GANEX

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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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Selection by III-N French experts

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monthly newsletter

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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 and Mathieu Leroux (CRHEA-CNRS)

Hole injection mechanism in the quantum wells of blue light emitting diode with V pits for micro-display application

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Applied Physics Express
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The current injection mechanisms for blue light emitting diodes (LEDs) with and without V pits were examined by controlling the bandgaps of InGaN quantum wells (QWs), which were changed by reducing the indium content. To identify the distribution of holes in the QWs, the electroluminescence of the LEDs was characterized by varying the positions of the QWs with the wider bandgap consecutively from n-cladding to p-cladding sides. For the LEDs without V pits, holes were injected through the top QWs (p-cladding side), while for the LEDs with V pits, holes were injected mainly through the bottom QWs (n-cladding side).

High power surface emitting InGaN superluminescent light-emitting diodes

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Applied Physics Letters
https://doi.org/10.1063/1.5118953

A high power InGaN superluminescent light-emitting diode emitting normal to the substrate is demonstrated. The device uses a structure in which a monolithically integrated turning mirror reflects the light at both ends of the in-plane waveguide to direct amplified spontaneous emission downward through the transparent GaN substrate. Record optical peak powers of >2 W (both outputs) are reported under pulsed operation at 1% duty cycle. A broad, smooth emission spectrum with a FWHM of 6 nm centered at 416 nm is measured at peak output and ascribed to very low feedback associated with the turning mirror and antireflection coating.

Strain relaxation of InGaN/GaN multi-quantum well light emitters via nanopatterning

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Optics Express
https://doi.org/10.1364/OE.27.030081

Strain in InGaN/GaN multiple-quantum well (MQW) light emitters was relaxed via nanopatterning using colloidal lithography and top-down plasma etching. Colloidal lithography was performed using Langmuir-Blodgett dip-coating of samples with silica particles (d = 170, 310, 690, 960 nm) and a Cl2/N2 inductively coupled plasma etch to produce nanorod structures. The InGaN/GaN MQW nanorods were characterized using X-ray diffraction (XRD) reciprocal space mapping to quantify the degree of relaxation. A peak relaxation of 32% was achieved for the smallest diameter features tested (120 nm after etching). Power-dependent photoluminescence at 13 K showed blue-shifted quantum well emission upon relaxation, which is attributed to reduction of the inherent piezoelectric field in the III-nitrides. Poisson-Schrödinger simulations of single well structures also predicted increasing spectral blueshift with strain relaxation, in agreement with experiments.

Surface-plasmon-enhanced LED based on multilayer gratings and core-shell Ag/SiO2 nanoparticles

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Materials Research Express
https://doi.org/10.1088/2053-1591/ab414f

This paper proposes a novel GaN-based LED with nano-grating structure based on surface plasmons. This structure mainly contains n-GaN, multiple quantum wells and p-GaN, Ag–SiO2 grating, core–shell Ag/SiO2 nanoparticle and ITO triangular grating. The basic principle of the light emitting characteristics of LED is described in detail. The COMSOL software is used to analyse properties and optimise parameters based on the finite element method. The radiated intensity, absorbed intensity and electric field distribution are obtained. The results indicate that this structure has a higher luminous efficiency with the luminous intensity increased to about 58.59 times compared with the ordinary structure and about 3.94 times compared with the reference structure, and can enhance the internal quantum efficiency and the external quantum efficiency of the LED simultaneously.

Enhancement of the optoelectronic performance of p-down multiquantum well N-GaN light-emitting diodes

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Physica Scripta
https://doi.org/10.1088/1402-4896/ab28c0

We present the numerical effect of the polarity of the built-in field on the GaN-based light-emitting diodes (LEDs). The results show that, in comparison to the Ga-polar device, the p-down N-polar device shows significant improvement in electronic and optical characteristics. In N-LED, the turn-on voltage, internal quantum efficiency and radiative recombination rate is improved by 6%, three times at 100 A cm−2 and 194%, respectively. It is shown that the effective barrier heights and energy band offsets are the governing reason behind the significant improvement in N-polar devices.

Light extraction enhancement of AlGaN-based vertical type deep-ultraviolet light-emitting-diodes by using highly reflective ITO/Al electrode and surface roughening

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Optics Express
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AlGaN-based vertical type high power ultraviolet-C light emitting diodes (UV-C LEDs), which have a Ga-face n-contact structure, were fabricated on a LED epilayer transferred to a carrier wafer through a laser lift-off (LLO) process. A significant light extraction enhancement of the vertical chip by using a highly reflective ITO/Al p-type electrode is demonstrated, along with surface roughening. A GaN-free LED epi structure is employed to prevent light absorption in the UV-C wavelength region. The vertical chip with the ITO/Al reflector and n-AlGaN surface roughening exhibited a high light output power of 104.4mW with a peak wavelength of 277.6nm at an injection current of 350mA. Comparing the device characteristics of the vertical chip and the flip chip showed that the light output power of the vertical chip was 1.31 times higher than that of the flip chip at 350mA. In particular, with the high power vertical type UV-C LED, a maximum light output power of 630mW could be achieved at a current of 3.5A, and this is mainly attributed to efficient heat dissipation through a metal substrate and the resulting relatively lower junction temperature of the vertical chip.

Fabricating GaN-based LEDs on (−2 0 1) β-Ga2O3 substrate via non-continuous/continuous growth between low-temperature undoped-GaN and high-temperature undoped-GaN in atmospheric pressure metal-organic chemical vapor deposition

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Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab3ff5

This study demonstrates two approaches to the growth of GaN-based LEDs on (−2 0 1)-oriented β-Ga2O3 single crystal substrates using metal-organic CVD under atmospheric pressure. One approach induces non-continuous growth between low-temperature undoped-GaN (u-GaN) and high-temperature u-GaN, whereas the other approach induces continuous growth. We observed the following reduction in the FWHM of X-ray diffraction rocking curves: GaN (0 0 2) on (−2 0 1) β-Ga2O3 substrate (from 464 to 342 arcsec) and GaN (1 0 2) (from 886 to 493 arcsec). An LED with six pairs of InGaN/GaN multiple quantum wells was successfully fabricated on the (−2 0 1) β-Ga2O3 single crystal substrate.

Analysis for optimal size of current blocking layer in InGaN-based vertical LEDs

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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab39bb

In this research, we sought to determine the optimal size of the current blocking layer (CBL) in a vertical light-emitting diode (V-LED) for maximized output power. As the area of the CBL increased, the amount of light generated from the active region in the V-LED decreased due to the increase in local current density in the active region; at the same time, the amount of light extracted from the V-LED chip increased due to minimized obstruction from the n-electrode. The total output power (product of the light generated from the active region and the light extracted from the chip) of a V-LED was calculated as the size of the CBL was varied and was found to be maximized when the size of the CBL was larger than that of the n-electrode. In a circular n-electrode with a diameter of 120 µm, the optimal size (diameter) of the CBL was found to be 220 µm; in a 3 × 3 mesh type n-electrode with a 20 µm stripe width, the optimal CBL was found to be 40 µm stripe width.

Enhanced optical output in InGaN/GaN light-emitting diodes by tailored refractive index of nanoporous GaN

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Nanotechnology
https://doi.org/10.1088/1361-6528/ab31d0

The light to be trapped inside light-emitting diodes (LEDs) greatly affects the luminous efficiency and device lifetime. Abrupt difference in refractive index between the sapphire substrate and GaN-based LEDs causes light trapping by total internal reflection, however, its optical loss has been taken for granted. In this study, we demonstrate that nanoporous GaN can be used as a refractive-index-matching layer to enhance the light transmittance at the sapphire–GaN interface in InGaN/GaN flip-chip light-emitting diodes (FCLEDs). The porosity and the refractive index of the nanoporous GaN layer are controlled by electrochemical etching of n-type GaN layer. The optical output power of FCLEDs with the nanoporous GaN layer grown on flat and patterned sapphire substrates is increased by 355% and 65% at an injection current of 20 mA, respectively, compared with that of an FCLED without the nanoporous GaN layer. The remarkable enhancement of optical output

is mostly attributed to the nanoporous GaN layer which drastically increases the light extraction efficiency by decreasing the reflection of light at the sapphire–GaN interface.

Purcell effect and light extraction of Tamm-plasmon-cavity green light-emitting diodes

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Tamm plasmons (TPs), whose plasmon modes are confined at the Bragg reflector/metal interface due to the photonic stopband of the reflector and the negative dielectric constant of the metal, exhibit many advantages over the conventional surface plasmons (SPs) and potential applications in sensors, filters, optical circuits and light-emitting devices. In this paper, a TP-cavity structure has been proposed for accelerating the light emission and alleviating the large metal loss, which is hopeful for solving the efficiency droop and “green gap” problems in InGaN green light-emitting diodes (LEDs). The light emission performance of TP-cavity LEDs was systematically investigated based on transfer matrix and finite-difference time domain methods. Purcell factor (Fp) and light extraction efficiency (LEE) were both remarkably enhanced, which would be attributed to the presence of the TP and/or SP modes induced by the TP-cavity structure. In addition, two important factors including the thicknesses of the top Ag film and medium layer were investigated in detail and taken into account for the balance between the Fp and the LEE. Finally, light emission intensity was significantly enhanced for the TP-cavity green LEDs after the structure optimization as compared to the conventional green LEDs.

Fabrication of High Power Deep Ultraviolet Light-Emitting Diodes with Glass Lenses Using Atomic Diffusion Bonding

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This work demonstrated that both the output power and external quantum efficiency of AlGaN-based deep ultraviolet light-emitting diodes (DUV-LEDs) are greatly enhanced by bonding glass lenses to the LED chips using atomic diffusion bonding (ADB). ADB is advantageous because it permits the bonding of glass to DUV-LEDs at room temperature. A Ti film was found to improve light transmittance through the bonding interface and to provide good bonding strength. In addition, hydrophilic treatment of the bonding surfaces prior to Ti film deposition during ADB and post-bonding annealing further enhanced the bonding strength. In this manner, 255 nm DUV-LEDs with glass lenses having n values almost equal to that of sapphire were fabricated, using the ADB process in conjunction with a 0.4-nm-thick Ti film on each side. Even though the glass lens exhibited some light absorption, the output power and the maximum external quantum efficiency of these glass-lens-bonded LEDs were both 2.5 times greater than the values for an LED without a lens.

Deep-Ultraviolet LEDs Fabricated by Nanoimprinting

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In this study, deep-ultraviolet 280-nm-wavelength light-emitting diodes (DUV LEDs) with a nanopatterned sapphire substrate (NPSS) were fabricated using a nanoimprint lithography process.

The output power of these flip-chip (FC) DUV LEDs was measured and analyzed in a ray-tracing simulation using NPSSs: cones with diameters of 2.5 µm (LED1), 400 (LED2) and 200 nm (LED3) as well as holes with diameters of 350 (LED4) and 750 nm (LED5). For comparison, a mirror for the c-plane FC DUV LEDs was introduced by coating Ni/Au and Al thin films. With the injection current at 350 mA, the output powers of the c-plane, LED1, LED2, LED3, LED4, and LED5 were 13.38, 14.68, 20.05, 16.79, 15.74, and 18.93 mW, respectively. The LED2 efficiency improved 49.9% compared with mirror LED and the result was consistent with ray-tracing simulation.

Monolithic integration of GaN-based phototransistors and light-emitting diodes

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Optics Express
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Monolithic integration of GaN-based phototransistors and light-emitting diodes (LEDs) is reported. Starting with an LED epitaxial wafer, selective Si diffusion was performed to produce an n–p–i–n structure for the phototransistor. A traditional AlGaN bulk electron-blocking layer (EBL) can block electron injection from an emitter to a collector, thereby hindering the photocurrent amplification process. We used an LED wafer with a superlattice EBL; blocking can be removed under a bias of approximately 7 V and above. External quantum efficiencies of more than 100% and 600% at approximately 380 nm and 330 nm, respectively, were achieved at room temperature and a bias of 11 V, corresponding to responsivities of 0.31 and 1.6 A/W, respectively, significantly higher than commercially available ultraviolet (UV) detectors. Furthermore, we demonstrated an integrated operation of the device. UV light was detected using a phototransistor that sent signals to drive an integrated LED as an indicator.

Enhanced Optical performance of AlGaN-based deep ultraviolet light-emitting diodes by electrode patterns design

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IEEE Electron Device Letters
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Low external quantum efficiency of deep ultraviolet light-emitting diodes (DUV LEDs) and current crowding can result in considerable heat generation, which has a great negative impact on device performance. In this paper, we investigate the influence of different electrode patterns on the photoelectric and thermal performance of DUV LEDs. We find that different electrode designs can achieve drastically different optical powers, with the superior design being the n-type electrode surrounding the active region. Moreover, compared with the counterpart, the superior design does not affect the electrical performance. The main reason is that the N-surrounding electrode pattern can provide enough current paths for carrier transport, thus realizing a more uniform current injection and can further improve the external quantum efficiency for DUV LEDs.

48 × 48 pixelated addressable full-color micro display based on flip-chip micro LEDs

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Applied Optics
https://doi.org/10.1364/AO.58.008383

This paper reports on the design and fabrication of a 48×48 full-color pixelated addressable light-emitting diode on silicon (LEDoS) micro display. The

metallization pattern was designed and fabricated on a silicon substrate, while red, green, and blue monochromatic micro LEDs were integrated on the silicon substrate using transfer printing. The red, green, and blue micro LEDs are flip-chip structures in which red micro LEDs were fabricated using substrate transfer, mesa etching, metal deposition, and chip dicing. The integration process does not require wire bonding, which reduces the full-color pixel size and increases the integration speed. The LEDoS micro display can be addressed individually for each LED pixel and display representative patterns.

Current Spreading Length and Injection Efficiency in ZnO/GaN-Based Light-Emitting Diodes

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2942183

We report on carrier injection features in light-emitting diodes (LEDs) based on nonintentionally doped-ZnO/p-GaN heterostructures. These LEDs consist of a ZnO layer grown by chemical-bath deposition (CBD) onto a p-GaN template without using any seed layer. The ZnO layer (~1-µm thickness) consists of a dense collection of partially coalesced ZnO nanorods, organized in wurtzite phase with marked vertical orientation, whose density depends on the concentration of the solution during the CBD process. Due to the limited conductivity of the p-GaN layer, the recombination in the n-region is strongly dependent on the spreading length of the holes, Lh, coming from the p-contact. Moreover, the evaluation of Lh is not easy and generally requires the design and the fabrication of several LED test patterns. We propose a simple and effective method to calculate Lh, just based on simple considerations on I-V characteristics, and a way to improve the injection efficiency in the n region based on a noncircular electrode geometry. In particular, an interdigitated electrode structure is proved to be more efficient in terms of hole injection from n- to p-region.

Piezo-phototronic Effect in InGaN/GaN Semi-Floating Micro-disk LED Arrays

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Nano Energy
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With enhanced light output efficiencies, InGaN/GaN micro-disk LED has received intensive attentions recently. Combining isotropic and anisotropic dry etching processes, an innovative semi-floating InGaN/GaN micro-disk LED array is fabricated, which shows remarkable light intensity enhancement up to 150% compared to the broad-base LED. A systematic studies of micro-spectrums and Poisson-Schrodinger coupling self-consistent calculation reveal that there is non-uniform residual stress distribution on the micro-disk LED. Along micro-disk center to micro-disk edge, as the Si substrate is etched off, the in-plane tensile stress in the GaN layer reduces, while the compressive stress in InGaN layer increases gradually. This gradient stress distribution has caused a non-uniform piezo-phototronic effect in the micro-disk LED, which in turn results in a maximum wavelength shift of 16 meV for the light emitted along micro-disk center to micro-disk edge. This study not only opens research of flexo-optoelectronic effect, e.g. non-uniform piezo-phototronic effect, in complex micro/nano optoelectronic/electronic devices, but also provides important guidance for the significant enhancement of light emission efficiency in micro-disk LEDs.

Energy Efficiency Analysis of GaN-Based Blue Light Emitters

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ECS J. Solid State Sci. Technol
https://doi.org/10.1149/2.0262001JSS

GaN-based light sources are in high demand for lighting, displays, medical equipment and other applications. InGaN/GaN blue light-emitting diodes (LEDs) reach an electrical-to-optical power conversion efficiency of more than 80% but less than 10% are reported for blue superluminescent light-emitting diodes (SLEDs) and less than 50% for blue laser diodes (LDs). We here analyze the physical mechanisms behind this surprising discrepancy in peak energy efficiency of GaN-based light emitters. Our study reveals that the Mg-doping of group-III-nitride layers, which was pioneered by Isamu Akasaki and collaborators, plays a key role in understanding this efficiency difference.

Monolithic integration of deep ultraviolet LED with a multiplicative photoelectric converter

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Nano Energy
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Vertically monolithic integration of multiple devices on a single chip has emerged as a promising approach to overcome the fundamental limits of material and physical properties, providing unique opportunities to harness their complementary physics through integrated solutions to significantly enhance device performance. Herein, we demonstrate a deep ultraviolet light emitting diode (DUV LED) integrated with a multiplicative photoelectric converter (MPC) that is composed of p-GaN/intrinsic GaN/n-GaN (p-i-n GaN) structure to induce the electric-optic conversion, thus considerably improve the hole injection efficiency. This p-i-n GaN structure acts as hole-multiplier via firstly DUV light absorption and then electron-hole pair generation. The newly generated electron-hole pairs are firstly separated by the electric field in the p-i-n GaN structure so that multiple holes are driven into multiple quantum wells (MQWs), and finally contribute to the radiative recombination, thus achieving a high wall plug efficiency (WPE) of 21.6%, which exhibits a 60-fold WPE enhancement compared to the conventional DUV LEDs. The monolithic integration strategy demonstrated here sheds light on developing highly efficient light emitters.

Scanning electron microscope as a flexible tool for investigating the properties of UV-emitting nitride semiconductor thin films

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Photonics Research
https://doi.org/10.1364/PRJ.7.000B73

In this paper we describe the scanning electron microscopy techniques of electron backscatter diffraction, electron channeling contrast imaging, wavelength dispersive X-ray spectroscopy, and cathodoluminescence hyperspectral imaging. We present our recent results on the use of these non-destructive techniques to obtain information on the topography, crystal misorientation, defect distributions, composition, doping, and light emission from a range of UV-emitting nitride semiconductor structures. We aim to illustrate the developing capability of each of these techniques for understanding the properties of UV-emitting nitride

semiconductors, and the benefits were appropriate, in combining the techniques.

Many-Body Effects in Strongly Disordered III-Nitride Quantum Wells: Interplay Between Carrier Localization and Coulomb Interaction

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PHYSICAL REVIEW APPLIED
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The joint impact of Anderson localization and many-body interaction is observed in the optical properties of strongly disordered III-nitride quantum wells, a system where the Coulomb interaction and the fluctuating potential are pronounced effects with similar magnitude. A numerical method is introduced to solve the six-dimensional coupled Schrodinger equation in the presence of disorder and Coulomb interaction, a challenging numerical task. It accurately reproduces the measured absorption and luminescence dynamics of (In,Ga)N quantum wells at room-temperature: absorption spectra reveal the existence of a broadened excitonic peak, and carrier lifetime measurements show that luminescence departs from a conventional bimolecular behavior. These results reveal that luminescence is governed by the interplay between localization and Coulomb interaction, and provide practical insight into the physics of modern light-emitting diodes.

Stability and electronic properties of GaN phases with inversion symmetry to inherently inhibit polarization

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PHYSICAL REVIEW MATERIALS
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Two centrosymmetric gallium nitride phases, one with a body-centered-tetragonal structure (bct-GaN) and the other base-centered orthorhombic (Z-GaN), are predicted. The inversion symmetry inherently inhibits spontaneous polarization, and more importantly, piezoelectric polarization regardless of heteroepitaxial growth direction and even in the presence of shear strain, offering alternative solutions to the polarization-induced electrostatic field problem encountered by group-III nitride-based light-emitting diodes (LEDs), beyond those promised by nonpolar and semipolar wurtzite (w-GaN) and zinc-blende GaN. Density functional theory calculations, validated by agreement with experiment for w-GaN, reveal equilibrium structures, phonon dispersions, and band structures of bulk bct-GaN and Z-GaN. To ensure their stability at room temperature, we first carry out an analysis of dynamical and thermal stability using phonon calculations and molecular dynamics simulations, which indicate that these centrosymmetric structures are dynamically stable and remain stable at high temperature. Moreover, the relative stability of GaN polymorphs is highly dependent on sample thickness. We predict that bct-GaN and Z-GaN are energetically more favorable than w-GaN for freestanding ultrathin films up to 47 and 70 layers, respectively, thus suggesting the possibility of the kinetic growth of these two phases. The GW self-energy corrected, direct band gaps of bct-GaN and Z-GaN are close to the w-GaN value, promising LED applications in the same spectral ranges.

Transfer-Free Graphene-Like Thin Films on GaN LED Epiwafers Grown by PECVD Using an Ultrathin Pt Catalyst for Transparent Electrode Applications

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Materials
https://doi.org/10.3390/ma12213533

In this work, we grew transfer-free graphene-like thin films (GLTFs) directly on gallium nitride (GaN)/sapphire light-emitting diode (LED) substrates. Their electrical, optical and thermal properties were studied for transparent electrode applications. Ultrathin platinum (2 nm) was used as the catalyst in the plasma-enhanced chemical vapor deposition (PECVD). The growth parameters were adjusted such that the high temperature exposure of GaN wafers

was reduced to its minimum (deposition temperature as low as 600 °C) to ensure the intactness of GaN epilayers. In a comparison study of the Pt-GLTF GaN LED devices and Pt-only LED devices, the former was found to be superior in most aspects, including surface sheet resistance, power consumption, and temperature distribution, but not in optical transmission. This confirmed that the as-developed GLTF-based transparent electrodes had good current spreading, current injection and thermal spreading functionalities. Most importantly, the technique presented herein does not involve any material transfer, rendering a scalable, controllable, reproducible and semiconductor industry-compatible solution for transparent electrodes in GaN-based optoelectronic devices.

Semi-Polar InGaN-Based Green Light-Emitting Diodes Grown on Silicon

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physica status solidi a
https://doi.org/10.1002/pssa.201900654

High quality semi-polar (11-22) GaN has been obtained by means of growth on patterned (113) silicon substrates featured with stripy grooves and extra periodic gaps which are perpendicular to the grooves. Ga melting-back during the GaN growth at a high temperature has been eliminated as a result of our special patterning design. On-axis x-ray rocking curve measurements show the linewidth has been significantly reduced to down to 339 arcsec. Photoluminescence (PL) measurements at 10 K show strong GaN band-edge emission only, meaning that any basal stacking fault related emission has not been observed. Furthermore, green InGaN/GaN light emitting diodes (LEDs) with an emission wavelength of around 530 nm have been achieved on the semi-polar GaN grown on the patterned Si substrates. Excitation power dependent PL measurements do not show a shift in wavelength, meaning a significant reduction in polarization-induced piezoelectric fields. Electroluminescence measurements exhibit that the output power of the semi-polar LED increases linearly with increasing injection current. It is worth highlighting that the overgrowth technology on our designed patterned (113) silicon is a potential approach to manufacturing high performance semi-polar GaN emitters on Si substrates in a long wavelength region.

Unambiguously Enhanced Ultraviolet Luminescence of AlGaN Wavy Quantum Well Structures Grown on Large Misoriented Sapphire Substrate

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Advanced Functional Materials
https://doi.org/10.1002/adfm.201905445

High-quality epitaxy consisting of Al1−xGaxN/Al1−yGayN multiple quantum wells (MQWs) with sharp interfaces and emitting at ≈280 nm is successfully grown on sapphire with a misorientation angle as large as 4°. Wavy MQWs are observed due to step bunching formed at the step edges. A thicker QW width accompanied by a greater accumulation of gallium near the macrostep edge than that on the flat-terrace is observed on 4° misoriented sapphire, leading to the generation of potential minima with respect to their neighboring QWs. Consequently, a significantly enhanced photoluminescence intensity (at least ten times higher), improved internal quantum efficiency (six times higher at low excitation laser power), and a much longer carrier lifetime are achieved. Importantly, the wafer-level output-power of the ultraviolet light emitting diodes on 4° misoriented substrate is nearly increased by 2–3 times. This gain is attributed to the introduction of compositional inhomogeneities in AlGaN alloys induced by gallium accumulation at the step-bunched region thus

forming a lateral potential well for carrier localization. The experimental results are further confirmed by a numerical modeling in which a 3D carrier confinement mechanism is proposed. Herein, the compositional modulation in active region arising from the substrate misorientation provides a promising approach in the pursuit of high-efficient ultraviolet emitters.

