands having an initial lattice parameter arranged on the flow layer. The strained semiconductor islands are selectively treated so as to form a first group of strained islands having a first lateral expansion potential, and a second group of strained islands having a second lateral expansion potential that is different from the first lateral expansion potential. The substrate is heat treated at a temperature at or above a glass transition temperature of the flow layer to cause differentiated relaxation of the islands of the first and second groups, such that a lattice parameter of the first group of relaxed islands differs from a lattice parameter of the second group of relaxed islands.



Emissive devices for displays wafer and the making of a method

Publication Number: US20180261785
Patent Applicant: INTEL

Embodiments related to emissive devices for displays are discussed. Some embodiments include light emitting diodes including an electron transport layer core having a tube shape with an inner and an outer sidewall, an emission layer on the inner and outer sidewalls, and a hole transport layer on the emission layer, displays and systems including such light emitting diodes, and methods for fabricating them. Other embodiments include emissive laser devices having an emission layer between a hole transport layer and an electron transport layer and first and second metasurface mirrors adjacent to the hole transport layer and the electron transport layer, respectively, displays and systems including such emissive laser devices, and methods for fabricating them.



Switching device with charge distribution structure

Publication Number: EP3370260, CN108538917, JP2018152555
Patent Applicant: POWER INTEGRATIONS

A semiconductor device includes a substrate and a first active layer (120) disposed over the substrate. The semiconductor device also includes a second active layer (115) disposed on the first active layer such that a lateral conductive channel (155) arises between the first active layer and the second active layer. a source (125), gate (130) and drain (150) contact are disposed over the second active layer. A conductive charge distribution structure (135, 140, 145) is disposed over the second active layer between the gate and drain contacts. The conductive charge distribution structure is capacitively coupled to the gate contact.

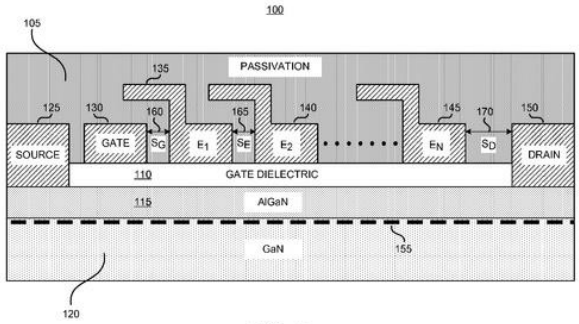


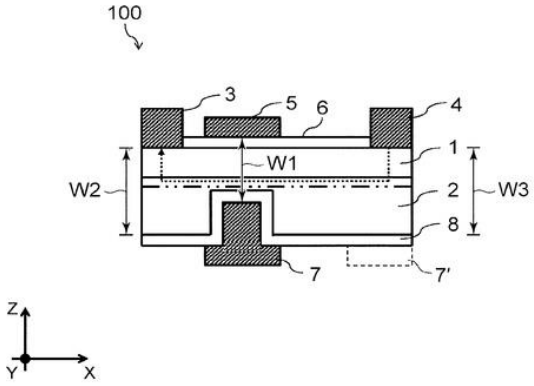
FIG. 1

Nitride semiconductor device

Publication Number: US20180269290

Patent Applicant: TOSHIBA

A nitride semiconductor device includes a first semiconductor layer including a nitride semiconductor, a second semiconductor layer contacting the first semiconductor layer and including a nitride semiconductor, a source electrode, a drain electrode, a first gate electrode, a second gate electrode provided on an opposite side, a first insulating layer and a second insulating layer. The gate electrode has a protrusion portion inside the semiconductor layer. A distance between the first gate electrode and the protrusion portion of the second gate electrode is shorter than a distance between the source electrode and the second insulating layer, and shorter than a distance between the drain electrode and the second insulating layer.



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