Integrable Quasi-Vertical GaN UMOSFETs for Power and Optoelectronic Ics

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https://doi.org/10.1002/pssa.201900615

Integrable, hexagonal-cell, high-voltage, quasi-vertical GaN power U-shaped trench-gate metal-oxide-semiconductor field-effect transistors (UMOSFETs) fabricated in the n+/p/n-/n+ GaN epi on sapphire substrates are experimentally demonstrated for the first time. Hexagonal cells, with pitch ranging from 11 to 20 µm, are employed to obtain identical m-plane sidewalls for gate and drain trenches. Metallization compatible with LED optoelectronic integration is used. The dependence of device performance on different parameters is systematically studied and analyzed. The lowest Ron,sp of 23 mΩ-cm2 and highest drain saturation current of 295 A/cm2 were obtained by measuring an 11-µm cell-pitch UMOSFET. The breakdown voltage of an open-cell design variation (208 V) is higher than that of a closed-cell design variation (89 V), while the closed-cell design exhibits a lower off-state leakage current of 1.4×10-5 A/cm2. A hexagonal-cell specific on-state resistance Rcell,sp of 8.5 mΩ-cm2 and buried n+ layer sheet resistance RBL,□ of 223 Ω/□ are extracted by applying a two dimensional resistance network model to UMOSFETs of varying sizes.

Near-Complete Elimination of Size-Dependent Efficiency Decrease in GaN Micro-Light-Emitting Diodes

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https://doi.org/10.1002/pssa.201900380

Herein, a successful elimination of the size-dependent efficiency decrease in GaN micro-light-emitting diodes (micro-LEDs) is achieved using damage-free neutral beam etching (NBE). The NBE technique, which can obtain ultralow-damage etching of GaN materials, is used in place of the conventional inductively coupled plasma to form the micro-LED mesa. It is found that all the fabricated micro-LEDs with sizes ranging from 40 to 6 µm show external quantum efficiency (EQE) versus current density characteristics similar to those of large-area GaN LEDs, with a maximum in EQE curves at a current density of as low as about 5 A cm−2. Furthermore, all the fabricated micro-LEDs, even the 6 µm one, show a similar value of maximum EQE with a variation of less than 10%, clearly indicating a negligible size dependence of emission efficiency of micro-LEDs fabricated by the NBE technique at least down to the size of 6 µm. These results suggest that the NBE process is a promising method of fabricating high-efficiency sub-10 µm GaN micro-LEDs required for high-efficiency, high-brightness, and high-resolution micro-LED displays.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowmade

Single transverse mode operation of GaN-based vertical-cavity surface-emitting laser with monolithically incorporated curved mirror

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Applied Physics Express
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We report single transverse mode operation of a blue GaN-based vertical-cavity surface-emitting laser (GaN-VCSEL) with a monolithically incorporated curved mirror. For a device with a 4 µm current aperture diameter and a curved mirror with a radius of curvature (ROC) of 51 µm, single transverse mode operation was confirmed up to an output power of 3.2 mW under continuous wave operation at 20 °C. For a device with a smaller ROC of 31 µm, multi transverse mode operation was confirmed, indicating that the transverse mode can be controlled by the cavity design of such GaN-VCSELs.

Demonstration of blue semipolar (2021) GaN-based vertical-cavity surface-emitting lasers

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Optics Express
https://doi.org/10.1364/OE.27.023707

We successfully demonstrated an electrically injected blue(2021)semipolar vertical-cavity surface-emitting laser with a 5λ cavity length, an ion implanted aperture, and a dual dielectric DBR design. The peak power under pulsed operation was 1.85 mW, the threshold current was 4.6 kA/cm2, and the differential efficiency was 2.4% for the mode at 445 nm of a device with a 12 µm aperture. Lasing was achieved up to a 50% duty cycle and the thermal impedance was estimated to be 1800 K/W. The lasing emission was found to be 100% plane polarized along the a-direction.

Realization of thin-film m-plane InGaN laser diode fabricated by epitaxial lateral overgrowth and mechanical separation from a reusable growth substrate

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Optics Express
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A nonpolar edge emitting thin film InGaN laser diode has been separated from its native substrate by mechanical tearing with adhesive tape, combining the benefits of Epitaxial Lateral Overgrowth (ELO) and cleavability of nonpolar GaN crystal. The essence of ELO is mainly to weakening strength between native substrate and the fabricated laser device on top of it. We report a 3 mm long laser bar removed from its native GaN substrate. We confirmed edge emitting lasing operation after cleaving facets on a separated thin bar. Threshold current density of the laser was measured to be as low as 2.15 kA/cm2.

Self-injection locking efficiency of a UV Fabry–Perot laser diode

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Optics Letters
https://doi.org/10.1364/OL.44.004175

In this Letter, we have studied the performance of a gallium nitride 370 nm Fabry–Perot laser diode self-injection locked via a high quality (Q-) factor magnesium fluoride whispering gallery mode (WGM)

resonator and show that the state of locking strongly depends on frequency detuning between the internal laser cavity and the resonator modes. Optimizing the detuning, we were able to observe monochromatic laser emission with a sub-100 kHz linewidth. The Q-factor of the resonator measured in this regime exceeded 109.

Thermal Design Considerations for III-N Vertical-Cavity Surface-Emitting Lasers Using Electro-Opto-Thermal Numerical Simulations

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IEEE Journal of Quantum Electronics
https://doi.org/10.1109/JQE.2019.2937991

III-N VCSELs undergo severe self-heating which limits the output optical power. This makes thermal management a critical design consideration. The three most common VCSEL structures (hybrid VCSELs, flip-chip VCSELs and ELOG VCSELs) have been studied using advanced self-consistent electro-opto-thermal numerical simulations. The key geometric and material parameters affecting the thermal resistance of these devices have been identified. Our simulations suggest that some of the proposed solutions and design modifications can increase the maximum optical output power by as much 100%. This manuscript also describes the correct method of using numerical simulation in device design—to predict trends and isolate the key factors affecting device performance.

High-efficiency, yellow-light Dy3+-doped fiber laser with wavelength tuning from 568.7 to 581.9 nm

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Optics Letters
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We report, to the best of our knowledge, the first demonstration of a wavelength-tunable and highly efficient Dy3+-doped fiber laser operating in the yellow spectral region. A 2-m-long Dy3+:ZBLAN fiber pumped by a 447-nm GaN laser diode provides a strong down-conversion gain around 575 nm. A fiber end-facet mirror and a visible reflective grating in the Littrow configuration construct the resonant cavity and introduce the wavelength tunability. A stable yellow laser with a <0.05−nm narrow linewidth is achieved and continuously tuned from 568.7 nm to 581.9 nm, covering more than half of the yellow spectral range. The slope efficiency is as high as 34.9%, and the maximum output power is 142 mW at 576.44 nm, which is 13 times higher than previously reported. It is, to the best of our knowledge, the highest power and conversion efficiency of a yellow-light Dy3+-doped fiber laser with wavelength tunability.

Performance improvement of InGaN-based laser grown on Si by suppressing point defects

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Optics Express
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High performance InGaN-based laser diodes (LDs) monolithically grown on Si is fundamentally interesting and highly desirable for photonics integration on Si platform. Suppression of point defects is of crucial importance to improve the device performance of InGaN-based LDs grown on Si. This work presents a detailed study on the impact of point defects, such as carbon (C) impurities and gallium vacancies (VGa), on the device characteristics of InGaN-based LDs grown on Si. By suppressing the VGa-related defect within the waveguide layers, reducing the thermal degradation of InGaN-based quantum wells, and controlling the C impurity concentrations within the thick p-type cladding layers, the as-fabricated InGaN-based LDs grown on Si exhibited a significantly reduced threshold current density of 2.25 kA/cm2 and an operation voltage of 4.7 V.

GROUP 3 - Power Electronics

Group leader: Frédéric Morancho (LAAS-CNRS)

Information selected by Frédéric Morancho (LAAS-CNRS) and Yvon Cordier (CRHEA-CNRS)

Investigation of annealed, thin(~2.6 nm)-Al2O3/AlGaN/GaN metal-insulator-semiconductor heterostructures on Si(111) via capacitance-voltage and current-voltage studies

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Materials Research Express

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Annealed, thin(~2.6 nm)-Al2O3/AlGaN/GaN metal-insulator-semiconductor (MIS) heterostructures on Si(111) are fabricated and studied via capacitance–voltage (C–V) measurements to quantify densities of fast and slow interface trap states and via current–voltage (I–V) measurements to investigate dominant gate current leakage mechanisms. Dual-sweep C–V measurements reveal small voltage hysteresis (~1 mV) around threshold voltage, indicating a low density of slow interface trap states of ~109 cm−2. Frequency-dependent conductance measurements show fast interface trap state density ranging from 8 × 1012 to 5 × 1011 eV−1 cm−2 at energies from 0.275 to 0.408 eV below the GaN conduction band edge. Temperature-dependent I–V characterizations reveal that trap-assistant tunneling (TAT) dominates the reverse-bias carrier transport while the electric field across the Al2O3 ranges from 3.69 to 4.34 MV cm−1, and the dominant Al2O3 trap state energy responsible for such carrier transport is identified as 2.13 ± 0.02 eV below the Al2O3 conduction band edge. X-ray photoelectron spectroscopy measurements on Al2O3 before and after annealing suggest an annealing-enabled reaction between Al-O bonds and inherent H atoms. Overall, we report that annealed, thin-Al2O3 dielectric is an effective (Al)GaN surface passivation alternative when minimizing passivation-associated parasitic capacitance is required, yet non-ideal for significantly suppressing gate leakage current in MIS structures due to the governing TAT carrier transport mechanism.

Breakdown Enhancement and Current Collapse Suppression in AlGaN/GaN HEMT by NiOX/SiNX and Al2O3/SiNX as Gate Dielectric Layer and Passivation Layer

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IEEE Electron Device Letters

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We propose two kinds of stacked materials that effectively yield low drain off-state leakage current, high off-state breakdown voltage and low current collapse simultaneously in AlGaN/GaN HEMT. The two kinds of stacked materials, which is NiOX/SiNX and Al2O3/SiNX respectively, act as gate dielectric layer and passivation layer for the devices. The NiOX and Al2O3 are prepared through depositing Ni and Al thin film by electron beam evaporation and then annealing in O2 ambient by rapid thermal processing. The SiNX is deposited by plasma-enhanced chemical vapor deposition. Compared to the single SiNX layer, the NiOX/SiNX stack layer and Al2O3/ SiNX stack layer can distinctly reduce the drain off-state leakage current of devices. Meanwhile, high off-state breakdown voltage is also achieved. The off-state breakdown voltage in the devices with NiOX/SiNX stack layer and Al2O3/SiNX stack layer are 52% and 36% higher than that of the devices with single SiNX layer respectively. Especially, the current collapse under 200 V stress bias is reduced by 90% and 58% in the devices with NiOX/SiNX stack layer and Al2O3/SiNX stack layer compare to the devices with single SiNX layer respectively.

Multi-pulse characterization of trapping/detrapping mechanisms in AlGaN/GaN high electromobility transistors

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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab3fe8

GaN high-electro mobility transistors (HEMTs) are among the most promising candidates for use in high-power, high-frequency, and high-temperature electronics owing to their high electrical breakdown threshold and their high saturation electron velocity. The applications of these AlGaN/GaN HEMTs in power converters are limited by the surface trapping effects of drain-current collapse. Charge-trapping mechanisms affect the dynamic performance of all GaN HEMTs used in power switching applications. This study analyzes the dynamic resistance of GaN HEMTs and finds that the effects of dynamic resistance can be suppressed by controlling switching conditions and on-off cycles.

Influence of reactive-ion-etching depth on interface properties in Al2O3/n-GaN MOS diodes

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Japanese Journal of Applied Physics
https://doi.org/10.7567/1347-4065/ab3d11

Influence of etching depth on the interface properties in Al2O3/n-GaN MOS diodes has been investigated. The n-GaN surface was etched by inductively coupled reactive-ion-etching (RIE) with shallow (20 nm) and deep etching (1200 nm) depth. The resulting Al2O3/n-GaN interface properties were then evaluated by the capacitance/conductance–voltage (C/G–V) and current–voltage (I–V) characteristics measurements. It was found that: (i) the interface state density of the shallow-etched MOS diode is almost the same as that of the un-etched reference sample, (ii) the deep-etched MOS diode showed around five times higher interface state density than the shallow-etched MOS diode, (iii) the increased interface state density with deep etching was not recovered by Tetra-Methyl-Ammonium Hydroxide (TMAH) treatment nor by post annealing, and (iv) the deep-etched MOS diode indicated about five orders of magnitude higher leakage current, which could be attributed to the lowering of the effective barrier height in the Fowler–Nordheim type conduction. The results obtained in this study indicate that improved RIE process has to be developed for the fabrication of GaN MOS FETs that require deep etching such as vertical trench-type FETs.

All GaN Power Integration: Devices to Functional Sub-circuits and Converter Ics

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IEEE Journal of Emerging and Selected Topics in Power Electronics
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This paper reports the Au-free GaN power integration platform and a complete integration scheme from devices to functional sub-circuits, and to application-oriented GaN converter ICs. The design and experimental demonstration of all GaN DC-DC converter IC with high level of integration is presented. Through the developed GaN power integration platform, devices are monolithically integrated and functional sub-circuits are demonstrated, which have realized expected application-oriented functions and are feasible for high-level integration. The all GaN converter IC with monolithically integrated high-side gate driver, pulse width modulation (PWM) feedback controller and over-current protection circuits is proposed, numerically analyzed, experimentally demonstrated and characterized. It can realize stable 10 V output with constant output ripples below 4% from 15-30 V input line voltage. Stable output with constant ripples can be maintained according to designed feedback control when input and load conditions are abruptly changed. When subjected to over-current incident, the converter IC can be protected according to desired over-current threshold values within one duty cycle period. The developed all GaN power integration platform, together with functional sub-circuits and DC-DC converter IC, can be a practical

verification of all GaN IC scheme oriented towards power conversion application, and a useful reference for all GaN IC designs.

Investigation of dry-etch-induced defects in >600 V regrown, vertical, GaN, p-n diodes using deep-level optical spectroscopy

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Journal of Applied Physics
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The impact of dry-etch-induced defects on the electrical performance of regrown, c-plane, GaN p-n diodes where the p-GaN layer is formed by epitaxial regrowth using metal-organic, chemical-vapor deposition was investigated. Diode leakage increased significantly for etched-and-regrown diodes compared to continuously grown diodes, suggesting a defect-mediated leakage mechanism. Deep level optical spectroscopy (DLOS) techniques were used to identify energy levels and densities of defect states to understand etch-induced damage in regrown devices. DLOS results showed the creation of an emergent, mid-gap defect state at 1.90 eV below the conduction band edge for etched-and-regrown diodes. Reduction in both the reverse leakage and the concentration of the 1.90 eV mid-gap state was achieved using a wet chemical treatment on the etched surface before regrowth, suggesting that the 1.90 eV deep level contributes to increased leakage and premature breakdown but can be mitigated with proper post-etch treatments to achieve >600 V reverse breakdown operation.

Investigation on the Short-Circuit Oscillation of Cascode GaN HEMTs

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IEEE Transactions on Power Electronics
https://doi.org/10.1109/TPEL.2019.2947274

This paper presents the study on the self-sustained oscillation of cascode gallium nitride (GaN) high-electron-mobility transistors (HEMTs) which occurs under the short-circuit (SC) condition. Based on the SC test, it is found that the self-sustained oscillation can be excited in the SC event of cascode GaN HEMTs. Moreover, the gate resistance RG does not have a significant damping effect on the self-sustained SC oscillation. The Spice simulation is performed to study the oscillation waveforms of the internal depletion-mode HEMT (DHEMT) and low voltage (LV) MOSFET. The study reveals two positive feedback loops which excite the SC oscillation. One loop is related to the positive feedback process of DHEMT itself. Another loop is induced by the interaction between the DHEMT and LV MOSFET. The two positive feedback loops are interrelated and can reinforce each other. As a result, a very strong driving force is generated to excite the self-sustained oscillation. During the oscillatory transient, the parasitic elements of the device's package play a critical role in exciting the positive feedback process. By analyzing the influence of the parasitic elements on the positive feedback process, the necessary methods are proposed to suppress the SC oscillation. The Spice simulation validates the effectiveness of the proposed methods.

Evaluation and Analysis of Temperature-dependent Dynamic R(DS,ON) of GaN Power Devices Considering High-Frequency Operation

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IEEE Journal of Emerging and Selected Topics in Power Electronics
https://doi.org/10.1109/JESTPE.2019.2947575

Commercial Enhancement-Mode Gallium nitride (GaN) HEMTs device is a superior candidate for high-frequency power electronics applications. However, GaN power devices have a unique dynamic R(DS,ON) problem which increases the conduction loss of the converter during operation. In this paper, the temperature-dependent dynamic R(DS,ON) at high frequency is evaluated experimentally for the first time using the double pulse test (DPT) and multiple pulse test (MPT) techniques. The different temperature-dependent dynamic R(DS,ON)

characteristics between the DPT and the MPT at high temperatures are investigated. The significance of the dynamic R(DS,ON)'s temperature-dependence is important since GaN devices are typically operating at elevated temperatures. The results suggest that the traditional wafer-level test method using one pulse or two pulses, and the MPT without heating consideration or at lower pulse frequency may not be sufficient to evaluate the dynamic R(DS,ON) effect. Combined with high frequency, high voltage and high current stress, high operating temperatures result in severe R(DS,ON) degradation, hence, there is a diminished return on operating the devices at high temperatures.

Improved Current Collapse in Recessed AlGaN/GaN MOS-HEMTs by Interface and Structure Engineering

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2019.2940749

Enhancement-mode (E-mode) GaN MOS-HEMTs using recess process typically face the challenge of precise thickness control, surface roughness issue, and interface traps, all of which could lead to the degradation of the device performance and cause reliability issues. In this article, we use a combined process of atomic layer etching (ALE) technique and atomic layer deposited (ALD) HfSiO dielectric. ALE is repeated oxidation and dry etching process with minimal surface damage, leading to a precisely controlled low-damage recess channel area. The fabricated AlGaN/GaN MOS-HEMTs exhibit E-mode operation with a positive threshold voltage (Vth) of +2.1 V with small Vth dispersion for different devices, an ultrahigh drain current on-off ratio over 10^{10} and a low on-resistance (Ron) of 11.5 Ω ·mm at gate-to-drain length (LGD) of 25 µm. Source field plate (SFP) structure is employed to reduce the charge trapping process and improve the reliability at high voltages. The current collapse of the E-mode device with SFP structure can be effectively suppressed due to the optimized redistribution of the peak electric field in the gate-to-drain access region, where a significantly improved dynamic Ron of only 1.17 times increase from the static Ron after off-state VDS stress of 600 V. Moreover, the enhanced vertical electric field with decreased AlGaN barrier thickness and the positive shift in threshold voltage for the E-mode device can effectively suppress the current collapse, which outperforms the depletion-mode counterpart. The breakdown voltage reaches a considerable value of 1560 V at an off-state current density of 1 µA/mm.

Design and Experimental Demonstration of Integrated Over-current Protection Circuit for GaN DC-DC Converters

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This paper reports the design and the first experimental demonstration of the monolithically integrated over-current protection circuit in GaN power converters. The design criterions and protection time estimation methods are proposed. Through the GaN integration platform based on normally-OFF AlGaN/GaN MIS-HEMTs, over-current protection circuit is monolithically integrated with gate driver and GaN switches. At over-current incident, the current sensing signal is compared with over-current thresholds, then the generated protection action signal is clamped to disable the high-side gate driver and shut down the GaN DC-DC buck converter. The analysis in current paths, SPICE-based simulations and numerical descriptions of protection process are carried out to support the proposed design criterions and estimation methods. The experiment results show that the GaN DC-DC buck converter can be protected within one duty cycle period according to desired preset over-current thresholds. The consistent results of calculated and measured time periods in over-current protection

process have verified the proposed design criterions and estimation methods. The proposed over-current protection circuit together with the analysis can help researchers to design and estimate the over-current protection process in integrated GaN power converters.

Characterization and Failure Analysis of 650 V Enhancement-mode GaN HEMT for Cryogenically-Cooled Power Electronics

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In order to evaluate the feasibility of newly developed GaN devices in a cryogenically-cooled converter, this paper characterizes a 650 V enhancement-mode Gallium-Nitride high-electron-mobility transistor (GaN HEMT) at cryogenic temperatures. The characterization includes both static and dynamic behaviors. The results show that this GaN HEMT is an excellent device candidate to be applied in cryogenic-cooled applications. For example, transconductance at cryogenic temperature (93 K) is 2.5 times higher than one at room temperature (298 K), and accordingly, peak di/dt during turn-on transients at cryogenic temperature is around 2 times of that at room temperature. Moreover, the on-resistance of the channel at cryogenic temperature is only one-fifth of that at room temperature. The corresponding explanations of performance trends at cryogenic temperatures are also given from the view of semiconductor physics. In addition, several device failures were observed during the dynamic characterization of GaN HEMTs at cryogenic temperatures. The ultra-fast switching speed induced high di/dt and dv/dt at cryogenic temperatures amplifies the negative effects of parasitics inside the switching loop. Based on failure waveforms, two failure modes were classified, and detailed failure mechanisms caused by ultra-fast switching speed are given in this paper.

Capture and emission mechanisms of defect states at interface between nitride semiconductor and gate oxides in GaN-based metal-oxide-semiconductor power transistors

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A physical insight into the capture and emission behavior of interface/oxide states in a GaN-based metal-oxide-semiconductor (MOS) structure is of great importance to understanding the threshold voltage (VTH) instability in GaN power transistors. A time-dependent VTH shift in Ni/Al2O3/AlGaN/GaN MOS-HFETs (heterojunction field-effect transistors) and a distribution of Al2O3/III-nitride interface states (Dit) were successfully characterized by constant-capacitance deep level transient spectroscopy. It is found that in situ remote plasma pretreatments in plasma-enhanced atomic-layer-deposition could suppress Dit (EC-ET > 0.4 eV) down to below 1.3×1012 cm−2 eV−1. Under high applied gate bias (e.g., VG > 8 V), tunnel filling of oxide states in the Al2O3 dielectric comes into play, contributing to remarkable VTH instability in the MOS-HFETs. The tunnel distance between the 2D Electron Gas (2DEG) channel and oxide states ET,ox in the Al2O3 dielectric decreases from 3.75 to 0.82 nm as VG increases from 2 to 8 V. A further increase of VG to 11 V makes the Fermi level approach ET,ox (EC − ET ∼ 1.62 eV), which may enable direct filling. High electric field induced tunnel filling of gate oxide states could be an assignable cause for VTH instability in normally-OFF III-nitride MOS-HFETs.

Breakdown Walkout in Polarization-Doped Vertical GaN Diodes

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We demonstrate the avalanche capability and the existence of breakdown walkout in GaN-on-GaN vertical devices with polarization doping. By means of combined electrical and optical characterization, we demonstrate the following original results: 1) vertical p-n junctions with polarization doping have avalanche capability; 2) stress in avalanche regime induces an increase in breakdown voltage, referred to as breakdown walkout; 3) this process is fully-recoverable, thus being related to a trapping mechanism; 4) temperature-dependent measurements of the breakdown walkout identify CN defects responsible for this process; and 5) capacitance deep level transient spectroscopy (C-DLTS) and deep level optical spectroscopy (DLOS) confirm the presence of residual carbon in the devices under test. A possible model to explain the avalanche walkout is then proposed.

Numerical analysis of high-voltage RESURF AlGaN/GaN high-electron-mobility transistor with graded doping buffer and slant back electrode

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A reduced surface field (RESURF) AlGaN/GaN high-electron-mobility transistor (HEMT) with graded doping buffer (GDB) and slant back electrode (SBE) is proposed. In the GDB, the p-dopant density increases linearly both from top to bottom and right to left. The concentrated negative space charges in the lower-left corner of GDB attract the electric field lines from the channel and barrier towards the gate under OFF-state, which flats the electric field and enhances the breakdown voltage (V br). Additionally, the low p-dopant density near the top of GDB achieves the device with low ON-state resistance (R ON). The SBE flats the electric field along the channel above it and introduces a peak electric field near its edge. Simulation results show a V br of 2150 V and R ON of 7.05 Ωmm for the proposed device, compared with 1701 V and 7.73 Ωmm for the conventional back electrode RESURF HEMT (BE-RESURF HEMT) with the same gate -drain spacing. Moreover, due to the reduced depletion of 2DEG from the GDB, the proposed device shows slight increases in f T and f max (8.76 and 14.80 GHz), comparing with the conventional BE-RESURF HEMT (8.24 and 13.84 GHz).

High Lateral Breakdown Voltage in Thin Channel AlGaN/GaN High Electron Mobility Transistors on AlN/Sapphire Templates

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Micromachines
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In this paper, we present the fabrication and Direct Current/high voltage characterizations of AlN-based thin and thick channel AlGaN/GaN heterostructures that are regrown by molecular beam epitaxy on AlN/sapphire. A very high lateral breakdown voltage above 10 kV was observed on the thin channel structure for large contact distances. Also, the buffer assessment revealed a remarkable breakdown field of 5 MV/cm for short contact distances, which is far beyond the theoretical limit of the GaN-based material system. The potential interest of the thin channel configuration in AlN-based high electron mobility transistors is confirmed by the much lower breakdown field that is obtained on the thick channel structure. Furthermore, fabricated transistors are fully functional on both structures with low leakage current, low on-resistance, and reduced temperature dependence as measured up to 300 °C. This is attributed to the ultra-wide bandgap AlN buffer,

which is extremely promising for high power, high temperature future applications.

Ultra-wide bandgap AlGaN metal oxide semiconductor heterostructure field effect transistors with high-k ALD ZrO2 dielectric

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We report on Al0.65Ga0.35N/Al0.4Ga0.6N metal oxide semiconductor heterojunction field-effect transistor (MOSHFET) with high-k ZrO2 gate-dielectric deposited using atomic layer deposition process. As extracted from frequency dependent capacitance–voltage (CV) characteristics, the oxide gates resulted in an interfacial state trap density of ~2 × 1012 cm−2. A comparative study, on the same material, shows the gate-leakage current of the ZrO2 MOSHFETs to be lower by five orders; their ON/OFF current ratio (~107) to be higher by about four orders and their threshold voltage to decrease (less negative) by 3.5 V with respect to the Schottky gate devices

Proton Irradiation Effects on the Time-Dependent Dielectric Breakdown Characteristics of Normally-Off AlGaN/GaN Gate-Recessed Metal-Insulator-Semiconductor Heterostructure Field Effect Transistors

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Micromachines
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In this work, we investigated the time-dependent dielectric breakdown (TDDB) characteristics of normally-off AlGaN/GaN gate-recessed metal–insulator–semiconductor (MIS) heterostructure field effect transistors (HFETs) submitted to proton irradiation. TDDB characteristics of normally-off AlGaN/GaN gate-recessed MISHFETs exhibited a gate voltage (VGS) dependence as expected and showed negligible degradation even after proton irradiation. However, a capture emission time (CET) map and cathodoluminescence (CL) measurements revealed that the MIS structure was degraded with increasing trap states. A technology computer aided design (TCAD) simulation indicated the decrease of the vertical field beneath the gate due to the increase of the trap concentration. Negligible degradation of TDDB can be attributed to this mitigation of the vertical field by proton irradiation.

Low on-Resistance and Low Trapping Effects in 1200 V Superlattice GaN-on-Silicon Heterostructures

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We report on the development of GaN-on-silicon heterostructures targeting 1200 V power applications. In particular, it is shown that the insertion of superlattices (SL) into the buffer layers allows pushing the vertical breakdown voltage above 1200 V without generating additional trapping effects as compared to a more standard optimized step-graded AlGaN-based epi-structure using a similar total buffer thickness. DC characterizations of fabricated transistors by means of back-gating measurements reflect both the enhancement of the breakdown voltage and the low trapping effects up to 1200 V. These results show that a proper buffer optimization along with the insertion of SL pave the way to GaN-on-silicon lateral power transistors operating at 1200 V with low on-resistance and low trapping effects.

Avalanche Multiplication Noise in GaN p–n Junctions Grown on Native GaN Substrates

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GaN p–n junction diodes grown on native GaN substrates have been fabricated and characterized. The devices exhibit a positive temperature coefficient

of breakdown obtained from variable temperature current–voltage measurements, confirming the impact ionization avalanche. The low-frequency noise characteristics of these devices have been measured under forward and reverse bias conditions. The forward bias noise spectra are dominated by the 1/f noise, and the current spectral density is proportional to I1.6. Under reverse bias, the noise spectra show 1/f noise at reverse biases below the avalanche threshold. However, at reverse biases in the avalanche regime, the multiplication noise overwhelms the 1/f noise, resulting in a white noise spectrum. To further characterize the avalanche process, the excess noise factor, F, is obtained from the measured noise spectra of diodes biased in reverse avalanche. For the case of pure hole injection (achieved by incorporating a thin pseudomorphic In0.07Ga0.93N layer at the cathode of the device and illuminating with 390 nm UV light), a low excess noise factor is achieved. The impact ionization ratio α/β extracted from the multiplication noise ranges from 0.07 to 0.38 over the electric field ranging from 2.8 to 3.7 MV cm−1, consistent with the impact ionization coefficients reported previously using the photomultiplication method.

Integrable Quasi-Vertical GaN UMOSFETs for Power and Optoelectronic Ics

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Integrable, hexagonal-cell, high-voltage, quasi-vertical GaN power U-shaped trench-gate metal-oxide-semiconductor field-effect transistors (UMOSFETs) fabricated in the n+/p/n-/n+ GaN epi on sapphire substrates are experimentally demonstrated for the first time. Hexagonal cells, with pitch ranging from 11 to 20 µm, are employed to obtain identical m-plane sidewalls for gate and drain trenches. Metallization compatible with LED optoelectronic integration is used. The dependence of device performance on different parameters is systematically studied and analyzed. The lowest Ron,sp of 23 mΩ-cm2 and highest drain saturation current of 295 A/cm2 were obtained by measuring an 11-µm cell-pitch UMOSFET. The breakdown voltage of an open-cell design variation (208 V) is higher than that of a closed-cell design variation (89 V), while the closed-cell design exhibits a lower off-state leakage current of 1.4×10-5 A/cm2. A hexagonal-cell specific on-state resistance Rcell,sp of 8.5 mΩ-cm2 and buried n+ layer sheet resistance RBL,□ of 223 Ω/□ are extracted by applying a two dimensional resistance network model to UMOSFETs of varying sizes.

GaN-based Monolithic Inverter Consisting of Enhancement- and Depletion-Mode MOSFETs by Si Ion Implantation

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This paper investigated the effects of Si ion-implantation on GaN in a dose range of 1014 to 1014 cm−2 towards a GaN-based monolithic inverter circuit consisting of n-channel enhancement and depletion-mode MOSFETs (E-MOSFET and D-MOSFET). The implantation dose dependence was investigated by capacitance–voltage (C–V) measurement of Si-implanted GaN metal-oxide-semiconductor (MOS) capacitors. Enhanced stretches of C–V curve in voltage bias direction in higher dose samples, and its non-linear dependence on Si dose are discussed. Characteristics of E-MOSFET and D-MOSFET fabricated on p-GaN with Mg doping concentration of [Mg]=1×1019 cm−3 on sapphire substrate are presented. The operation of E- and D-MOSFET with normally-on and normally-off characteristics was obtained. To further improve MOSFET characteristics, a low Mg-concentration p-GaN layer with [Mg] of 1×1017 cm−3 on GaN substrate was used for monolithic E- and D-MOSFET fabrication. Improved E-MOSFET characteristics were confirmed by effective mobility of 38 cm2/Vs. The successful operation of an E/D type inverter with a maximum voltage gain 1.5

beyond unity is presented in monolithic E-MOSFET and D-MOSFET on the same chip.

Minority Carrier Traps in Ion-Implanted n-Type Homoepitaxial GaN

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Ion implantation is a key step for device processing. This is required for anode/cathode or junction termination extension formation, which relies on the use of multiple-energy implantation profiles (box profile). However, electrically active defects are known to arise after implantation, especially in the implant-tail region. Although there are studies on majority carrier traps in implanted GaN, not much is known on minority carrier traps. For this reason, the electrical characterization of minority carrier levels is conducted in ion-implanted n-type GaN. Three electrically active levels are found in the 0.18–1.2 eV energy range, above the valence band edge, and their nature is discussed in the light of theoretical studies found in the literature.

GaN Micropillar Schottky Diodes with High Breakdown Voltage Fabricated by Selective-Area Growth

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Herein, selective-area growth (SAG) of lightly n-doped GaN micropillars on masked GaN-on-sapphire templates is investigated. Using the micropillar SAG approach, the maximum GaN drift layer thickness in Schottky diodes on foreign substrates is increased. Thus, cost-efficient vertical power devices with large breakdown voltages (VBD) based on heteroepitaxy are enabled. The influence of different hard-mask materials and SAG temperatures (TSAG) on growth selectivity, morphology, and net doping concentration (ND–NA) is investigated. By using an AlOx hard mask and TSAG = 1045 °C, 3.7 µm high GaN micropillars are grown in circular mask openings. Quasi-vertical Schottky diodes on these pillars exhibit low ND–NA = 5.2 × 1016 cm−3, VBD = 393 V, and a critical electric field EC = 2.63 MV cm−1.

Simulation of Structure Parameters' Influence on the Threshold Voltage of Normally-Off p-GaN/AlGaN/GaN Transistors

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The influence of different parameters of p-GaN/AlGaN/GaN structure on a threshold voltage of transistors is studied. The parameters that are varied are the thickness of the p-type GaN layer, its doping concentration, doping concentration of the GaN channel layer, and Schottky barrier height. Increasing the thickness of the p-GaN layer is found to increase the threshold voltage. Also, increasing doping concentration of the p-GaN layer increases the threshold voltage. The doping concentration of the GaN channel layer has the decisive effect on the possibility to use capacitance measurement for the threshold voltage assessment. Simulations show an interesting result of the Schottky barrier height threshold voltage dependence. For higher Schottky barrier height, lower threshold voltage is received, which is connected with the contribution of the negative differential capacitance of the p-GaN layer. This starts to increase for higher positive voltage if the Schottky barrier height is lower.

GROUP 4 - Advanced Electronics and RF

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High-performance InAlN/GaN HEMTs on silicon substrate with high f T × L g

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Applied Physics Express
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We report an 80 nm gate-length In0.17Al0.83N/GaN high-electron mobility transistor (HEMT) on silicon substrate with a record low gate leakage current of 7.12 × 10−7 A mm−1, a record high on/off current ratio of 1.58 × 106, and a steep subthreshold swing of 65 mV dec−1, which are excellent features among the reported InAlN/GaN HEMTs on Si. Due to the excellent DC performance, a current gain cutoff frequency f T of 200 GHz is achieved, resulting in f T × L g = 16 GHz µm for GaN HEMTs on Si which to the best of our knowledge is a new record.

Improvement in DC and pulse characteristics of AlGaN/GaN HEMT by employing dual metal gate structure

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Semiconductor Science and Technology
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This paper presents the fabrication and electrical characterization of dual metal gated high electron mobility transistors (DMG-HEMTs) on AlGaN/GaN/SiC hetero-structure using oblique and normal angle deposition of Nickel and Titanium respectively as gate metals. A noteworthy advance in the device characteristics has been achieved including DC and pulse drain current, transconductance, ON-resistance. The upsurge in DC drain current and transconductance is ~8% and 11% respectively. Pulse I–V measurements have been executed to evaluate the dynamic performance of DMG-HEMTs. Pulse I–V unveils significant improvement in drain lag, gate lag and current collapse in these devices which is due to the redistribution of electric field under the gate.

Defect evolution of oxygen induced Vth-shift for ON-state biased AlGaN/GaN HEMTs

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The origin of the threshold voltage (Vth) shift that occurs in ON-state biased AlGaN/GaN high-electron mobility transistors (HEMTs) is proposed in terms of experimental researches and first-principles calculations. Experimentally, ~20% negative shift of the Vth is found for the 0.2 µm gate length T-gate AlGaN/GaN HEMT under the ON-state stress. 1/f noise measurements are carried out to investigate the evolution of defect distribution in the GaN channel, which indicates that the Vth shift is accompanied by the diminishing of the defect level of Ev + 0.8 eV. Combined with first-principles studies based on hybrid functionals defect calculations, we find that the defect evolution of O from negatively charged VGa-ON to neutral ON-H gives rise to the decrease in acceptors in the GaN channel and thus the negative shift of Vth. Our work indicates that the strengthening of oxygen-related defects in GaN during material growth and device fabrication would improve the reliability of AlGaN/GaN HEMTs.

Optimization of Metal-Organic Chemical Vapor Deposition Regrown n-GaN

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GaN devices for high-frequency and high-power applications often need n-doped GaN layers on top of their structures. Such layers can be either grown in an epitaxial reactor or formed by implantation or annealing of Si-containing layers (e.g., a SiO2 mask). These processes are typically performed at high temperatures, which generate the undesired effect of atom diffusion between the different epitaxial layers; consequently, the electrical performance of the final device will be hampered. Herein, an optimized epitaxial growth process of n-GaN layers is developed with the focus on minimizing the atom diffusion process, while preserving a high material quality and excellent electrical characteristics, such as very low contact resistance for n-GaN ohmic contacts or high electron mobility in GaN npin structures. A low growth temperature process combined with improved growth conditions to minimize the incorporation of impurities is successfully optimized and demonstrated on different epitaxial reactors.

Investigation of self-heating effect on DC and RF performances in AlGaN/GaN high electron mobility transistors on CVD-Diamond

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We have investigated the self-heating effect on DC and RF performances of identically fabricated AlGaN/GaN HEMTs on CVD-Diamond (GaN/Dia) and Si (GaN/Si) substrates. Self-heating induced device performances were extracted at different values drain bias voltage (VD) and dissipated DC power density (PD) in continuous wave (CW) operating condition. The effect of self-heating was observed much lesser in GaN/Dia HEMTs than GaN/Si HEMTs in terms of ID, IG, gm, fT and fmax reduction. Increased channel temperature caused by joule heating at high PD reduces the 2-DEG carrier mobility in the channel of the device. This behaviour was also confirmed by TCAD simulation which showed 3.9-times lower rising rate of maximum channel temperature and lowers thermal resistance (Rth) in GaN/Dia HEMTs than GaN/Si HEMTs. Small signal measurements and equivalent circuit parameter extraction were done to analyze the variation in performance of the devices. Our investigation reveals that the GaN/Dia HEMT is a promising candidate for high power density CW operation without significant reduction in electrical performance in a large drain bias range.

High performance graphene/AlGaN/GaN Schottky junctions for hot electron transistors

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The electronic properties of the graphene (Gr) Schottky junction with an Al0.22Ga0.78N/GaN heterostructure on silicon have been investigated, both experimentally and using ab-initio DFT calculations. A peculiar high n-type doping (1.1×1013 cm-2), observed for Gr in contact with AlGaN, was explained by the combined effect of Fermi level pinning by AlGaN surface states and charge transfer. Spatially uniform current injection across the Gr/AlGaN/GaN heterojunction was revealed by nanoscale resolution conductive atomic force microscopy (CAFM) analyses. Furthermore, a Gr/AlGaN/GaN Schottky diode with excellent rectifying behavior has been demonstrated and used as the key building block for a hot electron transistor (HET) with a 10 nm Al2O3 base-collector barrier. Thanks to the highly efficient hot electron injection from the AlGaN/GaN emitter, this transistor exhibits high on-state current density (JC,ON≅1 A/cm2), high-

on state over off-state current density ratio (JC,ON/JC,OFF≅106) and a common-base current gain α≅0.15, solely limited by the high Al2O3 base collector barrier. The excellent performances of the Gr/AlGaN/GaN Schottky junction represent an important step towards the development of a HET technology compatible with the state-of-the-art GaN high electron mobility transistors.

Low frequency noise and trap density in GaN/AlGaN field effect transistors

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We report experimental results on the low-frequency noise in GaN/AlGaN transistors fabricated under different conditions and evaluate different methods to extract the effective trap density using the McWhorter model. The effective trap density is found to be below 1019 cm−3 for some of the wafers. This trap density is of the same order of magnitude as that reported in Si MOSFETs with a high-k dielectric. One of the structures manifested about two orders of magnitude higher noise level. These measurements correlate with the results of secondary ion mass spectroscopy and terahertz electroluminescence measurements which indicated a ∼30% higher concentration of uncompensated oxygen in this structure. Effective trap density extracted from noise measurements is proven to be a very sensitive figure of merit parameter for the GaN/AlGaN field effect transistors and material quality assessment.

Multidimensional thermal analysis of an ultrawide bandgap AlGaN channel high electron mobility transistor

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Improvements in radio frequency and power electronics can potentially be realized with ultrawide bandgap materials such as aluminum gallium nitride (AlxGa1−xN). Multidimensional thermal characterization of an Al0.30Ga0.70N channel high electron mobility transistor (HEMT) was done using Raman spectroscopy and thermoreflectance thermal imaging to experimentally determine the lateral and vertical steady-state operating temperature profiles. An electrothermal model of the Al0.30Ga0.70N channel HEMT was developed to validate the experimental results and investigate potential device-level thermal management. While the low thermal conductivity of this III-N ternary alloy system results in more device self-heating at room temperature, the temperature insensitive thermal and electrical output characteristics of AlxGa1−xN may open the door for extreme temperature applications.

A new lattice-matched In0.17Al0.83N ~ GaN based heterostructure IMPATT diode for terahertz application

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Simulation studies are made on the dc and microwave performance of a novel lattice-matched

In0.17Al0.83N/GaN heterostructure impact avalanche transit time (IMPATT) diode designed at the low-end terahertz frequency of 220 GHz. The electric field, breakdown voltage, rf output power and the dc-to-rf conversion efficiency of the heterostructure IMPATT diodes are compared with the GaN homostructure IMPATT diode. The results show that, a more localized avalanche region width is obtained for the heterostructure IMPATT diodes. With value of 45 nm of the In0.17Al0.83N layer width, the heterostructure IMPATT diode gives the highest efficiency (15.4%) with moderate rf output power density (1.62 MW cm−2), and the lowest Q-factor (6.57) as compared to other heterostructure and homostructure IMPATT diodes.

Investigation of Quaternary Barrier InAlGaN/GaN/AlGaN Double-Heterojunction High-Electron-Mobility Transistors (HEMTs) for High-Speed and High-Power Applications

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We report direct current (DC) and microwave performance of a 50-nm gate length (Lg) quaternary-based InAlGaN/GaN/AlGaN high-electron-mobility transistor (HEMT) on SiC substrate with SiN passivation and by using a T-gate. The proposed HEMT structure is simulated using industry-standard Synopsys Sentaurus technology computer-aided design (TCAD). The regrown n++ GaN source/drain ohmic contacts show a peak drain current density (Idmax) of 2.9 A/mm along with low on-resistance of 0.49 Ω mm. A record power gain cut-off frequency (fmax) of 425 GHz along with current gain cut-off frequency (ft) of 310 GHz are obtained by the substantial reduction in the device's intrinsic and extrinsic parasitic resistances and capacitances. A very thin 7-nm In0.13Al0.83Ga0.04N quaternary barrier with an AlGaN back-barrier structure effectively mitigates the short-channel effect with an improved breakdown voltage (VBR) of 38 V. The prominent DC and microwave characteristics of the proposed HEMT make it an appropriate candidate for next-generation high-power millimeter-wave electronics.

A high-efficiency design for 2.0-2.9 GHz 5-W GaN HEMT Class-E power amplifier using passive Q-constant non-Foster network

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Microwave and Optical Technology Letters
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A novel load network for designing a high-efficiency broadband Class-E power amplifier, ranging from 2.0 to 2.9 GHz (37% at the central frequency of 2.45 GHz), is proposed using a non-Foster cell that behaves as a negative capacitor with constant quality factor (Q) for optimal fundamental matching over the overall bandwidth. As mathematical analysis, the realization of this element is based on a passive architecture, which exhibits a negative group delay response without constraint of the reference impedance. To improve efficiency in a practical circuit, a close approximation using distributed sections is implemented. The in-band efficiency observed is around 69.0-78.3% with an average of 74% making it the highest for this frequency band today. The output power is maintained in the range of 5-8 W with 12-dB to 14-dB power gain over the band while the two first harmonics are suppressed below −49 dBc.

LDMOS versus GaN RF Power Amplifier Comparison Based on the Computing Complexity Needed to Linearize the Output

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Electronics
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In order to maximize the efficiency of telecommunications equipment, it is necessary that the radio frequency (RF) power amplifier is situated as closely as possible to its compression point. This makes its response nonlinear, and therefore it is necessary to linearize it, in order to minimize the interference that nonlinearities cause outside the useful band (adjacent channel). The system used for this linearization occupies a high percentage of the hardware and software resources of the telecommunication equipment, so it is interesting to minimize its complexity in order to make it as simple as possible. This paper analyzes the differences between the laterally diffused MOSFET (LDMOS) and gallium nitride (GaN) power amplifiers, in terms of their nonlinearity graphs, and in terms of the greater or lesser difficulty of linearization. A correct choice of power amplifier will allow for minimization of the linearization system, greatly simplifying the complexity of the final design.

Thermal Analysis of AlGaN/GaN High-Electron Mobility Transistors using I-V Pulsed Characterizations and infra Red Microscopy

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IEEE Transactions on Device and Materials Reliability
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This paper presents a method based on IV pulsed characterizations to estimate the junction temperature of AlGaN/GaN high-electron mobility transistors (AlGaN/GaN HEMTs). This technique allows a 2D plan evaluation of the average temperature of the transistor and the thermal resistance as a function of the dissipated power and the base plate temperature. In order to validate this method, our outcomes are compared with infra-red (IR) microscopy measurements realized with a Quantum Focus Instrument (QFI) Infrascope. The measured data show a good agreement with the results of our approach. Further analyses are carried out with IR microscopy to investigate the dependence of temperature on electrical parameters.

GROUP 5 – MEMS and Sensors

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Information selected by Knowmade

Switching performance of bistable membranes activated with integrated piezoelectric thin film transducers

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Journal of Micromechanics and Microengineering
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In this paper we report on the fabrication of bistable micro electromechanical systems (MEMS) membranes, which have diameters in the range of 600–800 µm, a total thickness of 3.13 µm and feature integrated low power piezoelectric transducers based on aluminium nitride. To estimate the impact of the membrane asymmetry due to the integrated piezoelectric transducers, an asymmetric constant in the potential energy calculation of the bistable system is introduced, thus enabling a proper theoretical prediction of the membrane behaviour. To switch between the two bistable ground states, rectangular pulses with frequencies in the range of 50–100 kHz and a peak-to-peak voltage of 30 V pp are applied. Two different actuation schemes were investigated, whereas one shows positive and the other negative pulse amplitudes. With a Laser-Doppler Vibrometer the velocity of the membranes during the bistable switching process is measured and integrated over time to calculate the membrane displacement in the centre. FFT (fast Fourier transform) spectra of an applied broadband white noise signal were determined in both ground states and showed a strongly decreased dominant resonance frequency in the lower ground state. The results also showed, that the asymmetry of the system causes different switching behaviours for each bistable ground state, whereas it requires less energy to switch from the lower to the upper ground state. Furthermore, it was demonstrated that a minimum of two pulses are needed for switching when using positive rectangular pulses of 30 V pp in contrast to four when applying negative pulses. The pulse frequency causing switching was in the range of 60–110 kHz, strongly depending on the geometry and applied signal scheme. Additionally, a positive voltage offset applied to the pulse signal characteristics resulted in both a wider range of frequencies suitable for switching and in a decrease of the dominant resonance frequency, which is also beneficial for the switching process and indicates the potential for efficient switching of bistable MEMS membranes.

A self-powered electronic-skin for detecting CRP level in body fluid based on the piezoelectric-biosensing coupling effect of GaN nanowire

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Smart Materials and Structures
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A self-powered biosensing electronic-skin for real-time blood analysis has been presented based on the piezoelectric-biosensing coupling effect of GaN nanowire. The piezoelectric output generated by GaN nanowires can be regarded as both the power source to drive the device and the piezoelectric-biosensing signal for detecting C-reactive protein (CRP). The outputting voltage of the device immersing in the test solution is significantly affected by the CRP concentration, and the response is up to 78.2% against 0.624 mg ml−1. The CRP antigen-antibody specific binding reaction occurs on the surface of GaN nanowire, it not only influence the surface carrier density but also influence piezoelectric output. The actual application of the device for testing the CRP concentration in rabbit blood samples (fever or not) has been confirmed. The existing results can stimulate a study trend on self-powered nanosystems and promote the development of flexible biosensors.

Ultra-Low Acoustic Loss Micro-Machined Butterfly Lamb Wave Resonators on AlN Plates

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IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control

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This study reports the design of a novel Butterfly Lamb wave resonator (LWR) employing S0 mode in AlN plate, and for the first time, its ultra-high parallel-resonance quality factor (Qp) of 4,021 is demonstrated, indicating an ultra-low acoustic loss. Although the series resonance quality factor (Qs) is widely used for various loss comparisons, it's inconclusive since Qs is always dominated by the routing resistance (Rs) which is normally huge without the thick metal re-wiring. Instead, Qp is a precise representation of the acoustic loss level for its independence of Rs and as it's closer to Qmax of Bode Q-curve in the IDT-excited devices. A butterfly-shape resonance cavity, theoretically predicted to reduce the anchor loss and suppress the transverse spurious mode, has been applied to the AlN LWR and experimentally shown to boost the Qp by 2.3 times. In addition, a directly measured Bode-Q curve for the LWR is reported for the first time, showing superior Q profile for the Butterfly-LWR than the conventional-LWR and good agreement with the 3dB-Qp's.

Surface smoothing with BCl3 plasma post-treatment to improve the performance of GaN avalanche photodiodes

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Japanese Journal of Applied Physics
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This paper reports a plasma post-treatment technique to improve the performance of GaN ultraviolet avalanche photodiodes (APDs). A BCl3-based plasma post-etching technique was developed to smooth the roughened GaN surface after inductively-coupled-plasma etching. Atomic-scale surface roughness around 0.278 nm rms and photoluminescence intensity more than doubled were achieved after the post-treatment. The surface smoothing technique was applied to the fabrication process of double-mesa structure GaN APDs grown on a sapphire substrate. Compared to the non-treated APDs, the post-treated GaN APDs show high field leakage current suppressed more than two orders and the average gain increased from 2 × 104 to 1 × 105, indicating the low surface damage after BCl3 plasma post-treatment. For the GaN APDs fabricated into a 3 × 3 array, the devices show uniform distribution of the breakdown voltages after the plasma post-treatment

A p-Si/n-GaN diode fabricated by nanomembrane lift-off and transfer-print technique

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Semiconductor Science and Technology
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In this paper, we successfully demonstrated a high quality p-Si/n-GaN heterojunction diode through van der Waals bonding implemented by nanomembrane lift-off and transfer-print technique. A nanoscale native oxide layer is observed at the interface by transmission electron microscope, which plays a role as passivation-layer. The heterojunction diode has excellent electrical performance with a high rectification ratio of 4.75 × 105 at ± 3 V and a low reverse dark current density of 4.03 × 10–4 A cm−2 at −3 V. In addition, the heterojunction diode responds to both near ultraviolet (375.6 nm) and red light (650 nm) with responsivity of 429.9 mA W−1 and 66.8 mA W−1 (at −3 V) respectively. This result indicates that a large-lattice-mismatched semiconductor heterojunction can be fabricated based on GaN by using transfer-print technique, thereby expanding the operating band of GaN-based detectors from ultraviolet region to visible region.

High-bandwidth InGaN self-powered detector arrays toward MIMO visible light communication based on micro-LED arrays

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This work reports the use of the chip-based GaN-based micro-LED (µLED) arrays for multifunctional applications as micro-display, data transmitters, photodetectors and solar cells. The functions of display and transmitter have been reported, and particularly we experimentally demonstrated that µLED arrays could be used as self-powered, high-performance and wavelength-selective photodetectors (PDs) enabling high-speed multiple-input multiple-output (MIMO) visible light communications (VLC) under on-off keying (OOK) modulation scheme using 405 nm violet laser diodes (LDs) as transmitters. The optoelectronic and communication characteristics of the µLED-based PDs with diameters of 40-µm, 60-µm and 100-µm were systematically studied. The optoelectronic analysis shows superior performances of µLED-based PDs at 405 nm wavelength compared with other previously reported GaN-based PDs. Under a bias voltage of -5 V, the comparable peak responsivities of 0.27, 0.31 and 0.24 A/W, specific detectivities of 1.1 × 1011, 2.3 × 1012 and 2.1 × 1012 cm · H1/2 · W-1, and linear dynamic ranges (LDRs) of 152, 162 and 164 dB were achieved for 40-µm, 60-µm and 100-µm µLEDs, respectively. Even at zero-bias, i.e. self-powered mode, we have achieved high peak responsivities of 0.24, 0.29 and 0.21 A/W, high specific detectivities of 7.5 × 1012, 1.5 × 1013 and 1.3 × 1013 cm · H1/2 · W-1 and high LDR up to 186, 196 and 197 dB for 40-µm, 60-µm and 100-µm µLEDs, respectively. The µLEDs could also be used to harvest the optical energy of the system, working as solar cells. The µLED-based PD arrays were tested as receivers in VLC system to implement high-speed parallel communication, which yields maximum data rates of 180 Mbps, 175 Mbps and 185 Mbps for a single 40-µm, 60-µm and 100-µm µLED-based PDs at a distance of 1 m with BERs of 3.5 × 10-3, 3.7 × 10-3 and 3.5 × 10-3, respectively. Furthermore, 2 × 2 MIMO parallel VLC system was achieved to increase the VLC data rate, which suggests the potential of using a large µLED-based PD arrays for multiple Gbps and even Tbps VLC applications.

Piezotronic Effect Modulated Flexible AlGaN/GaN High-Electron-Mobility Transistors

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Flexible electronic technology has attracted great attentions due to its wide range of potential applications in the fields of healthcare, robotics and artificial intelligence, etc. In this letter, we have successfully fabricated flexible AlGaN/GaN High-Electron-Mobility Transistors (HEMTs) arrays through a low damage and wafer-scale substrate transfer technology from a rigid Si substrate. The flexible AlGaN/GaN HEMTs have excellent electrical performances with the Id,max achieving 290 mA/mm at Vgs = +2 V and the gm,max reaching to 40 mS/mm. The piezotronic effect provides a new freedom to optimize device performances, and flexible HEMTs can endure larger mechanical distortions. Based on the piezotronic effect, we applied an external stress to significantly modulate the electrical performances of the flexible HEMTs. The piezotronic effect modulated flexible AlGaN/GaN HEMTs exhibit great potentials in human-machine interface, intelligent micro-inductor system, and active sensors, etc, and open a new window to sensing or feedback external mechanical stimuli and so on.

Hydrogen Gas Adsorption on Pd and Pt Decorated GaN (0001) Surface: A First-Principles Study

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physica status solidi b
https://doi.org/10.1002/pssb.201900420

In this work, density functional theory (DFT) calculations were carried out to investigate the hydrogen gas adsorption on Pd (Pt)-decorated GaN (0001) surface. We find that the diffusion barrier of Pd (Pt) on the GaN (0001) surface is 0.3996(0.602) eV. Hydrogen molecule adsorbed on the Pt-decorated GaN (0001) surface can dissociate into hydrogen atoms. The comparison of the density of states and Mulliken charge analysis of the hydrogen molecule adsorption on Pd (Pt)-decorated GaN (0001) surface are analyzed in detail. We found that the Pt-decorated GaN (0001) surface has a high sensing ability for hydrogen molecules from the theoretical point of view.

Numerical analysis of anchor loss and thermoelastic damping in piezoelectric AlN-on-Si Lamb wave resonators

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Even though many thin-film piezoelectric aluminum nitride (AlN) on silicon (Si) Lamb wave resonators have been proposed in the literature, little focus has been set on the modeling of the quality factors Q. Their Qs are associated with numerous dissipation sources, which are often difficult to separate from each other in experiments. Besides, the values of Q measured in experiments can largely deviate from sample-to-sample of the same design. In order to gain better insight into these issues, we have applied numerical models to estimate anchor losses and thermoelastic damping to a large set of AlN-on-Si resonators specifically designed to have significantly different Qs. The data set includes biconvex resonators of different curvatures (designed to reduce anchor losses), regular flat-edge resonators, and different electrode patterns. For the broad range of devices tested, we show that the computed values of Q agree well with the experimental data. In particular, the experimentally measured values of Q in regular flat-edge Lamb wave resonators are due to comparable contributions of the two types of losses.

Suspended AlGaN/GaN HEMT NO_2 Gas Sensor Integrated With Micro-heater

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Journal of Microelectromechanical Systems
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We developed an AlGaN/GaN high electron mobility transistor (HEMT) sensor with a tungsten trioxide (WO_3) nano-film modified gate for nitrogen dioxide (NO_2) detection. The device has a suspended circular membrane structure and an integrated micro-heater. The thermal characteristic of the Platinum (Pt) micro-heater and the HEMT self-heating are studied and modeled. A significant detection is observed for exposure to a low concentration of 100 ppb NO_2 /N_2 at ~300 °C. For a 1 ppm NO_2 gas, a high sensitivity of 1.1% with a response (recovery) time of 88 second (132 second) is obtained. The effects of relative humidity and temperature on the gas sensor response properties in air are also studied. Based on the excellent sensing performance and inherent advantages of low power consumption, the investigated sensor provides a viable alternative high performance NO ₂ sensing applications. It is suitable

for continuous environmental monitoring system or high temperature applications.

New Disposable Nitric Oxide Sensor Fabrication Using GaN Nanowires

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ACS Omega
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Gallium nitride (GaN) nanowires anchored on the surface of cost-effective pencil graphite electrodes (PGEs) have been developed as a new disposable nitric oxide (NO) sensor through a hydrothermal method followed by annealing treatment. The as-obtained nanomaterials were examined by field emission scanning electron microscopy, high-resolution transmission electron microscopy, Raman spectroscopy, X-ray photoelectron spectroscopy, and EIS. Concurrently, the electrocatalytic performance has been analyzed using cyclic voltammetry and amperometric measurements. The experimental results exhibit good electrochemical sensing performance toward the generated NO in NO2– with a wide linear detection range of 1.0 µM to 1.0 mM with a correlation coefficient of 0.999 and a detection limit of 0.180 µM. In addition, the GaN nanowire-modified PGE surface showed high selectivity for the detection of NO as compared to other relevant biomolecules. This confirms that the PGE/GaN nanowire is a new promising electrochemical sensor for the sensitive detection of NO.

Sensitive and Selective Detection of Pb2+ ions using 2,5-Dimercapto-1,3,4-Thiadiazole Functionalized AlGaN/GaN High Electron Mobility Transistor

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IEEE Electron Device Letters
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We report sensitive and selective AlGaN/GaN High Electron Mobility Transistor (HEMT)-based sensor for Lead ion (Pb2+) detection. The gate region of the HEMT was functionalized by 2,5-dimercapto-1,3,4-thiadiazole (DMTD). The response of the sensor is observed by monitoring drain to source current (IDS) for different concentrations of Pb2+ ions at a fixed drain to source voltage (VDS). Our sensor reaches the lower detection limit of 0.018 ppb, which is much lower than the standard detection limit recommended by the World Health Organization (WHO) for drinking water. Furthermore, the sensor exhibited a rapid response time of ~ 4 seconds and high sensitivity of 0.607 µA/ppb. Moreover, the selectivity analysis was performed and found that the sensor was highly selective towards Pb2+ ions. The change in electron concentration at 2-dimensional electron gas (2DEG) upon the capture of Pb2+ ions at gate region by DMTD, causes a change in the IDS, which showed excellent sensing response towards Pb2+ ions. The highly sensitive, selective, and rapid detection of Pb2+ ions paves the way for stable sensing performance based on DMTD functionalized AlGaN/GaN HEMT sensor.

Dynamic Q-enhancement in aluminum nitride contour-mode resonators

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Applied Physics Letters
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In this letter, we discuss a dynamic quality factor (Q)-enhancement technique for aluminum nitride (AlN) contour-mode resonators. This technique is implemented by applying an external voltage source that has a specific frequency-dependent phase relationship with respect to the driving voltage source. In this way, the effective spring, damping, and mass of the resonator become dependent on the frequency. With proper gain and phase delay between external and driving signals at resonance, 3-dB Q of the resonator's spectral admittance can be dramatically boosted beyond the fundamental limit of the AlN f-Q product. Meanwhile, the effective electromechanical coupling, k2t, is also improved regardless of the material piezoelectricity limit. These

two enhancements correspond to the reduction of the effective damping and spring, respectively. Unlike other active Q-enhancement methods, which use complex electrical circuits to convert resonator displacement/output current into a feedback signal, in this approach, the external and driving signals are generated from the same source and split via a power splitter without resorting to any closed loop operation. The external signal is amplified and shifted by an amplifier and a delay line, respectively. Thus, the demonstrated dynamic Q-enhancement method is relatively simple to implement and intrinsically immune to self-oscillations.

MEMS AlN pyroelectric infrared detector with medium to long wave IR absorber

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Sensors and Actuators A: Physical
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Polycrystalline Aluminum Nitride (AlN) thin films are of significant interest due to their pyroelectric properties for last few years. In this paper, study on development of a polycrystalline AlN thin film based bulk micromachned pyroelectric IR detector is presented. Structural optimization of IR detector has been carried out using 3D finite element modeling (FEM) and simulations. A 1.0 µm thick thermally grown SiO2 layer used for thermal isolation, also serves as a diaphragm to hold the fabricated IR detector. Rate of temperature change (dT/dt) of the detector under dynamic heating is 0.12 to 0.15 ºK/s, and agrees well with the simulated value of 0.1 ºK/s. High pressure, N2 ambient sputtered Au film of thickness 160 nm has been used to enhance the IR absorptivity. IR absorptivity of detector on medium to long wave (2.5-25 µm) radiations is nearly 67%, and creates thermal gradient of 0.23 ºK between detector and substrate. Developed pyroelectric IR detector exhibits response time 8.0 ms, pyroelectric coefficient (ρ) 0.32 × 10-4 C/m2K, ρ/ε figure of merit (FOM) 0.3 C/m2K, and pyroelectric current responsivity (Ri) of 2.5 × 10-6 A/W.

Highly-Linear Magnet-Free Microelectromechanical Circulators

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Journal of Microelectromechanical Systems
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This paper reports the first demonstration of a magnet-free, high performance microelectromechanical system (MEMS) based circulator. An innovative circuit based on the commutation of MEMS resonators with high quality (Q) factor using RF switches is designed and implemented. Thanks to the high Q factor, a much smaller modulation frequency can be achieved compared to the previous demonstrations, reducing the power consumption and enabling the use of high power-handling switches. Furthermore, the MEMS resonators greatly reduce the required inductance value, guaranteeing much smaller form factor compared to the previous LC demonstrations. The demonstrated circulator shows broad BW (15 dB-IX BW=34.7 MHz for an operational frequency around 2.5 GHz), low IL (4 dB), high IX (30 dB), high linearity (P1dB=28 dBm; IIP3=40 dBm) and at the same time low power consumption, addressing several of the current limitations hindering the full development of magnet-free circulators.

Bulk-Micromachined Test Structure for Fast and Reliable Determination of the Lateral Thermal Conductivity of Thin Films

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A novel bulk-micromachined test structure is presented for the fast and reliable determination of the lateral thermal conductivity of thin films. The

device is composed of a heater resistor and thermocouples that are fabricated in polysilicon (poly-Si), and the associated processing and DC measurement procedures are straightforward. The validity of the method is supported by numerical simulations and verified by experimental determination of the lateral thermal conductivity of aluminum (Al), aluminum nitride (AlN), p-doped poly-Si, and silicon nitride (SiN) thin films. For Al, an average value of 217 W m -1 K -1 was found for 1-mum thick layers. For the other layers, a number of thicknesses were studied, and the increase of thermal conductivity with thickness was effectively detected: for AlN, values from 7 to 11.5 W m -1 K -1 were found, and for p-doped poly-Si, values went from 21 to 46 W m -1 K -1 for thicknesses from 0.15 to 1 mum. For SiN, a value of 1.8 was extracted for layers thicker than 0.5 mum.

Study on ultra-high sensitivity piezoelectric effect of GaN micro/nano columns

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Nano Convergence
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High-quality GaN micro/nano columns were prepared with self-organized catalytic-free method. Young's modulus of GaN nanocolumns were measured under both compressive stress and tensile stress. It was found that the Young's modulus decreases with the increasing of nanocolumn diameter due to the increase of face defect density. Furthermore, we measured the piezoelectric properties and found that there was a 1000-fold current increase under a strain of 1% with a fixed bias voltage of 10 mV. Based on the Schottky Barrier Diode model, we modified it with the effect of polarization charge, image charge and interface state to analyze the experiment results which reveals that the strong piezopolarization effect plays an important role in this phenomenon. Therefore, the GaN nanocolumns has a great prospect to be applied in high-efficiency nanogenerators and high-sensitivity nanosensors.

From bulk to porous GaN crystal: precise structural control and its application in ultraviolet photodetectors

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Journal of Materials Chemistry C
https://doi.org/10.1039/C9TC04820K

Porous GaN has many unique merits, such as a large specific surface area, adjustable bandgap and excellent optical performance. Here, we develop a simple and effective method for preparing porous GaN single crystals through high temperature annealing. The effects of different annealing temperatures on the porous structure, crystal quality and optical properties of GaN are investigated. The relationship model of annealing temperatures, times and GaN porous structures is summarized. An ultraviolet (UV) photodetector based on porous GaN is fabricated. The effects of porous structures on the performance of the GaN UV photodetector are investigated for the first time. We found that the appropriate GaN porous structure can improve the performance of the photodetector. A possible performance enhancement mechanism has been proposed. Based on the high performance and simple fabrication process, porous GaN crystal can be an excellent candidate for UV photodetectors.

3D FEM Analysis of High-Frequency AlN-Based PMUT Arrays on Cavity SOI

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This paper presents three-dimensional (3D) models of high-frequency piezoelectric micromachined ultrasonic transducers (PMUTs) based on the finite element method (FEM). These models are verified

with fabricated aluminum nitride (AlN)-based PMUT arrays. The 3D numerical model consists of a sandwiched piezoelectric structure, a silicon passive layer, and a silicon substrate with a cavity. Two types of parameters are simulated with periodic boundary conditions: (1) the resonant frequencies and mode shapes of PMUT, and (2) the electrical impedance and acoustic field of PMUT loaded with air and water. The resonant frequencies and mode shapes of an electrically connected PMUT array are obtained with a laser Doppler vibrometer (LDV). The first resonant frequency difference between 3D FEM simulation and the measurement for a 16-MHz PMUT is reasonably within 6%, which is just one-third of that between the analytical method and the measurement. The electrical impedance of the PMUT array measured in air and water is consistent with the simulation results. The 3D model is suitable for predicting electrical and acoustic performance and, thus, optimizing the structure of high-frequency PMUTs. It also has good potential to analyze the transmission and reception performances of a PMUT array for future compact ultrasonic systems

InGaN as a Substrate for AC Photoelectrochemical Imaging

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Sensors
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AC photoelectrochemical imaging at electrolyte–semiconductor interfaces provides spatially resolved information such as surface potentials, ion concentrations and electrical impedance. In this work, thin films of InGaN/GaN were used successfully for AC photoelectrochemical imaging, and experimentally shown to generate a considerable photocurrent under illumination with a 405 nm modulated diode laser at comparatively high frequencies and low applied DC potentials, making this a promising substrate for bioimaging applications. Linear sweep voltammetry showed negligible dark currents. The imaging capabilities of the sensor substrate were demonstrated with a model system and showed a lateral resolution of 7 microns.

Hybrid Light Emitters and UV Solar-Blind Avalanche Photodiodes based on III-Nitride Semiconductors

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In the last two decades, remarkable progress has been achieved in the field of optoelectronic devices based on III-nitride semiconductors. In terms of photonics applications in the visible–UV spectral range, III-nitrides are one of the most promising materials. For instance, emerging gallium nitride (GaN)-based micro-light-emitting diode (LED) technology for high-resolution display, and UV photo-detection for environmental monitoring, health, and medical applications. In this work, hybrid micro/nano-LEDs with integration of II–VI quantum dots by means of lithography and nano-imprinting patterning techniques are demonstrated, and high-performance red/green/blue and white emissions are achieved. Consequently, plasmonic nanolasers are designed and fabricated using a metal-oxide-semiconductor structure, where strong surface plasmon polariton coupling leads to the efficient lasing with a low excitation threshold from the visible to UV tunable spectral range. Furthermore, performance-improved AlGaN UV solar-blind avalanche photodiodes (APDs) with a separate absorption and multiplication structure by polarization engineering are reported. These APDs deliver a record-high avalanche gain of up to 1.6 × 105. These newest advances in nano/micro-LEDs, nanolasers, and APDs can shed light on the emerging capabilities of III-nitride in cutting-edge applications.

Wearable Multiparameter Platform Based on AlGaN/GaN High-electron-mobility Transistors for Real-time Monitoring of pH and Potassium Ions in Sweat

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Electroanalysis
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Biosensors based on field-effect transistor (FET) structures have attracted considerable attention because they offer rapid, inexpensive parallel sensing and ultrasensitive label-free detection. However, long-term repeatable detection cannot be performed, and Ag/AgCl reference electrode design is complicated, which has hindered FET biosensors from becoming truly wearable health-monitoring platforms. In this paper, we propose a novel wearable detection platform based on AlGaN/GaN high-electron-mobility transistors (HEMTs). In this platform, a sweatband was used to continuously collect sweat, and a pH detecting unit and a potassium ion detecting unit were formed by modifying different sensitive films to realize the long-term stable and repeatable detection of pH and potassium ions. Experimental data show that the wearable detection platform based on AlGaN/GaN HEMTs has good sensitivity (pH 3–7 sensitivity is 45.72 μA/pH; pH 7.4–9 sensitivity is 51.073 μA/pH; and K+ sensitivity is 4.94 μA/lgαK+), stability (28 days) and repeatability (the relative standard deviation (RSD) of pH 3–7 sensitivity is 2.6 %, the RSD of pH 7.4–9 sensitivity is 2.1 %, and the RSD of K+ sensitivity is 7.3 %). Our newly proposed wearable platform has excellent potential for predictive analytics and personalized medical treatment.

The Effect of Inductively Coupled Plasma Etching on the I–V Curves of the APD with GaN/AlN Periodically-Stacked-structure

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https://doi.org/10.1002/pssa.201900655

Inductively Coupled Plasma (ICP) is widely used in dry etching of III-nitride materials, wherein the etching parameters of GaN and AlN are very different. In this paper, the ICP dry etching process parameters of GaN/AlN periodically-stacked-structure (PSS) for avalanche photodiode fabrication have been intensively studied and optimized. The flow rate ratio of Cl2/BCl3/Ar plasma, bias voltage, and the GaN-to-SiNx selectivity of ICP etching were optimized to achieve excellent surface morphology and nearly vertical sidewalls. It was found that the etching rate and the etched surface roughness of GaN/AlN material were significantly influenced by the flow rate of Cl2. After optimizing the etching procedure, the root-mean-square roughness (RMS) of the etched surface was measured to be 1.46 nm, which is close to the as grown surface. By employing the optimized ICP dry etching in the fabrication of the GaN/AlN PSS avalanche photodiode (APD), the dark current was suppressed from 3.6 A /cm2 to 8.2×10-3 A/cm2 at -90V.

GROUP 6 - Photovoltaics and Energy harvesting

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Information selected by Knowmade

Superhigh out-of-plane piezoelectricity, low thermal conductivity and photocatalytic abilities in ultrathin 2D van der Waals heterostructures of Boron Monophosphide and Gallium Nitride

Nanoscale
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A stable 2D van der Waals (vdW) heterobilayer constituted by the recently synthesized Boron monophosphide (BP) and Gallium Nitride (GaN) monolayers has been explored for different kinds of energy conversion and nanoelectronics. The nearly matched lattice constants of GaN and BP are commensurate with each other in their lattice structures. The out-of-plane inversion asymmetry coupled with the large difference in atomic charges between the GaN and BP monolayers induces in the heterobilayer a giant out-of-plane piezoelectric coefficient (|d_33|_max≈ 40 pm/V), which is the highest ever reported in 2D materials of a finite thickness. It is exceedingly higher than the out-of-plane piezoelectric coefficient reported earlier in multilayered Janus transition metal dichalcogenide MXY (M = Mo, W; X, Y = S, Se, Te) (|d_33|_max= 10.57 pm/V). Such a high out-of-plane piezoelectricity found in GaN/BP heterobilayer can bring about a gigantic strain-tunable top gating effects in nanopiezotronic devices based on the same. Moreover, electron mobility (~ 10^4 cm^2/V.s.) reaches much higher than that of transition metal dichalcogenides and conventional semiconductors. The origin of low lattice thermal conductivity (κ_L~25.25 W/mK) in GaN/BP at room temperature, which is lower than black phosphorene (78 W/mK), buckled arsenene (61 W/mK), BCN (90 W/mK), MoS2 (34.5 W/mK) and WS2 (32 W/mK) monolayers, has been systematically investigated via phonon dispersion, lattice thermal conductivity, phonon lifetime and mode Gru parameters. Valence band maximum (VBM) and conduction band minimum (CBM) arising from GaN and BP monolayers respectively result in a type II vdW heterobilayer, which is found to be thermodynamically favorable for photocatalytic water splitting in both acidic and neutral media. The exciton binding energies are comparable to that of MoS2 and C3N4 single layers, while the absorbance reaches as high as ~ 10^5 cm-1 in the visible wavelength region. The emergence of high piezoelectricity, high carrier mobility, low lattice thermal conductivity and photocatalytic water splitting abilities in the proposed vdW heterobilayer signify enormous potential for its versatile applications in nanoscale energy harvesting, e.g., nano-sensors in medical devices, future nanopiezotronics, 2D thermoelectrics and solar energy conversion.

High-Temperature Selective Emitter Design and Materials: Titanium Aluminum Nitride Alloys for Thermophotovoltaics

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The efficiency of a thermophotovoltaic (TPV) system depends critically upon the spectral selectivity and stability of an emitter, which may operate most effectively at temperatures in excess of 1000 °C. We computationally design and experimentally demonstrate a novel selective emitter design based on multilayer nanostructures, robust to off-normal emission angles. A computational search of the material and temperature compatibility space of simple emitter designs motivates new material classes and identifies several promising multilayer nanostructure designs for both TPV absorber and emitter applications. One such structure, comprising a thin (<100 nm) tunable TixAl1–xN (TiAlN) absorber and refractory oxide Bragg reflector is grown on W

metal foil. In agreement with simulations, the emitter achieves record spectral efficiency (43.4%) and power density (3.6 W/cm2) for an emitter with at least 1 h of high temperature (>800 °C) operation.

Indium-rich InGaN/GaN solar cells with improved performance due to plasmonic and dielectric nanogratings

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Energy Science & Engineering
https://doi.org/10.1002/ese3.436

In this study, we propose an indium-rich InGaN/GaN p-i-n thin-film solar cell which incorporates a dual nanograting (NG) structure: Ag nanogratings (Ag-NGs) on the backside of the solar cell and gallium nitride nanogratings (GaN-NGs) on the frontside. Finite-difference time-domain (FDTD) simulation results show that the dual NG structure couples the incident sunlight to the plasmonic and photonic modes, thereby increasing the absorption of the solar cell in a broad spectral range. It is observed that the solar cells having the dual nanograting structures have a significant enhancement in light absorption as compared to cells having either no nanogratings or having only the frontside nanogratings or only the backside nanogratings. Analysis of light absorption in solar cells containing the dual NG structures showed that the absorption enhancement of longer wavelengths is mostly due to the Ag-NGs on the backside and of shorter wavelengths is mostly due to the GaN-NGs on frontside of the solar cell. The Jsc and power conversion efficiency (PCE) are calculated under AM1.5G solar illumination and are observed to be significantly enhanced due to the presence of optimized dual NG structures. While there is an increase in Jsc from 17.88 to 23.19 mA/cm2 (~30% enhancement), there is an increase in PCE from 15.49% to 20.24% (~31% enhancement) under unpolarized light (average of TM and TE). Moreover, the study of oblique light incidence shows significantly larger Jsc of the dual nanograting solar cells compared to the cells with no nanogratings.

Plasma-enhanced atomic-layer-deposited gallium nitride as an electron transport layer for planar perovskite solar cells

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Low-temperature deposited gallium nitride (GaN) thin-films have been introduced into planar perovskite solar cells (PSCs) as electron transport layers (ETLs) for the first time. Compact and amorphous n-type GaN layers were uniformly coated on fluorine-doped tin oxide (FTO) glass substrates via plasma-enhanced atomic layer deposition (PEALD) technology, in which an optimized deposition temperature of 280 °C was identified and adopted. The as-prepared GaN thin-films were subsequently employed to fabricate planar PSCs with the device configuration FTO/GaN/perovskite/spiro-OMeTAD/Au. Interestingly, although a conduction-band-minimum (CBM) mismatch of 0.59 eV is found at the interface of the 50-PEALD-cycle GaN/perovskite, a significantly enhanced device efficiency from 10.38% to 15.18% has also been achieved relative to the ETL-free PSCs. Meanwhile, the current–voltage hysteresis and device stability of GaN-based PSCs can be remarkably improved. It is found that the GaN layer can promote the electron extraction and reduce recombination at the FTO/perovskite interface. This work demonstrates the feasibility and potential of GaN films as ETLs in planar PSCs.

Surface polarity-induced spatial charge separation boosting photocatalytic overall water splitting on GaN nanorod arrays

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Photocatalytic overall water splitting has been recognized as a promising approach to convert solar energy into hydrogen. However, most of the photocatalysts suffer from low efficiencies mainly due to the poor charge separation property. Herein, taking a model semiconductor gallium nitride (GaN) as an example, we uncovered that photogenerated electrons and holes can be spatially separated to the nonpolar and polar surfaces of GaN nanorod arrays, which is presumably ascribed to the different surface band bending induced by the surface polarity. The photogenerated charge separation efficiency of GaN can be enhanced significantly from ~8% to more than 80% via co-exposing polar and nonpolar surfaces. Furthermore, spatially assembling of reduction and oxidation cocatalysts selectively on the nonpolar and polar surfaces remarkably boosts photocatalytic overall water splitting, with the quantum efficiency increased from 0.9% for the film photocatalyst to 6.9% for the nanorod arrays photocatalyst.

Ultrafast Hot Carrier Injection in Au/GaN: The Role of Band Bending and the Interface Band Structure

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Plasmon photochemistry can potentially play a significant role in photocatalysis. To realize this potential, it is critical to enhance the plasmon excited hot carrier transfer and collection. However, the lack of atomistic understanding of the carrier transfer across the interface, especially when the carrier is still “hot”, makes it challenging to design a more efficient system. In this work, we apply the nonadiabatic molecular dynamics simulation to study hot carrier dynamics in the system of a Au nanocluster on top of a GaN surface. By setting up the initial excited hole in Au, the carrier transfer from Au to GaN is found to be on a subpicosecond time scale. The hot hole first cools to the band edge of Au d-states while it transfers to GaN. After the hole has cooled down to the band edge of GaN, we find that some of the charges can return back to Au. By applying different external potentials to mimic the Schottky barrier band bending, the returning charge can be reduced, demonstrating the importance of the internal electric field. Finally, with the understanding of the carrier transfer’s pathway, we suggest that a ZnO layer between GaN and Au can effectively block the “cold” carrier from returning back to Au but still allow the hot carrier to transfer from Au to GaN.

MEMS-Based AlScN Resonating Energy Harvester With Solidified Powder Magnet

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Energy harvesters offer an attractive power source alternative in particular for the next generation of mobile sensor applications. The current work investigates the power output of bulk micromachined 3 mm x 2 mm x 50 µm sized cantilever-type piezoelectric (2 µm AlScN) energy harvesting device that is magnetically driven by miniaturized NdFeB permanent magnets attached to the free-end of the cantilevers. A novel energy harvester and one potential application is introduced. Properties and relevant figures-of-merit for AlScN in comparison to AlN are discussed on device level. Magnetic properties of the permanent magnet are summarized. The influences of the electrode area coverage, applied external magnetic field as well as fatigue properties of the harvesters are investigated. FEA results of the harvester's magnetic interactions

are presented. Finally the suitability of a coil in comparison to a piezoelectric energy harvester is evaluated. A maximum peak power of 15.6 µW is obtained from a 2 mm wide cantilever with 2 mm long top electrode when driven under an homogeneous external field of magnitude BAC = 1 G at resonance fres = 3240 Hz. The maximum power density is calculated as 15.8 mW/cm³ (2.6 W/m²) when applying the optimal load impedance approximately 117 kΩ .

GROUP 7 - Materials, Technology and Fundamental

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GaN nanowires as probes for high resolution atomic force and scanning tunneling microscopy

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Review of Scientific Instruments
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GaN nanowires are potential candidates for use in scanning probe microscopy due to their well-defined, reproducible, geometric shapes, their hardness, and their light guiding properties. We have developed and investigated probes for high resolution atomic force microscopy and scanning tunneling microscopy utilizing GaN nanowires as probes. The nanowires are n-doped and the morphology of the nanowires has been tailored for scanning probe microscopy by growing them with a sharp tip for measurements and high thickness for robustness. The individual GaN nanowires were removed from their growth substrate and attached onto commercial atomic force microscopy cantilevers or etched tungsten wires for scanning tunneling microscopy. A standard scanning electron microscope equipped with a nanoprobe, a focused ion beam column and a gas injection system was used to locate, transfer, and attach the nanowires. We evaluated the properties of the GaN probes on different substrates including HOPG, Au, SiO2, InAs, and GaAs. We demonstrate both atomic force microscopy and scanning tunneling microscopy measurements with single atomic layer resolution and evaluate the robustness of the tips by monitoring them before and after scanning. Finally, we explore the use of the tips for scanning tunneling spectroscopy demonstrating that reliable results, which can reveal information on the electronic properties of the surface-tip system, are obtainable. The fundamental properties of these probes, which are demonstrated in this work, show promise for future use of the probes in exploring semiconductor-semiconductor tunneling junctions at the nanoscale as well as for other scanning probe techniques where high resolution is required.

Deep Ultraviolet Luminescence Due to Extreme Confinement in Monolayer GaN/Al(Ga)N Nanowire and Planar Heterostructures

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NanoLetters
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We present experimental results confirming extreme quantum confinement in GaN/AlxGa1–xN (x = 0.65 and 1.0) nanowire and planar heterostructures, where the GaN layer thickness is of the order of a monolayer. The results were obtained from temperature- and excitation-dependent and time-resolved photoluminescence measurements. In the GaN/AlN nanowire heterostructure array sample, the measured emission peak at 300 K is ∼5.18–5.28 eV. This is in excellent agreement with the calculated optical gap of 5.23 eV and 160–260 meV below the calculated electronic gap of 5.44 eV, suggesting that the observed emission is excitonic in nature with an exciton binding energy of ∼160–260 meV. Similarly, in the monolayer GaN/Al0.65Ga0.35N planar heterostructure, the measured emission peak at 300 K is 4.785 eV and in good agreement with the calculated optical gap of 4.68 eV and 95 meV below the calculated electronic gap of 4.88 eV. The estimated exciton binding energy is 95 meV and in close agreement with our theoretical calculations. Excitation-dependent and time-resolved photoluminescence data support the presence of excitonic transitions. Our results indicate that deep-ultraviolet excitonic light sources and microcavity

devices can be realized with heterostructures incorporating monolayer-thick GaN.

Characterization of InGaN quantum dots grown by metalorganic chemical vapor deposition

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Semiconductor Science and Technology
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InGaN quantum dots were grown by metalorganic chemical vapor deposition and shown to exhibit a bimodal size distribution. Atom probe tomography was used to characterize the dots in conjunction with atomic force microscopy, photoluminescence, and x-ray diffraction. Small dots with low indium contents were found to coexist with larger, very high indium composition dots. Significant compositional fluctuations were observed in the small dot population. The dots showed abrupt interfaces with the surrounding GaN, verifying the ability to cap the dots without causing intermixing for even extremely high indium content dots.

A self-powered electronic-skin for detecting CRP level in body fluid based on the piezoelectric-biosensing coupling effect of GaN nanowire

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Smart Materials and Structures
https://doi.org/10.1088/1361-665X/ab3901

A self-powered biosensing electronic-skin for real-time blood analysis has been presented based on the piezoelectric-biosensing coupling effect of GaN nanowire. The piezoelectric output generated by GaN nanowires can be regarded as both the power source to drive the device and the piezoelectric-biosensing signal for detecting C-reactive protein (CRP). The outputting voltage of the device immersing in the test solution is significantly affected by the CRP concentration, and the response is up to 78.2% against 0.624 mg ml−1. The CRP antigen-antibody specific binding reaction occurs on the surface of GaN nanowire, it not only influence the surface carrier density but also influence piezoelectric output. The actual application of the device for testing the CRP concentration in rabbit blood samples (fever or not) has been confirmed. The existing results can stimulate a study trend on self-powered nanosystems and promote the development of flexible biosensors.

A p-Si/n-GaN diode fabricated by nanomembrane lift-off and transfer-print technique

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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/ab408b

In this paper, we successfully demonstrated a high quality p-Si/n-GaN heterojunction diode through van der Waals bonding implemented by nanomembrane lift-off and transfer-print technique. A nanoscale native oxide layer is observed at the interface by transmission electron microscope, which plays a role as passivation-layer. The heterojunction diode has excellent electrical performance with a high rectification ratio of 4.75 × 105 at ± 3 V and a low reverse dark current density of 4.03 × 10–4 A cm−2 at −3 V. In addition, the heterojunction diode responds to both near ultraviolet (375.6 nm) and red light (650 nm) with responsivity of 429.9 mA W−1 and 66.8 mA W−1 (at −3 V) respectively. This result indicates that a large-lattice-mismatched semiconductor heterojunction can be fabricated based on GaN by using transfer-print technique, thereby expanding the operating

band of GaN-based detectors from ultraviolet region to visible region.

MOCVD Growth and Characterization of InN Quantum Dots

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physica status solidi b
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Metal-polar InN quantum dots (QDs) are grown by metalorganic chemical vapor deposition at temperatures between 500 and 600 °C. Dot densities between 4 × 108 and 4 × 1010 cm−2 are observed. InN QDs exhibit room-temperature photoluminescence (PL) with peak wavelengths from 1100 to >1550 nm. GaN cap layers grown on InN QDs have little effect on either peak PL wavelength or intensity, a step toward creating multilayer structures for InN QD devices.

The influence of an AlN seeding layer on nucleation of self-assembled GaN nanowires on silicon substrates

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Nanotechnology
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Gallium nitride (GaN)-based nanowires (NWs) have attracted much attention for the fabrication of novel nanostructured devices. In this paper, the influence of an AlN seeding layer on the nucleation of self-assembled GaN NWs grown by plasma-assisted molecular beam epitaxy (MBE) on Si (111) substrates has been investigated. Not only is the formation of a two-dimensional compact GaN layer at the bottom of the NWs suppressed, but also a high density of vertically aligned well-separated GaN NWs originating from GaN islands are successfully obtained after introducing annealing and nitridation processes. Scanning electronic microscope and transmission electron microscope measurements show that the NWs have a high crystalline wurtzite structure nearly free of dislocations and stacking faults and the NW diameter remains constant over almost the entire length. Due to the temperature-dependent diffusion length of Ga adatoms during the nucleation process, the formation of well-separated NWs relies on the distribution and morphology of the underlying AlN seeding layer. Moreover, the SiNx layer served as mask to inhibit coalescence at the nucleation sites. The developed growth processes and the obtained results provide a viable path facilitating the use of MBE growth techniques to fabricate III-nitride NW-based materials and related devices on Si substrates.

Surface polarity-induced spatial charge separation boosting photocatalytic overall water splitting on GaN nanorod arrays

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Photocatalytic overall water splitting has been recognized as a promising approach to convert solar energy into hydrogen. However, most of the photocatalysts suffer from low efficiencies mainly due to the poor charge separation property. Herein, taking a model semiconductor gallium nitride (GaN) as an example, we uncovered that photogenerated electrons and holes can be spatially separated to the nonpolar and polar surfaces of GaN nanorod arrays, which is presumably ascribed to the different surface band bending induced by the surface polarity. The photogenerated charge separation efficiency of GaN can be enhanced significantly from ~8% to more than 80% via co-exposing polar and nonpolar surfaces. Furthermore, spatially assembling of reduction and oxidation cocatalysts selectively on the nonpolar

and polar surfaces remarkably boosts photocatalytic overall water splitting, with the quantum efficiency increased from 0.9% for the film photocatalyst to 6.9% for the nanorod arrays photocatalyst.

Design of AlGaN/AlN Dot-in-a-wire Heterostructures for Electron-Pumped UV Emitters

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physica status solidi a
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This paper describes the fabrication of nitrogen-polar AlxGa1-xN/AlN (x = 0, 0.1) quantum dot superlattices integrated along GaN nanowires for application in electron-pumped UV sources. The nanowires are grown using plasma-assisted molecular-beam epitaxy on n-type Si(111) wafers using a low-temperature AlN nucleation layer. Growth conditions are tuned to obtain a high density of non-coalesced nanowires. To improve the uniformity of the height along the substrate, the growth begins with a base long nanowire (∽900 nm), with a diameter of 30-50 nm. The AlxGa1-xN/AlN active region is 400 nm long (88 periods of quantum dots), long enough to collect the electron-hole pairs generated by an electron beam with an acceleration voltage ≤5 kV. The spectral response is tuned in the 340 to 258 nm range by varying the dot/barrier thickness ratio and the Al content in the dots. Internal quantum efficiencies as high as 63% are demonstrated.

NON POLAR / SEMI POLAR

Information selected by Philippe de Mierry

In-plane optical polarization and dynamic properties of the near-band-edge emission of an m-plane freestanding AlN substrate and a homoepitaxial film

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Applied Physics Letters
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For accelerating the development of deep-ultraviolet light-emitting diodes based on high AlN mole fraction (x) AlxGa1-xN for sterilization, disinfection, and skin therapy applications, in-plane optical polarization and dynamic properties of the near-band edge (NBE) cathodoluminescence (CL) peak of a low threading dislocation density (<103 cm−2) m-plane freestanding AlN substrate and a homoepitaxial film are assessed. Consistent with the polarization selection rules, the electric field (E) component of the NBE emission was essentially polarized parallel to the c-axis (E∥c). Low-temperature CL spectra of the homoepitaxial film exhibited exciton fine structures: CL peaks at 6.0410 and 6.0279 eV, which were polarized E∥c and E perpendicular to the c-axis (E⊥c), respectively, are assigned as being due to the recombination of free A-excitons of irreducible representations Γ1 and Γ5. The hydrogenic binding energy of the Γ1 A-exciton being 51 meV is verified. Detectable CL peaks under E∥c polarization at 6.0315 and 6.0212 eV are tentatively assigned as Γ1-mixed Γ5-exciton-polaritons. The concentration of multiple vacancies consisting of an Al-vacancy (VAl) and N-vacancies (VNs), namely, VAl(VN)2−3, in the substrate was estimated by the positron annihilation measurement to be 2–3 × 1016 cm−3, while that in the epilayer was lower than the

detection limit (<1016 cm−3). The NBE CL lifetime of 28 ps of the epilayer subsurface at 300 K is likely limited by the recombination at carbon deep-acceptors on nitrogen sites (3 × 1017 cm−3) and/or VAl(VN)2−3 Shockley-Read-Hall nonradiative recombination centers (∼1 × 1016 cm−3) with hole capture coefficients of approximately 1×10−7 and 3×10−6 cm3 s−1, respectively.

Semi-Polar InGaN-Based Green Light-Emitting Diodes Grown on Silicon

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physica status solidi a
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High quality semi-polar (11-22) GaN has been obtained by means of growth on patterned (113) silicon substrates featured with stripy grooves and extra periodic gaps which are perpendicular to the grooves. Ga melting-back during the GaN growth at a high temperature has been eliminated as a result of our special patterning design. On-axis x-ray rocking curve measurements show the linewidth has been significantly reduced to down to 339 arcsec. Photoluminescence (PL) measurements at 10 K show strong GaN band-edge emission only, meaning that any basal stacking fault related emission has not been observed. Furthermore, green InGaN/GaN light emitting diodes (LEDs) with an emission wavelength of around 530 nm have been achieved on the semi-polar GaN grown on the patterned Si substrates. Excitation power dependent PL measurements do not show a shift in wavelength, meaning a significant reduction in polarization-induced piezoelectric fields. Electroluminescence measurements exhibit that the output power of the semi-polar LED increases linearly with increasing injection current. It is worth highlighting that the overgrowth technology on our designed patterned (113) silicon is a potential approach to manufacturing high performance semi-polar GaN emitters on Si substrates in a long wavelength region.

MATERIAL / CHARACTERIZATION / EQUIPMENT / NUMERICAL SIMULATION

Information selected by Agnès Trassoudaine (Université d'Auvergne), Yvon Cordier and Mathieu Leroux (CRHEA-CNRS)

Single-phase ε-Fe3N film on GaN grown by magnetron sputtering

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Materials Research Express
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Single-phase ε-Fe3N film has been fabricated on GaN substrate by magnetron sputtering. It is found that the thickness within the range of 50 nm~200 nm will be favorable to the formation of single-phase ε-Fe3N. The grain size and average surface roughness of the single-phase ε-Fe3N film are 35~85 nm and 7.45 nm respectively, while the magnetic and electrical properties are in agreement with the preceding experiments. This work will establish the solid foundation to the application of ε-Fe3N/GaN structure which is a promising system consisting of two materials that are both nitrides.

Period size effect induced crystalline quality improvement of AlN on a nano-patterned sapphire substrate

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Japanese Journal of Applied Physics
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A comprehensive strategy of crystal quality control for AlN grown on a nano-patterned sapphire substrate has been explored based on the period size effect. It is found that the crystalline perfection of AlN can be greatly improved by enlarging the period size from 1.0 to 1.4 μm, and the X-ray diffraction ω-scan FWHM values for (0002) and (10-

12) planes reach 162 and 181 arcsec, respectively, owning to the significantly reduced area ratio of the coalescence zone. Our results indicate the pattern design requires a critical balance between reducing the area ratio of the coalescence zone and decreasing the coalescence thickness.

Thick adherent diamond films on AlN with low thermal barrier resistance

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Growth of >100µm thick diamond layers adherent on aluminium nitride with low thermal boundary resistance between diamond and AlN is presented in this work. Thermal barrier resistance (TBReff) was found to be in the range of 16 m2K/GW which is a large improvement on the current state-of-the-art. While thick films failed to adhere on untreated AlN films, hydrogen/nitrogen plasma treated AlN films retained the thick diamond layers. Clear differences in zeta potential measurement confirms surface modification due to hydrogen/nitrogen plasma treatment. An increase in non-diamond carbon in the initial layers of diamond grown on pre-treated AlN is seen by Raman spectroscopy. The presence of non- diamond carbon has minimal effect on the thermal barrier resistance. The surfaces studied with x-ray photoelectron spectroscopy (XPS) revealed a clear distinction between pre-treated and untreated samples. The surface aluminium goes from nitrogen rich environment to an oxygen rich environment after pre-treatment. A clean interface between diamond and AlN is seen by cross sectional transmission electron microscopy.

Epitaxial GaN films with ultralow threading dislocation densities grown on an SiO2-masked patterned sapphire substrate

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Applied Physics Express
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This letter reports on epitaxial GaN layers with ultralow threading dislocation (TD) densities grown by metal organic chemical vapor deposition on SiO2-masked patterned sapphire substrates (SMPSSs). The patterning employs periodic micro-scale SiO2 cone-shaped features on thin sapphire pedestals surrounded by flat c-plane sapphire substrate surfaces. Cross-sectional transmission electron microscopy results demonstrate that GaN films grown on SMPSSs provide an ultralow TD density of 8.5 × 106 cm−2. A GaN LED structure grown on SMPSS-based GaN film provides an optical output power that is 130% greater than that obtained for an equivalent LED structure grown on a standard PSS-based GaN film.

Manipulated magnetic behaviors of c-oriented ε-Fe2~3N films on GaN

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Materials Research Express
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We synthesized c-oriented ε-Fe2~3N films on c-GaN by magnetron sputtering. The saturation magnetization and Curie temperature of ε-Fe2~3N films are decreased due to the reducing of Fe-Fe ferromagnetic exchange coupling with increasing N participation. The state transitions of magnetization

at low temperature are observed. The presented results on manipulable magnetic properties by Fe:N ratio show that ε-Fe2~3N/GaN structure provides an advanced platform both for studying basic properties of ε-Fe2~3N and for the design of spintronics devices.

Study on the charging current of surface traps in AlGaN/GaN high electron mobility transistors with a slot gate structure

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Applied Physics Letters
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The charging current of surface traps in AlGaN/GaN high electron mobility transistors with a slot gate structure was investigated. A slot was formed in the middle of the gate metal via the lift-off process. Even though the slot gate only partially controlled the channel, the transient drain current gradually decreased toward a saturated off-state value with increasing measurement time after application of an off-state gate voltage. This indicated that the slot gate was still capable of turning off the entire channel. Analysis of the experimental results indicated that electrons were injected from the gate and trapped in the slot region, resulting in the depletion of the slot channel. An equivalent charging current by the surface traps on AlGaN could be inferred via the charge conservation principle. Temperature-dependent measurements of the charging current showed that it could be well fitted by the Poole-Frenkel conduction mechanism, with an extracted trap energy level of 0.129 eV.

In situ and selective area etching of GaN by tertiarybutylchloride (TBCl)

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Applied Physics Letters
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In situ etching (ISE) of gallium nitride (GaN) can enable lateral and vertical junctions through selective area etching (SAE) and regrowth. We report the study of ISE and SAE of GaN using an organometallic precursor, tertiarybutylchloride (TBCl), in a metal-organic chemical vapor deposition reactor. Compared to the conventional etching in hydrogen, the use of TBCl allows in situ etching at a much lower temperature (<850 °C), likely due to a more reactive etchant and a more efficient desorption rate of the etching products. The TBCl etching is near equilibrium and can be significantly changed with the change of the NH3 flow rate. We also report initial results of SAE on SiO2 patterned GaN samples. An important finding is the need to control the desorption of the reaction products in order to achieve smooth surfaces. TBCl etching is crystallographically anisotropic with low etch rates on N-terminated facets. The use of TBCl and possibly other organometallic halogen precursors is expected to enable the design and implementation of III-nitride lateral junction devices that have not been possible.

Reduced dislocation density and residual tension in AlN grown on SiC by metalorganic chemical vapor deposition

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Applied Physics Letters
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Crack-free AlN films with threading dislocation density (TDD) below 109 cm−2 are needed for deep-UV optoelectronics. This is typically achieved using pulsed lateral overgrowth or very thick buffer layers (>10 μm), a costly and time-consuming approach. A method for conventional metalorganic chemical vapor deposition growth of AlN/SiC films below 3 μm with greatly improved quality is presented. Focusing on substrate pretreatment before growth, we reduce average film stress from 0.9 GPa (tension) to −1.1 GPa (compression) and eliminate cracking. Next, with optimized growth conditions during initial deposition, AlN films with x-ray rocking curve widths of 123 arc-sec (0002) and 304 arc-sec (202—1) are developed, and TDD is confirmed via plan view transmission electron microscopy (TEM) to be 2 × 108 cm−2. Film stress

measurements including x-ray 2θ-ω, reciprocal space mapping, and curvature depict compressively stressed growth of AlN on 4H-SiC due to lattice mismatch. The thermal expansion coefficient mismatch between AlN and SiC is measured to be Δα=αAlN−αSiC=1.13×10−6 °C−1 and is found to be constant between room temperature and 1400 °C. TEM confirms the existence of dense misfit dislocation (MD) networks consistent with MD formation near SiC step edges and low MD density regions attributed to nearly coherent AlN growth on SiC terraces. These low-TDD, crack-free AlN/SiC buffers provide a platform for deep-UV optoelectronics and ultrawide bandgap electronics.

Planar anisotropic Shubnikov-de-Haas oscillations of two-dimensional electron gas in AlN/GaN heterostructure

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Two-dimensional electron gas (2DEG) buried in ultrathin barrier AlN/GaN heterostructures is the key to exploit high-speed and high-power devices in the aspect of modern semiconductor electronics. Here, we report Shubnikov-de-Haas oscillations of the 2DEG in an AlN/GaN heterostructure with planar anisotropy along [11-20] and [1-100] axes. The effective mass extracted from oscillations exhibits an evident disparity, as (0.19 ± 0.02)me along the [11-20] axis and (0.24 ± 0.02)me along the [1-100] axis. Meanwhile, the quantum scattering time is obviously different along the aforementioned directions, with 0.08 vs 0.26 ps for the first subband and 0.19 vs 0.27 ps for the second subband. Both the effective mass and the quantum scattering time contribute to the anisotropy of the quantum mobility, which are 750 and 1907 cm2/V s for E1 and 1760 and 1980 cm2/V s for E2 along [11-20] and [1-100] axes, respectively. These parameters are obviously crucial in designing devices using AlN/GaN heterostructures.

Recovery process for trimethyl-indium (TMIn) precursor used in compound semiconductors such as InGaN

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TMIn is used as a metal organic precursor for MOCVD to grow InGaN or InN, which form the basis of solar cells or green LEDs. However, TMIn has a residual amount of about 10% in a used TMIn canister. This study aims to recover the residual amount of TMIn and to re-use it as a precursor after purification. Analysis of the inorganic impurities after refining TMIn shows that the total impurity is lower than 530 µg/L by ICP-AES. In the FT-NMR of detective organic chemical bonding of “(CH3)3In” peak is observed with no defective organic structure of bonding. In addition, InGaN MQW was deposited using refined TMIn and characterization was carried out. The structural and optical properties of the MQW analyzed by XRD and TEM were very similar to the reference MQW.

Investigation of nitrogen polar p-type doped GaN/AlxGa(1-x)N superlattices for applications in wide-bandgap p-type field effect transistors

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Applied Physics Letters
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In this study, the metal-organic chemical vapor deposition growth and electrical properties of N-polar modulation doped p-AlGaN/GaN superlattices (SLs) were investigated. Hole sheet charge density and mobility were studied as a function of the concentration of the p-type dopant Mg in the SL and the number of SL periods. Room temperature Hall measurements were carried out to determine

the hole mobility and the sheet charge density. While the hole density increased with the increasing number of SL periods, the hole mobility was largely unaffected. Hole mobilities as high as 18 cm2/V s at a simultaneously high hole density of 6.5 × 1013 cm−2 were observed for N-polar SLs with a Mg modulation doping of 7.5 × 1018 cm−3. For comparable uniformly doped Ga-polar SL samples, a mobility of 11 cm2/V s was measured. These results confirm the presence of abrupt Mg doping profiles in N-polar p-type GaN/AlxGa(1−x)N SL, allowing the demonstration of SLs with properties comparable to those of state-of-the-art Ga-polar modulation doped AlGaN/GaN SLs grown using molecular beam epitaxy. The lowest sheet resistance in the GaN/AlGaN material system of 5 kΩ/□ is also reported. Test-structure transistors were also fabricated to investigate the applicability of these SL structures, with the planar device resulting in a current of 5 mA/mm and a FinFET structure resulting in a current of over 100 mA/mm.

Electrical properties and interface abruptness of AlSiO gate dielectric grown on (000-1) N-polar and (0001) Ga-polar GaN

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Applied Physics Letters
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The electrical properties and the interface abruptness of aluminum silicon oxide (AlSiO) dielectric grown in situ on (0001—) N-polar and (0001) Ga-polar GaN by metal organic chemical vapor deposition were studied by means of capacitance-voltage (CV) and atom probe tomography (APT) measurements. The growth of AlSiO on N-polar GaN resulted in a positive flatband voltage shift of 2.27 V with respect to that on Ga-polar GaN, which exemplifies the influence of the GaN surface polarization charge on the electrical properties of GaN-based metal oxide semiconductor (MOS) devices. The AlSiO/GaN(N-polar) interface was sharp, which resulted in nondispersive CV characteristics and a relatively low density of interface states (Dit) of 1.48 × 1012 cm−2. An intermixed layer of AlGaSiO was present at the interface between AlSiO and Ga-polar GaN, which contributed to the measured dispersive CV characteristics and resulted in an ∼2× higher Dit than that on N-polar GaN. The superior properties of the N-polar AlSiO MOS devices are promising for further advancement of N-polar GaN-based high electron mobility transistors for high-frequency and power electronics applications.

Boosting the doping efficiency of Mg in p-GaN grown on the free-standing GaN substrates

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Applied Physics Letters
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The Mg doping efficiency is found to be drastically enhanced in the p-GaN films grown on the free-standing GaN substrates by metal organic chemical vapor deposition. The free hole concentrations are five and ten times higher in the lightly and heavily Mg-doped homoepitaxial p-GaN, respectively, than those in the p-GaN-on-GaN/sapphires grown and activated at the same conditions although the Mg incorporation concentrations {[Mg]} are much lower. The indication of the p-type conductivity in the photoluminescence spectra at room temperature in p-GaN-on-GaN substrates is found to be the dominant ultraviolet luminescence band located at around 3.26 eV. This behavior is different in the heteroepitaxial p-GaN, for which the fingerprint of the p-type conductivity is the emergence of blue luminescence bands at around 2.9 eV. The markedly enhanced activation efficiency

is attributed to the suppression of self-compensation centers in the high-quality homoepitaxial films. The Mg-Ga-O disordered layer, which is typically observed on the surface of p-GaN-on-GaN/sapphires due to the Mg diffusion along edge-type dislocations, is also inhibited on the homoepitaxial p-GaN film, which is beneficial for the stable operation of the vertical-type metal-oxide-semiconductor field effect transistors.

Growth of InGaN films on hardness-controlled bulk GaN substrates

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We carried out an evaluation of the crystalline quality of bulk GaN substrates and the properties of InGaN films grown on them. The Urbach energy estimated by photothermal deflection spectroscopy and the tail states near the valence band maximum determined by hard x-ray photoemission spectroscopy were larger for hardness-controlled bulk GaN (hard GaN) than those for conventional bulk GaN (conventional GaN). However, InGaN on hard GaN grows in a step-flow-like mode, while InGaN grown on conventional GaN exhibits spiral-like growth. The photoluminescence decay at room temperature for InGaN grown on the hard GaN was 470 ps, compared with 50 ps for that grown on the conventional GaN. This can be attributed to the suppression of spiral-like growth due to the resistance to deformation of the hard GaN. These results indicate that substrate hardness is one of the most important factors for III–V nitride growth on the bulk GaN substrate.

Molecular beam epitaxial growth of scandium nitride on hexagonal SiC, GaN, and AlN

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RF plasma assisted MBE growth of scandium nitride (ScN) thin films on Ga-polar GaN (0001)/SiC, Al-polar AlN (0001)/Al2O3, and Si-face 6H-SiC (0001) hexagonal substrates is found to lead to a face centered cubic (rock salt) crystal structure with (111) out-of-plane orientation instead of hexagonal orientation. Cubic (111) twinned patterns in ScN are observed by in situ electron diffraction during epitaxy, and the twin domains in ScN are detected by electron backscattered diffraction and further corroborated by X-ray diffraction. The epitaxial ScN films display very smooth, subnanometer surface roughness at a growth temperature of 750 °C. Temperature-dependent Hall-effect measurements indicate a constant high n-type carrier concentration of ∼1 × 1020/cm3 and an electron mobility of ∼20 cm2/V s.

Thermal conductivity of ultra-wide bandgap thin layers – High Al-content AlGaN and β-Ga2O3

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Transient thermoreflectance (TTR) technique is employed to study the thermal conductivity of β-Ga2O3 and high Al-content AlxGa1-xN

semiconductors, which are very promising materials for high-power device applications. The experimental data are analyzed with the Callaway's model taking into account all relevant phonon scattering processes. Our results show that out-of-plane thermal conductivity of high Al-content AlxGa1-xN and (−201) β-Ga2O3 is of the same order of magnitude and approximately one order lower than that of GaN or AlN. The low thermal conductivity is attributed to the dominant phonon-alloy scattering in AlxGa1-xN and to the strong Umklapp phonon-phonon scattering in β-Ga2O3. It is also found that the phonon-boundary scattering is essential in thin β-Ga2O3 and AlxGa1-xN layers even at high temperatures and the thermal conductivity strongly deviates from the common 1/T temperature dependence.

Pervasive Shallow Donor Impurities in GaN

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Understanding the nature of defects and their role on fundamental physical properties of semiconductors is essential to obtain the necessary material control to reach the full realization of their technological potential. High-resolution infrared measurements in combination with high-sensitive SIMS of unintentionally doped GaN films unambiguously identified Si and O shallow donors and yielded their ground state binding energies. High-resolution, variable-temperature photoluminescence studies of recombination processes associated with excitons bound to donors leaving the donors in the ground states and excited states after exciton annihilation are in excellent agreement with the energies of donor intra-impurity transitions measured by infrared absorption. Photoluminescence studies of unintentionally doped and doped GaN films clarified conflicting aspects of donor identification and binding energies of shallow pervasive Si and O donors. These results provided the experimental foundation for the detection and identification of pervasive shallow donors in GaN by optical methods.

Surface reverse etching analysis of (Al)GaN-capped AlGaNGaN high electron mobility transistors

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Journal of Crystal Growth
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AlGaN/GaN-based high electron mobility transistor heterojunction with different thickness (Al)GaN cap layers were grown by metalorganic vapor phase epitaxy (MOVPE). The thickness of the cap layers was examined by x-ray photoelectron spectroscopy. It could be seen that the actual thickness of the GaN cap layer was about 1 nm thinner than the theoretical thickness, and however the results of the Al0.04Ga0.96N cap layer was basically the same. The surface quality was tested by atomic force microscopy and the strain properties of the cap layer were characterized by photoluminescence.

Electrochemical etching of AlGaN for the realization of thin-film devices

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Applied Physics Letters
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Heterogeneously integrated AlGaN epitaxial layers will be essential for future optical and electrical devices like thin-film flip-chip ultraviolet (UV) light-emitting diodes, UV vertical-cavity surface-emitting lasers, and high-electron mobility transistors on efficient heat sinks. Such AlGaN-membranes will also enable flexible and micromechanical devices. However, to develop a method to separate the AlGaN-device membranes from the substrate has proven to be challenging, in particular, for high-quality device materials, which require the use of a lattice-matched AlGaN sacrificial layer. We

demonstrate an electrochemical etching method by which it is possible to achieve complete lateral etching of an AlGaN sacrificial layer with up to 50% Al-content. The influence of etching voltage and the Al-content of the sacrificial layer on the etching process is investigated. The etched N-polar surface shows the same macroscopic topography as that of the as-grown epitaxial structure, and the root-mean square roughness is 3.5 nm for 1 µm×1 µm scan areas. Separated device layers have a well-defined thickness and smooth etched surfaces. Transferred multi-quantum-well structures were fabricated and investigated by time-resolved photoluminescence measurements. The quantum wells showed no sign of degradation caused by the thin-film process.

Verification of threading dislocations density estimation methods suitable for efficient structural characterization of AlxGa1−xN/GaN heterostructures grown by MOVPE

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Selection of a suitable chemical etching method for threading dislocations density estimation is crucial for the structural characterization of epilayers grown by MOVPE and thus further for device fabrication. In this work, threading dislocations density in single layer and AlxGa1−xN/GaN periodical heterostructures has been investigated by means of chemical etching and XRD analysis. For chemical etching, two types of agents have been used: phosphoric acid (220∘C/7.5min) and a molten mixture of KOH-NaOH (440∘C/2.5min). Estimation of dislocation density has been carried out on the basis of SEM images. It was shown that defect-selective etching in molten alkaline solution is more effective than etching in phosphoric acid and provides more accurate data that are in agreement with data obtained from XRD characterization.

Influence of the free-electron concentration on the optical properties of zincblende GaN up to 1×1020cm−3

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We analyze the optical properties of zincblende gallium-nitride in the infrared and ultraviolet spectral range (≈27meV–6.5eV) experimentally by spectroscopic ellipsometry and provide a quantitative description of these results by k·p perturbation theory. Free-electron concentrations above 1020cm−3 are achieved by introducing germanium as a donor. We determine the dielectric function as well as band filling effects like the Burstein-Moss shift and band gap renormalization. The Kane model for the band structure of semiconductors near the Γ-point allows to calculate the effective electron mass and to determine the nonparabolicity of the conduction band. At the same time, these results can be used to derive the free-electron concentration all-optically. The combination of Kane's model, Burstein-Moss shift, and band-gap renormalization can be used to expertly describe the measured transition energies up to ≈3.7eV dependent on the carrier concentration, yielding an averaged hole mass of ≈0.61me for the contributing valence bands.

Thermodynamic model for metalorganic vapor-phase epitaxy of N-polar group-III nitrides in step-flow growth mode: Hydrogen, competitive adsorption, and configuration entropy

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PHYSICAL REVIEW MATERIALS
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A thermodynamic model for metalorganic vapor-phase epitaxy (MOVPE) of the N-polar (000¯1) binary group-III nitrides (AlN, GaN, and InN) in the step-flow growth mode is proposed based on the Burton, Cabrera, and Frank (BCF) theory. The coverages of the group-III adatoms are thermodynamically evaluated under competitive adsorption with hydrogen, which is used as a carrier gas or dissociated from the NH3 source gas during MOVPE. The chemical potentials of the group-III and H adatoms on N-polar group-III nitride surfaces are modeled using the respective bond energies with the surface N atoms of the nitride and the vibrational frequencies of the adatoms. The coverages of the coadsorbed group-III and H adatoms are calculated using the Langmuir adsorption isotherm with these chemical potentials. The configuration entropy of the group-III adatoms bridges the gap between the thermodynamic model and the BCF theory. The coverage of the group-III adatoms plays a role like partial pressure of the group-III gas in the thermodynamics. The equilibrium coverage of the group-III adatoms and the equilibrium pressure of the NH3 gas are evaluated from the conditions of Gibbs energy balance between the sources (group-III adatom and NH3 gas molecule) and products (group-III nitride and 3/2H2 gas molecules) and of speed balance between group-III and N incorporation into step kinks. Fair agreements with the experimentally optimized growth conditions for MOVPE of N-polar GaN and InN are obtained by this method. Among the examined binary group-III nitrides, AlN growth is hardly affected by H2 gas pressure, GaN growth is controlled well by H2 gas pressure, and InN growth is strongly inhibited by H2 gas. A criterion for selecting the NH3/group-III flow ratio for maximum products/cost and minimum waste of the materials is demonstrated using the growth model and the estimated growth parameters. The offcut angle dependence of the growth rate on the vicinal substrates is also investigated.

Fabrication of Pyramid Structure Substrate Utilized for Epitaxial Growth Free-Standing GaN

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Crystals
https://doi.org/10.3390/cryst9110547

Metal–organic chemical vapor deposition (MOCVD)-grown GaN on sapphire substrate was etched by hot phosphoric acids. Pyramid structures were obtained in the N-polar face of the MOCVD–GaN. Details of the formation process and morphology of the structures were discussed. The crystallographic plane index of the pyramid facet was calculated dependent on the symmetry of the wurtzite crystal structure and the tilt angle. The substrates with pyramid structures were utilized in subsequent hydride vapor phase epitaxy (HVPE) growth of GaN. Free-standing crystals were obtained, while HVPE-grown GaN achieved a certain thickness. Raman spectroscopy was employed to obtain the stress conditions of the HVPE–GaN without and with sapphire substrate. The mechanism of the self-separation process was discussed. This facile wet etching method may provide a simple way to acquire free-standing GaN by HVPE growth.

Influence of Showerhead–Sample Distance (GAP) in MOVPE Close Coupled Showerhead Reactor on GaN Growth

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Materials
https://doi.org/10.3390/ma12203375

The distance between the showerhead and the sample surface (GAP) is one of the main growth parameters of the commonly used research reactor, Close Coupled Showerhead. We examine its

influence on the growth rate of GaN layers deposited under various conditions (growth temperature, carrier gas, V/III ratio and growth pressure). Regardless of other growth parameters, increasing the GAP value leads to a reduction in the growth rate.

Epitaxy of Single-Crystalline GaN Film on CMOS-Compatible Si(100) Substrate Buffered by Graphene

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Advanced Functional Materials
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Fabricating single-crystalline gallium nitride (GaN)-based devices on a Si(100) substrate, which is compatible with the mainstream complementary metal-oxide-semiconductor circuits, is a prerequisite for next-generation high-performance electronics and optoelectronics. However, the direct epitaxy of single-crystalline GaN on a Si(100) substrate remains challenging due to the asymmetric surface domains of Si(100), which can lead to polycrystalline GaN with a two-domain structure. Here, by utilizing single-crystalline graphene as a buffer layer, the epitaxy of a single-crystalline GaN film on a Si(100) substrate is demonstrated. The in situ treatment of graphene with NH3 can generate sp3 C□N bonds, which then triggers the nucleation of nitrides. The one-atom-thick single-crystalline graphene provides an in-plane driving force to align all GaN domains to form a single crystal. The nucleation mechanisms and domain evolutions are further clarified by surface science exploration and first-principle calculations. This work lays the foundation for the integration of GaN-based devices into Si-based integrated circuits and also broadens the choice for the epitaxy of nitrides on unconventional amorphous or flexible substrates.

Photoluminescence Line Shape Analysis of Highly n-Type Doped Zincblende GaN

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We present an investigation of different n-type doped zincblende Galliumnitride thin films measured by photoluminescence from 7 K to room temperature. The spectra change with increasing free carrier concentration due to many-body effects like Burstein-Moss shift and band gap renormalization. The samples were grown by molecular beam epitaxy on a 3C-SiC/Si (001) substrate and a free carrier concentration above 1020 cm−3 was achieved by introducing germanium as a donor. The analysis of the measured spectra by a line shape fit yields different transition processes for different doping concentrations and temperatures, such as a band-band transition and a band-acceptor transition. The conduction band dispersion of Kane's model is perfectly suited to explain the experimental data quantitatively.

Aluminium incorporation in polar, semi- and non-polar AlGaN layers: a comparative study of x-ray diffraction and optical properties

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Scientific Reports
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Growth of AlxGa1−xN layers ($0 \le x \le 1$) simultaneously on polar (0001), semipolar ($10\bar{1}3$) and ($11\bar{2}2$), as well as nonpolar ($10\bar{1}0$) and ($11\bar{2}0$) AlN templates, which were grown on planar sapphire substrates, has been investigated by metal-organic vapour phase epitaxy. By taking into account anisotropic in-plane strain of semi- and non-polar layers, their aluminium incorporation has

been determined by x-ray diffraction analysis. Optical emission energy of the layers was obtained from room-temperature photoluminescence spectra, and their effective bandgap energy was estimated from room-temperature pseudo-dielectric functions. Both x-ray diffraction and optical data consistently show that aluminium incorporation is comparable on the polar, semi- and non-polar planes.

Temperature-Dependent Polarized Photoluminescence from c-plane InGaN/GaN Multiple Quantum Wells Grown on Stripe-Shaped Cavity-Engineered Sapphire Substrate

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Temperature-dependent polarized photoluminescence from anisotropically strained c-plane InGaN/GaN multiple quantum wells on stripe-shaped cavity-engineered sapphire substrate is theoretically and experimentally investigated. Polarization ratios decrease from 0.98 to 0.74, and emission peak shifts increase from 0 to 50.9 meV with increasing temperature from 10 to 300 K, respectively. Theoretical calculations based on k·p perturbation theory reveal that the temperature dependence of polarized optical behaviors is attributed to the modified valence band structures and hole distributions in each subband. Theoretical results are in good agreement with the experimental results over temperature range from 10 to 300 K, providing in-depth understanding for the strain-induced valence band modification of III-nitride semiconductors.

Van der Waals Epitaxy of III-Nitride Semiconductors Based on 2D Materials for Flexible Applications

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Advanced Materials
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III-nitride semiconductors have attracted considerable attention in recent years owing to their excellent physical properties and wide applications in solid-state lighting, flat-panel displays, and solar energy and power electronics. Generally, GaN-based devices are heteroepitaxially grown on c-plane sapphire, Si (111), or 6H-SiC substrates. However, it is very difficult to release the GaN-based films from such single-crystalline substrates and transfer them onto other foreign substrates. Consequently, it is difficult to meet the ever-increasing demand for wearable and foldable applications. On the other hand, sp2-bonded two-dimensional (2D) materials, which exhibit hexagonal in-plane lattice arrangements and weakly bonded layers, can be transferred onto flexible substrates with ease. Hence, flexible III-nitride devices can be implemented through such 2D release layers. In this progress report, the recent advances in the different strategies for the growth of III-nitrides based on 2D materials are reviewed, with a focus on van der Waals epitaxy and transfer printing. Various attempts are presented and discussed herein, including the different kinds of 2D materials (graphene, hexagonal boron nitride, and transition metal dichalcogenides) used as release layers. Finally, current challenges and future perspectives regarding the development of flexible III-nitride devices are discussed.

Metalorganic Chemical Vapor Deposition of over 150-nm-Thick Quaternary AlGaInN Epitaxial Films near Alloy Composition Lattice-Matching to GaN on Sapphire and Their Structural and Optical Characterization

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physica status solidi a
https://doi.org/10.1002/pssa.201900597

Quaternary AlGaInN films with thickness greater than 150 nm are grown on c-plane GaN-on-sapphire templates by metalorganic chemical vapor deposition (MOCVD). The AlxGayInzN films near alloy composition lattice-matching to GaN on sapphire ($0.532 \le x \le 0.716$, $0.146 \le y \le 0.366$, and $0.092 \le z \le 0.182$) are confirmed to be epitaxially grown, and they show relatively flat surfaces regardless of their lattice strain and their direction. The crystal mosaicity in the AlGaInN films is observed to take over that of the underlying GaN films. The refractive index of AlGaInN films ranges from ≈2.4 to 2.3 in the whole visible wavelengths, largely independent of their alloy compositions. Spectroscopic ellipsometry and photoluminescence analyses indicate that the MOCVD-grown AlGaInN films have a certain degree of compositional fluctuation affecting their optical band edges.

Growth and Properties of Intentionally Carbon-Doped GaN Layers

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Crystal Research and Technology
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Carbon-doping of GaN layers with thickness in the mm-range is performed by hydride vapor phase epitaxy. Characterization by optical and electrical measurements reveals semi-insulating behavior with a maximum of specific resistivity of 2 × 1010 Ω cm at room temperature found for a carbon concentration of 8.8 × 1018 cm−3. For higher carbon levels up to 3.5 × 1019 cm−3, a slight increase of the conductivity is observed and related to self-compensation and passivation of the acceptor. The acceptor can be identified as CN with an electrical activation energy of 0.94 eV and partial passivation by interstitial hydrogen. In addition, two differently oriented tri-carbon defects, CN-a-CGa-a-CN and CN-a-CGa-c-CN, are identified which probably compensate about two-thirds of the carbon which is incorporated in excess of 2 × 1018 cm−3.

PRESS RELEASE

Technical and economic information selected by Knowmade

ELECTRONICS

High-frequency indium aluminium nitride barrier transistors on silicon

SemiconductorToday

University of Delaware in the USA claims a record for radio frequency (RF) performance of indium aluminium nitride (InAlN)-barrier gallium nitride (GaN) high-electron-mobility transistors (HEMTs) on silicon [Peng Cui et al, Appl. Phys. Express, vol12, p104001, 2019]. The device also demonstrates records for direct current (DC) characteristics such as low gate leakage, high on/off current ratio, and subthreshold swing, according to the researchers.

Usually for high performance, GaN HEMTs are produced on very expensive silicon carbide (SiC) substrates. Growth on low-cost, large-diameter silicon should open up more economic opportunities for high-power and high-frequency GaN-based devices.

Metal-organic chemical vapor deposition (MOCVD) on (111) resulted in an epitaxial structure with a 2µm undoped GaN buffer, a 4nm In0.12Ga0.88N back-barrier, a 15nm GaN channel, a 1nm AlN interlayer, an 8nm lattice-matched In0.17Al0.83N barrier, and a 2nm GaN cap. Hall measurements gave sheet electron concentration and electron mobility values in the two-dimensional electron gas (2DEG) channel of 2.28x1013/cm2 and 1205cm2/V-s, respectively.

Device fabrication included plasma reactive-ion etch of isolation mesas, and alloying of titanium/aluminium/nickel/gold ohmic source-drain contacts at 850°C. The source-drain distance was 2µm. The researchers used an oxygen plasma treatment to oxidize the surface between the source and drain with the aim of reducing gate leakage current (Ig) and improve RF performance. The 80nm-long nickel/gold gate was centered in the source-drain gap.

The oxygen plasma treatment increased the on/off current ratio (Ion/Ioff) by a factor of around two to reach 1.58x106. Another benefit was a reduction in subthreshold swing (SS) from 76mV/decade to 65mV/decade.

The team comments: “To the best of our knowledge, these DC measurement results all show record values among those reported InAlN/GaN HEMTs on silicon to-date (Ig of 7x10-6A/mm, Ioff of 7x10-6A/mm, Ion/Ioff ratio of 1.78x105, and SS of 82mV/decade are the best values that have been reported in InAlN/GaN HEMTs).”

The researchers admit that better values have been obtained for Ig and Ioff with 20nm aluminium gallium nitride (AlGaN) barrier HEMTs on silicon – of order 10-12A/mm for both. The resulting Ion/Ioff was 2.5x1011.

However, one benefit of the thinner InAlN-based barrier was better electrostatic control of current flow in the channel, reducing short-channel effects (SCEs). The InGaN back barrier reduces losses from current leaking into the buffer layer and improves confinement of charge carriers to the GaN-channel region.

The peak transconductance of the InAlN-HEMT was 391mS/mm with 10V drain bias, beating a 75nm-gate 11.4nm-barrrier AlGaN-HEMT's 374mS/mm that has been reported. An 80nm-gate AlN-HEMT on silicon has been presented with 580mS/mm peak transconductance, enabled by a very thin 6nm barrier.

The 1.26A/mm maximum drain current of the team's InAlN-HEMT has also been bettered by a similar device on silicon with a very small 300nm source-drain gap (2.66A/mm). The wider 2µm gap of the team's HEMT naturally increased the on-resistance. One would expect, although the paper does not report on this, that the wider gap would lead to a higher breakdown voltage performance.

RF measurements were made in the 1-65GHz range (Figure 1). With parasitic elements accounted for ("de-embedded"), the current gain cut-off (fT) was extracted as 200GHz, using a -20dB/decade extrapolation. The drain bias was 10V and the gate potential was set at -3V. The maximum oscillation/power gain (fmax) was 33GHz, suffering due to losses from the high resistance of the rectangular gate.

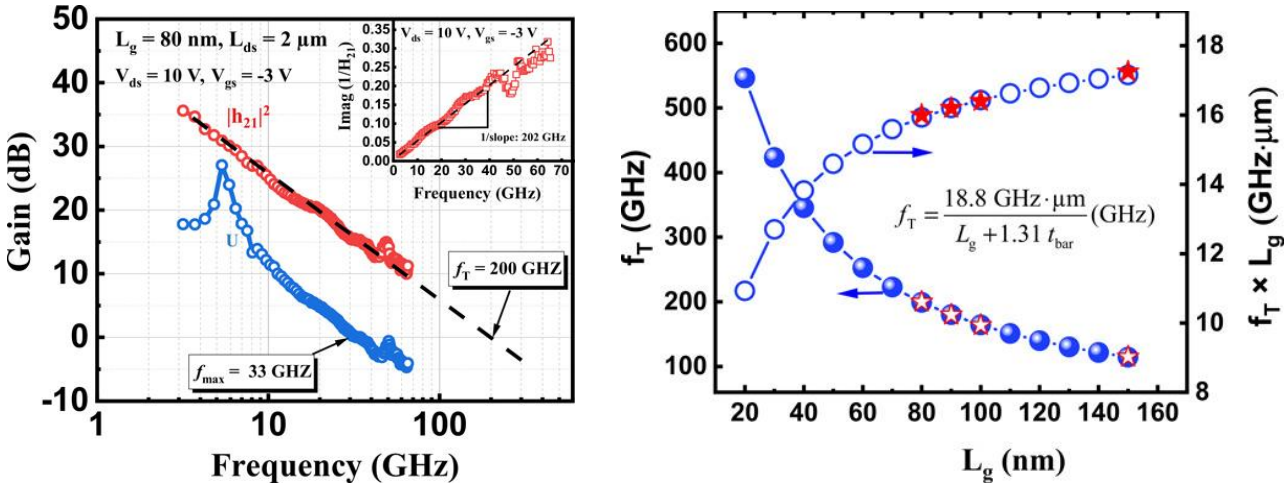


Figure: (left) RF performance of 80nm-gate-length InAlN/GaN HEMTs with 200/33GHz fT/fmax. Inset: Gummel's method showing 202GHz fT estimate. (right) Predicted fT and fTxLg as a function of Lg - stars represent experimental results.

The cut-off-gate-length product (fTxLg) was 16GHz-µm. The researchers compare this with best result obtained on SiC – 17.8GHz-µm from 162GHz fT and 110nm Lg. The team comments: "To the best of our knowledge, the fTxLg in our study achieves the highest value among all reported GaN HEMTs on silicon, and set a new record among GaN HEMTs on SiC/Si with Lg ⩽ 100nm."

Using an empirical model that relates fT to Lg, barrier thickness, the effective electron velocity and one fitting parameter, the researchers project that an fT of 546GHz could be achieved with 20nm Lg, giving a fTxLg value of 10.9GHz-µm (Figure 2).

EPC expands AEC Q101 product family with automotive qualification of EPC2216 15V eGaN FET for ToF LiDAR

SemiconductorToday

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – has announced AEC Q101 automotive qualification of the 15V EPC2216 designed for light detection and ranging (LiDAR) applications where increased accuracy is vital such as in self-driving cars and other time-of-flight (ToF) applications including facial recognition, warehouse automation, drones and mapping.

As an 15V, 26mΩ eGaN FET with a 28A pulsed current rating in a 1.02mm2 footprint, the EPC2216 is suitable use in for firing the lasers in LiDAR systems because the FET can be triggered to create high-current with extremely short pulse widths. The short pulse width leads to higher resolution, and the small size and low cost make eGaN FETs suitable for ToF applications from automotive to industrial, healthcare to smart advertising, gaming and security.

To complete AEC Q101 testing, EPC's eGaN FETs underwent environmental and bias-stress testingncluding humidity testing with bias (H3TRB), high-temperature reverse bias (HTRB), high-temperature gate bias (HTGB), temperature cycling (TC), as well as several other tests.

EPC says that its wafer-level chip-scale (WLCS) packaging passed all the same testing standards created for conventional packaged parts, demonstrating that the performance of chip-scale packaging does not compromise ruggedness or reliability. The eGaN devices are produced in facilities certified to the Automotive Quality Management System standard IATF 16949.

"This new automotive product joins a rapidly expanding family of EPC transistors and integrated circuits designed to enable autonomous driving and improve resolution and reduce cost in all time-of-flight applications," says CEO & co-founder Alex Lidow.

The EPC2216 eGaN FET is priced at 2.5Ku/reel at $0.532 each and is available from distributor Digi-Key Corp.

Navitas' GaNFast power ICs enable 300W adapter in NVIDIA's ACE reference design for world's fastest laptop

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA says that its power technology is enabling the highest-density power adapter for the world's fastest laptop – the Asus ProArt StudioBook One. An NVIDIA RTX Studio system, the ProArt One is the first laptop to feature the NVIDIA Quadro RTX 6000 GPU and is based on NVIDIA's ACE reference architecture.

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

Developed in collaboration with NVIDIA, the new 300W AC-DC adapter design exploits the high-speed power-conversion technology of Navitas' GaNFast power ICs to create a powerful yet lightweight and small-size mobile charger.

"Creatives and other professionals demand the highest computing performance with extreme mobility," says Navitas' CEO Gene Sheridan. "Navitas' dedicated technologists worked alongside the NVIDIA engineering design team to address this challenge as part of the NVIDIA ACE reference design, delivering a 300W laptop adapter in half the size of traditional adapters," he adds.

"The high-speed performance of the Navitas GaNFast power ICs is a perfect match for the high-speed NVIDIA Quadro RTX 6000 GPU in the ProArt StudioBook One," comments NVIDIA's director of engineering Gabriele Gorla. The result is a laptop with 16.3 TFLOPs of compute performance powered by a mobile adapter that fits in the palm of your hand.

The power adapter uses highly integrated, speed-optimized, next-generation GaN technology that replaces traditional, slow discrete silicon components, and enables the adapter to utilize high-frequency, soft-switching techniques in both power factor correction (PFC) and downstream DC-DC stages. High-frequency, high-efficiency switching shrinks the size, weight and cost of passive components and heatsinks. Navitas says that its GaNFast power ICs enable a new generation of fast-charging mobile adapters for smartphones, tablets and laptops from 27W to 300W+.

Empower launches 2kW L-band GaN-on-SiC solid-state amplifier for GPS denial

SemiconductorToday

Empower RF Systems Inc of Inglewood, CA and Holbrook, NY, USA (which produces RF and microwave power amplifiers for defense, commercial and industrial applications) says that its new model 2226 is a compact high-power gallium nitide (GaN) L-band solid-state continuous-wave (CW) emitter, producing a minimum of 2kW across the entire 900-1600MHz band, designed for GPS denial based on the established and field-proven next-generation system architecture. This architecture is tactically deployed and operating on multiple levels in support of a variety of critical US Department of Defense (DOD) missions.

Equally suited for jamming, threat simulation, multipaction, HIRF (high-intensity radiated field) and automotive EMC applications, the 2226 comes complete with internal DDC (direct digital controller), external forward and reverse sample ports, and an easy-to-use web-served graphical user interface (GUI). In-depth health monitoring with alarms visible on the front panel are also pushed out the LAN port. Output modes include manual gain control (MGC), automatic gain control (AGC) and automatic level control (ALC), which provide useful flexibility when integrating into various applications.

The 2226 is designed with the latest 50V GaN-on-SiC device technology, which lowers transistor count and reduces combining losses while increasing efficiency and reliability.

In addition to the standard array of user-configurable, multi-mission mode settings, the amplifier offers user-selectable 'Graceful Output Power Degradation', backing down power to a safe operating level in the event of component failure or excessive load VSWR (voltage standing wave ratio) condition.

Empower RF Systems is exhibiting in booth # 807 at the 56th Annual AOC International Symposium & Convention in Washington DC, USA (28-30 October).

Navitas showcasing production GaNFast-powered fast mobile chargers at CPSSC

SemiconductorToday

At the China Power Supply Society Conference (CPSSC 2019) in Shenzhen, China (1-4 November), Navitas Semiconductor Inc of El Segundo, CA, USA is showcasing more than 20 production GaNFast-powered fast mobile chargers.

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

"CPSSC is the highlight of the Asian power electronics calendar, with over 450 peer-reviewed technical papers and over 1500 attendees from industry and academia," notes Stephen Oliver, VP sales & marketing. "The

exhibition is a strong platform for Navitas to display 20+ production GaNFast chargers, demonstrating the aggressive adoption of gallium nitride for high-power yet small and lightweight mobile chargers," he adds.

"As a Diamond sponsor of CPSSC, with industry presentations and an exciting series of customer and partner meetings, Navitas once again shows commitment to bring GaNFast technology to Chinese customers." says Yingjie (Charles) Zha, country manager of Navitas Semiconductor (China). "We are very pleased with customers' adoption speed and innovation across a wide range of mobile, 5G, AI and IoT markets, using GaNFast monolithic integration to enable a new class of high-frequency, high-efficiency and high-density power systems."

Navitas is showcasing both its own GaN power ICs and GaN-enabled power systems on the exhibition floor (booth A007) and during the technology presentations.

See here Navitas' scheduled presentations.

StratEdge offering assembly services for high-frequency, high-power device die attach on CMC tabs

SemiconductorToday

StratEdge of Santee, near San Diego, CA, USA (which designs and manufactures packages and provides chip assembly & test services for microwave, millimeter-wave and high-speed digital devices) has announced its assembly services for attaching gallium nitride (GaN) and other high-frequency, high-power devices using gold-tin (AuSn) and gold-silicon (AuSi) onto copper-molybdenum-copper (CMC) tabs. The firm says that its proprietary eutectic die attach method maximizes the power output that a chip can achieve, optimizing its performance and providing an efficient way to dissipate heat to avoid overheating and failures during normal operation.

StratEdge uses the latest high-volume automated system in a cleanroom environment to perform eutectic AuSn die attach of compound semiconductor devices that have a backside gold surface finish. The bonder has micron placement accuracy. Solder preforms are matched to the size of the die to reduce solder bond line thickness to less than 6µm, maximizing power output for GaN devices, lowering junction temperatures, and increasing device reliability. For silicon devices, a AuSi eutectic die attach method is used to create a reliable solder joint with what is claimed to be excellent thermal dissipation.

"GaN on CMC is perfect for chip-on-board (COB) applications because organic boards cannot withstand the eutectic die attach temperature," says Casey Krawiec, VP of global sales. "Eutectic die attach is a highly controlled die attach process that provides void-free, high-reliability, high-accuracy chip attachment. The chip's performance benefits from the superior thermal characteristics of the CMC heat spreader before the chip is installed onto the board," he adds. "StratEdge provides the service along with the custom-built CMC tabs, which allows the chip to be placed directly on a layer of high thermally conductive copper."

StratEdge is exhibiting in booth 10 at the 2019 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS) at the Loews Vanderbilt Hotel, Nashville, TN, USA (3-6 November).

Fraunhofer IAF claims first MOCVD production of AlScN layers for transistors

SemiconductorToday

The Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg, Germany claims to be first to manufacture aluminium scandium nitride (AlScN) by metal-organic chemical vapor deposition (MOCVD), taking a step towards its goal of developing power electronics based on AlScN transistors for industrial applications.

Transistors based on AlScN are promising for various industrial applications such as data transfer, satellite communication, radar systems and autonomous driving, especially since existing devices based on silicon are reaching their physical limit in these applications. One reason for this is the size of silicon devices, which cannot be reduced further according to existing research.

High-electron-mobility transistors (HEMTs) far surpass the possibilities of silicon devices due to the materials on which they are based. AlScN has exceptional properties, allowing higher carrier concentrations than other materials. In the future, significantly more powerful and efficient HEMTs will be realized based on AlScN, reckons Fraunhofer IAF.

Previous manufacturing processes failed due to quality and productivity

The production of AlScN involves fundamental challenges. The state-of-the-art production process grows AlScN layers via sputtering. Unfortunately, the quality of these layers is insufficient for electronic applications such as light-emitting diodes (LEDs) and high-power transistors. An alternative method is to produce AlScN via molecular beam epitaxy (MBE), with which large amounts of scandium can be incorporated in the compound. The quality is also sufficient for the production of microelectronic devices. However, the procedure is complex and the productivity too low for industrial-scale productions.

MOCVD promises industrial-grade production

The production of AlScN by MOCVD promises not only the necessary quality but also sufficient productivity for industrial applications. “We knew that previous attempts by other scientists to produce gallium scandium nitride via MOCVD had failed,” says group leader Dr Stefano Leone. “We also know that many scientists all over the world are working to develop AlScN transistors, but no one before us has succeeded in doing it by using MOCVD, even though it is a very promising approach for industry,” he adds.



Picture: The research group of Stefano Leone (bottom right) together with the MOCVD system, modified for AlScN growth.

MOCVD reactor modified for scandium precursor

The challenge for researchers at Fraunhofer IAF is that there was no gas source for scandium. The precursors for scandium are very large and difficult to bring into the gas phase. “We studied the best possible precursor for scandium and planned adjustments of our MOCVD reactor for the necessary procedure,” says Leone. “We did a lot of research and had numerous discussions until we developed a setup that we are now even patenting. We

have now succeeded in growing AlScN layers via MOCVD with a very high crystal quality and the right amount of scandium in order to develop the next generation of power transistors," he adds. The MOCVD system at Fraunhofer IAF has been modified by the research group to enable a high-quality and reproducible AlScN production process.

First MOCVD-grown AlScN layers for transistors

After successful deposition of AlScN in the MOCVD system, the first AlScN layers for transistors were produced. The layers have already yielded promising results, with sheet resistance of ~200Ω/sq., mobility of ~600cm2/Vs and charge carrier density of ~4.0x1013cm-2.

The current goal of the researchers is to reduce the sheet resistance and to further increase the mobility and material quality. This should improve the performance of future transistors, so Fraunhofer IAF aims to take a significant step towards its goal of providing AlScN HEMTs for industrial power electronic applications.

Infineon adds 400V and 600V devices to CoolGaN portfolio

SemiconductorToday

Infineon Technologies AG of Munich, Germany has broadened its CoolGaN series with two new devices. The CoolGaN 400V device (IGT40R070D1 E8220) is tailored for premium HiFi audio systems where end users demand every detail of their high-resolution sound tracks. These have conventionally been addressed by bulky linear or tube amplifiers. Instead, audio designers can use the CoolGaN 400V switch as the class D output stage. The CoolGaN 600V industrial-grade device (IGLD60R190D1) enables performance and cost optimization for low- and mid-power applications, such as in the area of low-power SMPS and telecom rectifiers. Every product in the CoolGaN family meets JEDEC standards.

Infineon says that the CoolGaN 400V switch enables smoother switching and more linear class D output stage by offering low/linear Coss, zero Qrr, and normally-off swich. Suitable class D audio amplifiers offer 0% distortion and 100% efficiency. What impairs the linearity and power loss is highly dependent on the switching characteristics of the device. Infineon says that CoolGaN introduces zero reverse recovery charge in the body diode and very small, linear input and output capacitances. The resulting benefit to the end users is more natural and wider soundstage audio.

To further simplify the design, Infineon pairs the CoolGaN 400V device in an HSOF-8-3 (TO-leadless) package with a popular class D controller (IRS20957STRPBF) in an evaluation board.

The CoolGaN 600V portfolio is now also extended with a new 190mΩ, industrial-grade high-electron-mobility transistor (HEMT), developed to fit any consumer and industrial application on an optimized cost with the aim to lower the technology entry barrier. Easy design-in is supported with a standardized DFN 8x8 packaging and the matching driver ICs from the GaN EiceDRIVER series.

The CoolGaN 400V (IGT40R070D1 E8220) and CoolGaN 600V (IGLD60R190D1) devices can be ordered now. The evaluation board EVAL_AUDAMP24 will be available for order in February.

GaN Systems showcasing GaN advances at China Power Supply Society Conference

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, at the 23rd China Power Supply Society Conference (CPSSC 2019) in Shenzhen, China (1-4 November), it is giving presentations on the

application of GaN in industrial and automotive industries and displaying its latest solutions, design tools, and innovative products.

Additionally, customer demos are being shown that are more efficient, smaller in size and weight, and less expensive than silicon-based power systems.

Also, as part of its commitment to support the design engineering community, GaN Systems is sponsoring the 'GaN Systems Cup' design competition, with finalists and winners to be announced on 1 November.

Presentations
On 3 November, GaN Systems is sharing key insights on new power semiconductor devices and applications:

08.30-09.00 – 'High efficiency solutions up to 1kW for wireless power transfer applications';
10.00-10.30 – 'The effect of dynamic on-state resistance to system losses in GaN-based hard-switching applications';
15.00-15.30 – 'GaN device performance in industrial applications'.

Customer demonstrations
GaN Systems is also displaying solutions, design tools and product breakthroughs from game-changing companies.

Products and Tools:

- GS-065-150-1-D1 high-current, high-power device;
- GS-065-004,8,11-1-L small-form-factor PQFN devices;
- 1.2kW high-efficiency bridgeless totem-pole PFC (power factor correction) reference design;
- IMS reference designs for high power with high power density;
- 50W and 100W Wireless Power Transfer power amplifiers;
- EZDrive reference design kit.

Application examples include:

- mobile device chargers/adapters from 65W to 200W up to 4x smaller with GaN versus silicon;
- wireless charging examples for consumer, drone, robot and scooter from 30W to 700W;
- data-center power supply unit (PSU), 50% increase in power density with GaN versus silicon;
- 5G fixed-wireless access through-wall and through-window CPE wireless power;
- automotive electric vehicle (EV) traction inverter power designs.

Customer demonstrations highlight end products in the consumer, data-center, industrial and automotive industries, such as AC/DC and DC/DC power supplies, EV traction inverters and high-power wireless charging systems for drones, robots, scooters and 5G applications.

GaN Systems Cup
The winning teams of the GaN Systems Cup design competition are being announced at the live finals and awards ceremony on 1 November. This year's challenge is to design a high-efficiency, high-power-density AC/DC power supply for data-center server power applications using GaN Systems' 650V power transistors from design to build. Sponsored by GaN Systems in participation with China Power Supply Society (CPSS), China Power Society Science Popularization Committee and Tsinghua University, the annual challenge supports worldwide innovation in the power electronics industry leveraging the benefits of GaN transistors.

Navitas and Baseus deliver smallest 65W 3-port wall charger

SemiconductorToday

Navitas Semiconductor Inc of El Segundo, CA, USA has announced a partnership with Baseus (a consumer electronic brand of China-based Shenzhen Times Innovation Technology Co Ltd) to introduce the '2C1A' 65W 3-port mobile wall charger with GaNFast (gallium nitride) power IC technology to achieve what is said to be the world's smallest and lightest portable form-factor.

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

Baseus' 2C1A power adapter uses highly integrated, speed-optimized gallium nitride (GaN) technology that replaces slow discrete silicon components, and enables the adapter to utilize high-frequency, high-efficiency, soft-switching techniques to shrink the size, weight and cost of passive components and heatsinks, says Navitas. The 2C1A eliminates the need for three separate wall chargers by delivering three fast-charging outputs in a case size of only 3.2cm x 3.5cm x 7.5cm (84cc) and125g, which is less than half the size and weight of older, slower silicon-based designs, creating the ultimate all-in-one charger. To achieve optimal, simultaneous charging for a user's laptop, tablet and smartphone, the 2C1A provides 65W of total power, with 45W guaranteed from the USB-C port 1 and 20W shared across the USB-C port 2 and USB-A outputs.

"This is 'Baseus 3.0'," says Baseus' founder & CEO Shiyou He. "The market has begun to redefine Baseus, and Baseus has begun to redefine itself. As the star product, the 2C1A GaN charger was launched based on Navitas' GaNFast technology, which makes it the smallest three-port charger in the world," he adds. "Baseus has the vision to work with partners to lead consumers into the GaN charging era."

EPC expands technical leadership team with senior FAE manager for Europe

SemiconductorToday

To support its accelerating design activity and to provide local technical support to its widening customer base in Europe, Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – says that Marco Palma has joined its technical leadership team as senior FAE (field application engineer) manager for Europe, assisting customers in the adoption of eGaN FETs and integrated circuits for applications including DC-DC, LiDAR, and motor control.

Based in Turin, Italy, Palma has over 20 years of field experience in the semiconductor industry, working with customers to define innovative solutions to meet the unique challenges of each customer design. His primary responsibilities at EPC involve direct collaboration with customers throughout Europe to create and implement technical solutions to meet their design challenges.

"Marco Palma is an electronics engineer with extensive experience in assisting customers to implement leading-edge power semiconductor solutions in industrial and automation markets," comments Nick Cataldo, senior VP of global sales and marketing.

Palma joins EPC from Infineon, where he was director, Technical Marketing and Applications. He has held senior technical leadership positions with a strong focus on customer support and product definition.

"I look forward to working with customers to incorporate EPC's leading-edge gallium nitride FETs and integrated circuits into their products," Palma says.

IGaN and RAM partner on commercializing GaN-on-Si whole-body monitoring quantum sensor

SemiconductorToday

Singapore-based technology providers RAM Group (which has developed multi-parametric, single-point bio-electro-mechanical quantum sensor technology) and IGSS GaN Pte Ltd (IGaN) – which supplies proprietary 8-inch gallium nitride on silicon (GaN-on-Si) epitaxial wafer fabrication services for both power and radio frequency (RF) devices – have announced what is claimed to be the first clinically validated quantum device sensor (QDS) providing non-invasive, continuous whole-body organ system monitoring.

Targeted at an array of healthcare applications and wearables, QDS integrates a proprietary Artificial General Intelligence (AGI) engine to produce data sets with the potential to aid immediate and hyper-accurate diagnosis of diseases or disorders in the heart, lungs and other organs.

"Powered by AGI that operates 70% faster than AI in neural net analysis, the QDS addresses the need for a small, ultra-low power, non-invasive sensor that can simultaneously and continuously detect minute changes in electrical fields within the human body," says RAM Group's CEO & founder Ayal Ram. "It fundamentally transforms the way critical illnesses and disease states are detected, diagnosed and understood sooner with less stress and cost," he adds.

"We are excited to bring to this partnership IGaN's in-depth know-how in cost-competitive commercializing and accelerating time-to-market of GaN-on-Si based technologies," says Raj Kumar, founder & group CEO of IGSS Ventures Pte Ltd (of which IGaN is a subsidiary). "Successful clinical trialling and QDS' market-readiness is a case in point for the advanced capabilities of niche semiconductors like GaN-on-Si, particularly as a superior replacement for silicon chips," he adds. "With RAM Group we can, together, enable the adoption of GaN-on-Si sensor-based applications beyond healthcare to further drive Singapore's potential as a global innovation hub in emerging semiconductor applications."

GaN Systems receives ISO 9001:2015 certification

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has received International Organization for Standardization (ISO) 9001:2015 certification for the design and manufacture of power semiconductor products.

Both its Canadian headquarters and Taiwanese operations facilities received ISO certification from the British Standards Institute (BSI, the world's first national standards body and one of the largest). GaN Systems says that certification represents third-party validation of its commitment to providing high-quality products and services that align with the standards of excellence required by major multi-national customers.

The ISO 9000 family of standards is designed to ensure that GaN Systems meets the needs of customers and other stakeholders via its quality management systems (QMS) while meeting and exceeding qualification requirements for its Joint Electron Device Engineering Council (JEDEC) and Automotive Electronics Council (AEC-Q101) qualified GaN power transistor products.

ISO 9001 is considered the leading standard for quality management systems and performance worldwide. ISO 9001:2015 is the most recent version, with significant enhancements since the last ISO 9001:2008 update.

"The ISO 9001:2015 revision demands a higher degree of leadership and management commitment than the previous standards," says GaN Systems' CEO Jim Witham. "This commitment is consistent with our mission to be the place designers can go to realize all the system benefits of GaN in their power conversion applications," he adds.

GaN Systems Cup competition winners honored at China Power Supply Society awards ceremony

SemiconductorToday

At an awards ceremony on 3 November at the China Power Supply Society Conference (CPSSC), GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) - alongside the China Power Supply Society (CPSS), China Power Society Science Popularization Committee, and Tsinghua University - has announced the winners of the fifth annual 'GaN Systems Cup' design competition.

The contest challenges top engineering teams from China's leading universities to design new or improved power electronics systems using GaN power transistors from design to build that meets specified requirements. This year's challenge was to develop a high-efficiency, high-power-density AC/DC power supply for data-center server power applications with GaN Systems' 650V power transistors. The design had to meet several requirements: 400W-rated output power, 220VAC input voltage range/48VDC output voltage, and 94% efficiency at 50% load and greater than 3W/cm3 power density.

Forty teams participated in the first round of the competition, 30 teams moved on to the second round, and 12 participated in the final competition. Five engineering teams were awarded for their GaN-based inverter designs. Cash awards of 20,000-yuan, 10,000 yuan and 5,000 yuan were given to the top, first and second winning teams:

Top winner:
• Zhejiang University.

First:
• Huazhong University of Science and Technology
• North China University of Technology.

Second:
• Nanjing University of Aeronautics and Astronautics
• Heilongjiang University of Science and Technology.

Honorable mentions go to: Chongqing University of Technology, Hangzhou University of Electronic Science and Technology, Harbin Institute of Technology, Kunming University of Science and Technology, Shanghai Maritime University, Tsinghua University, and Yanshan University.

The top winning team from Zhejiang University designed a solution that had a 3.76W/cm3 power density with 93.8% efficiency. Designs were judged on meeting the design criteria, functionality during the test day, ingenuity, and quality of presentation.

"The 'GaN Systems Cup' continues to provide engineering students practical experience leveraging the benefits of GaN to address today's high-efficiency, high-power needs," says Paul Wiener, VP strategic marketing at GaN Systems.

GaN Systems and ON Semiconductor make available high-speed half-bridge evaluation board

SemiconductorToday

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) and ON Semiconductor of Phoenix, AZ, USA – which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices – have announced the availability of a high-speed, half-bridge GaN daughter board using GaN Systems' 650V, 30A GaN E-HEMTs and ON Semiconductor's NCP51820 high-speed gate driver evaluation board.

The evaluation board has been developed for existing and new PCB designs and allows designers to evaluate GaN in existing half-bridge or full-bridge power supplies. The kit has a reduced component count in an ultra-small 25mm x 25mm layout, minimizing PCB board space. Features, which include 1+MHz operation and a 200V/ns CMTI rating, provide increased power density and improved performance with fast-switching GaN power transistors.

With benefits said to include significant reductions in power losses, weight, size (up to 80% in layout size) and system costs (up to 60% BOM cost savings), suitable applications include AC-DC adapters, data-center power supplies, photovoltaic (PV) inverters, energy storage systems, and bridgeless totem pole topologies. The solution is one of many upcoming GaN-based power system solutions that both companies are developing.

"The expansion of the GaN components ecosystem – including driver ICs such as our NCP51820 – removes design barriers and takes advantage of the numerous benefits that GaN E-HEMTs provide," says ON Semiconductor's director of marketing Ryan Zahn. "With rising interest and adoption of GaN, we look forward to continued collaboration with GaN Systems in supporting and meeting the new power requirements taking place across many industries," he adds.

"The new evaluation board developed in collaboration with ON Semiconductor makes it easier and more cost effective to design with GaN – opening the door for smaller, lighter and more efficient power converters," says Charles Bailley, senior director, Worldwide Business Development at GaN Systems. "This collaboration signals the innovation not only happening with end-products designed with GaN but in components, design tools and reference designs that optimize the use of GaN."

OPTOELECTRONICS

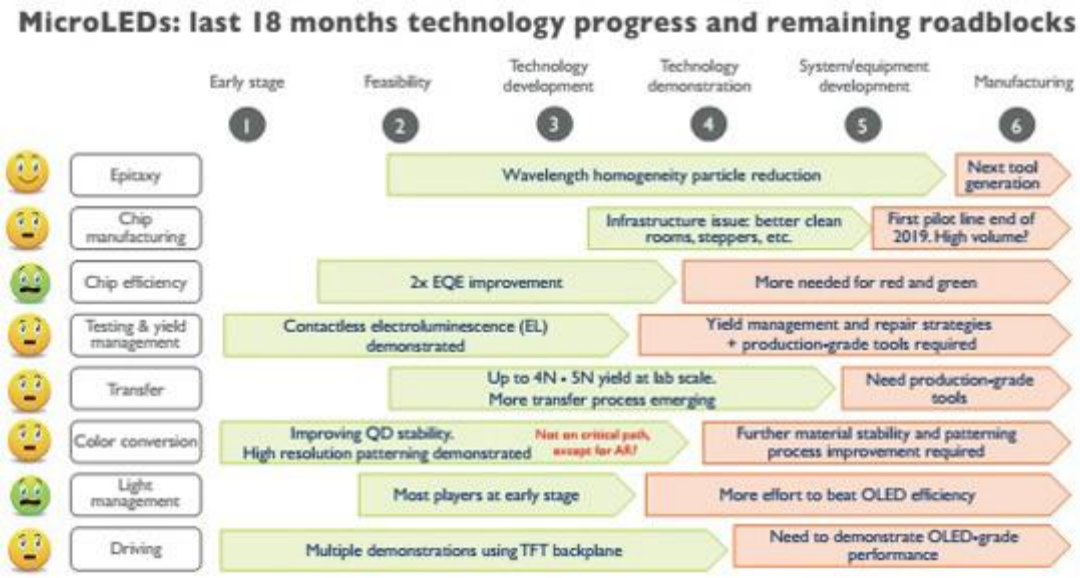
Micro-LED technologies make significant progress over last 18 months

SemiconductorToday

With micro-LEDs drawing an increasing amount of attention, startups have raised more than $800m to date, including at least $100m in 2019, and Apple has spent $1.5-2bn on the technology over the last five years, reckons market analyst firm Yole Développement in its report 'MicroLED Displays'. Panel makers such as Samsung Display, LG Display, AUO or Innolux have also significantly increased their efforts.

"Without doubt, micro-LEDs are today progressing on all fronts," says principal display market & technologies analyst Eric Virey PhD. Patent filings are growing exponentially and technology is progressing. The external quantum efficiency of blue and green micro-LED chips has more than doubled over the past 24 months. Some transfer and assembly processes are reaching performance close to what is required to enable some micro-LED

consumer applications. Progress is also visible in the proliferation of prototypes presented over the last 18 months by nearly 20 companies.



“The demos cover a broad range of display types, sizes and technologies,” notes technology & market analyst Zine Bouhamri PhD, part of the Display team at Yole.

“Native RGB or color-converted displays on TFT [thin-film transistor] backplanes are offered by many companies, with some examples including Playnitride, CSOT, Samsung, LG, glō, AUO, eLux and Kyocera. Lumiode has developed native RGB or color-converted displays on monolithicaly integrated LTPS [low temperature polysilicon],” he adds.

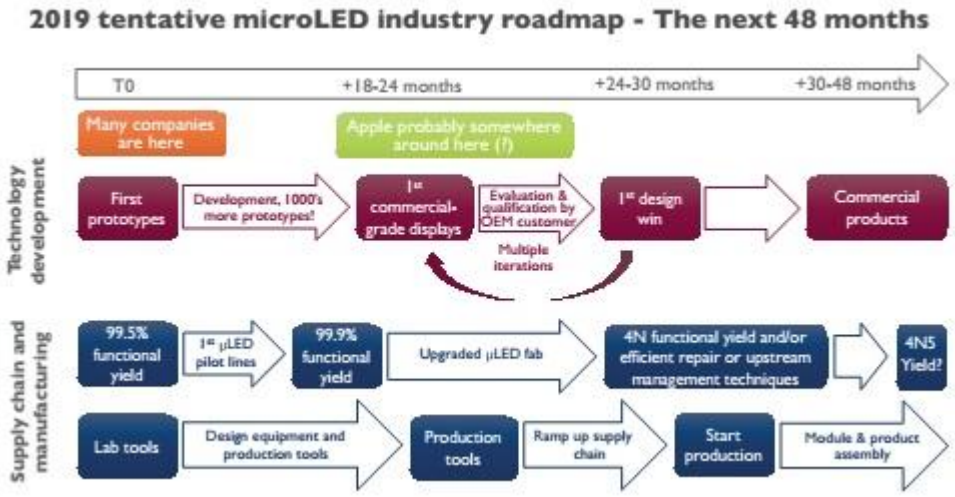
Micro-displays on CMOS backplanes have also been demonstrated by companies including Plessey, glō, Lumens, JB Display, Sharp and Ostendo. Finally, discrete micro-driver ICs have been developed by X-Display. The multiple prototypes based on TFT backplanes give credence to the idea that micro-LED displays could leverage existing panel makers’ capacity, simplifying and streamlining the supply chain.

“Equipment makers have taken notice and are starting to develop micro-LED-specific tools for assembly, bonding, inspection, testing and repair,” notes Eric Virey of Yole.

LED makers are also showing interest, with San’an planning to invest $1.8bn to set up a mini- and micro-LED manufacturing base. Osram, Seoul Semiconductor, Nichia and Lumileds are also increasing their activity and Playnitride is completing its first micro-LED pilot line.

However, significant roadblocks still exist for key applications. For many of them, economics are pushing die size requirements below 10µm. This compounds efficiency, transfer and manufacturability challenges and, despite significant improvement, small-die efficiency remains low. In most cases, display efficiency based on this technology still cannot match that of organic light-emitting diode (OLED) technology. Significant effort is therefore needed to further improve the internal quantum efficiency, light extraction and beam shaping of green and red micro-LED chips.

For micro-LED companies, the first few prototypes provide useful experience, but maturing toward consumer-grade displays could require thousands more. Startups are entering the 'valley of death': many might fail to raise enough money to successfully go through this more capital- and resource-intensive phase. Support from and partnership with large display makers or OEMs, either as strategic investors or development partners, is therefore critical, concludes Yole.



Bouhamri is presenting key results of Yole's micro-LED analysis in 'Impressive Technologies for MicroLED Displays' on 29 November (3:20pm) at the International Display Workshop (IDW '19) in Sapporo, Japan (27-29 November).

Bridgelux launches human-centric lighting options

SemiconductorToday

Bridgelux Inc of Fremont, CA, USA (a vertically integrated manufacturer of solid-state light sources for lighting applications) has announced the commercial availability of Thrive surface-mount device (SMD) 2835 and V Series chip-on-board (COB) LEDs. Thrive white-point options are designed to closely match the spectra of natural light by reducing blue spikes and cyan valleys, and providing full-spectrum, human-centric LED lighting solutions.

The loss of natural light benefits affects those who spend most of their time indoors, with office workers being one of the groups especially at risk. According to Harvard Business Review, the "health benefits of access to natural light are causing some firms to re-imagine their workspace and tout this as a recruiting tool." The lighting industry is moving beyond the efficacy race and towards human-centric lighting incorporating circadian elements that may impact well-being for anyone spending extended periods of time indoors, says Bridgelux.

First announced in March, Thrive uses proprietary chip, phosphor and packaging technologies to deliver a close spectral match to natural light. The high-fidelity spectral output of Thrive creates environments with excellent color rendering index (CRI) and outstanding TM-30 metrics, Bridgelux claims. Unlike other high-CRI light sources, Thrive has been engineered specifically to provide a close and continuous match to natural light across the visible wavelength range to enable human-centric lighting.

Thrive SMD 2835 1W 9V and V10C are available for ordering now. Additional SMD 2835 and V Series form factors will be available in late fourth-quarter 2019 and early first-quarter 2020.

"Today's announcement reflects our pledge to customers to deliver a clear path toward flexible, interoperable solutions to meet lighting requirements that demand natural-looking light, particularly projects in the office, education, healthcare, residential and retail markets," says Dr Brian Cumpston, VP of Solutions Development. "We are a technology partner committed to delivering new LED light source solutions as our roadmap evolves, including an expansion of Thrive white options onto our Vesta Series and EB Series tunable white light sources, and the expanding family of high-efficacy SMD products," he adds.

Bridgelux also announced performance upgrades to its SMD 2835 delivering luminous efficacy up to 221lm/W, and to its SMD 4014, now delivering up to 190lm/W, both in 4000K 80 CRI with a variety of 80 and 90 CRI color-point options available. The light sources are useful for a range of lighting applications including office, retail, residential and architectural lighting, assisting users to meet ever evolving regulatory based efficacy requirements.

Compound Photonics and Plessey partner on micro-LED displays for AR/MR applications

SemiconductorToday

Compound Photonics US Corp (CP) of Vancouver, WA, USA, a provider of compact high-resolution microdisplay technologies for augmented reality (AR) and mixed reality (MR) applications, and UK-based embedded micro-LED technology developer Plessey Semiconductors Ltd, have announced a strategic partnership to develop and introduce the smallest 1080p (1920x1080 pixel) gallium nitride-on-silicon (GaN-on-Si) micro-LED-based microdisplay solution suitable for integration into AR and MR smart glasses.

Plessey will bond CP's high-speed digital low-latency backplane silicon wafer with its proprietary GaN-on-Si monolithic micro-LED array wafer. In turn, CP will utilize its experience in microdisplay assembly, test and packaging to create display modules from the bonded wafers in combination with its NOVA high-performance display driver architecture to deliver a complete solution compatible with the industry-standard MIPI display pipeline.

"CP is the best partner for Plessey because of its deep and extensive decade-long experience with developing fully realized microdisplay-based projection solutions," comments Plessey Semiconductors' president Mike Lee. "Moreover, CP's flexible high-performance end-to-end digital architecture and leading-edge display driver IP are key enablers for delivering micro-LED displays with improved brightness at smaller pixel sizes, higher frame rates, extended greyscale bit depth and low power consumption to best serve next-generation emissive-display-based AR/MR smart glasses and heads-up/head-mounted displays (HUD/HMDs) applications," he adds.

"Plessey's monolithic GaN-on-silicon IP, fabrication technology and bonding process are well optimized for very small high-brightness pixels that match perfectly with CP's industry-leading 3.015µm pixel-pitch backplane design to deliver compact high-resolution microdisplays," comments Compound Photonics' CEO Yiwan Wong. "Through this partnership, Plessey and CP now lead the industry in addressing the full breadth of current, emerging and future requirements for AR/MR smart glasses and HUD/HMDs that span the range from CP's existing production-ready LCoS (liquid crystal on silicon) reflective displays to emerging micro-LED emissive display technology, and ultimately to achieving true holographic 3D display via CP's LCoS phase display solutions in the future," he reckons. "For the first time, we can provide customers in AR/MR space with an extensible software-configurable platform based on CP's efficient drive architecture that can operate with a wide range of display types to support various application requirements."

Initial samples of a 0.26"-diagonal, full-HD 1080p-resolution micro-LED display integrated with display driver IC to accept industry-standard MIPI input are expected to be available by mid-year 2020.

Vertical gallium nitride light-emitting diodes on 4-inch silicon wafers

SemiconductorToday

Researchers in China have integrated high-power, reliable vertical indium gallium nitride (InGaN) light-emitting diodes (LEDs) on 4-inch silicon substrates [Shengjun Zhou et al, Optics Express, vol27, pA1506, 2019]. The team from Wuhan University, Changchun Institute of Optics, Fine Mechanics and Physics, and Xiamen Changelight Co Ltd, used a number of measures to improve the performance of the final LEDs by reducing current crowding and protecting the device structure from humidity.

Contact	p-GaN	110nm
Electron blocking	p-AlGaN/GaN superlattice	48nm
Multiple quantum well	12x(InGaN/GaN)	12x(3nm/10nm)
Strain release	InGaN/GaN superlattice	200nm
Contact	n-GaN	3μm
Buffer	GaN	2.5μm
Nucleation	GaN	30nm
Substrate	Sapphire	

Figure 1: Vertical LED device layer MOCVD growth sequence.

The device layers were grown on patterned sapphire substrates using metal-organic chemical vapor deposition (MOCVD; see Figure 1). The LED fabrication began with inductively coupled plasma (ICP) etch into 1mmx1mm mesas for electrical isolation. A silicon dioxide (SiO2) current-blocking layer (CBL) was applied using plasma-enhanced CVD and patterning into 15μm-wide strips using photolithography and buffered-oxide wet etch (Figure 2).

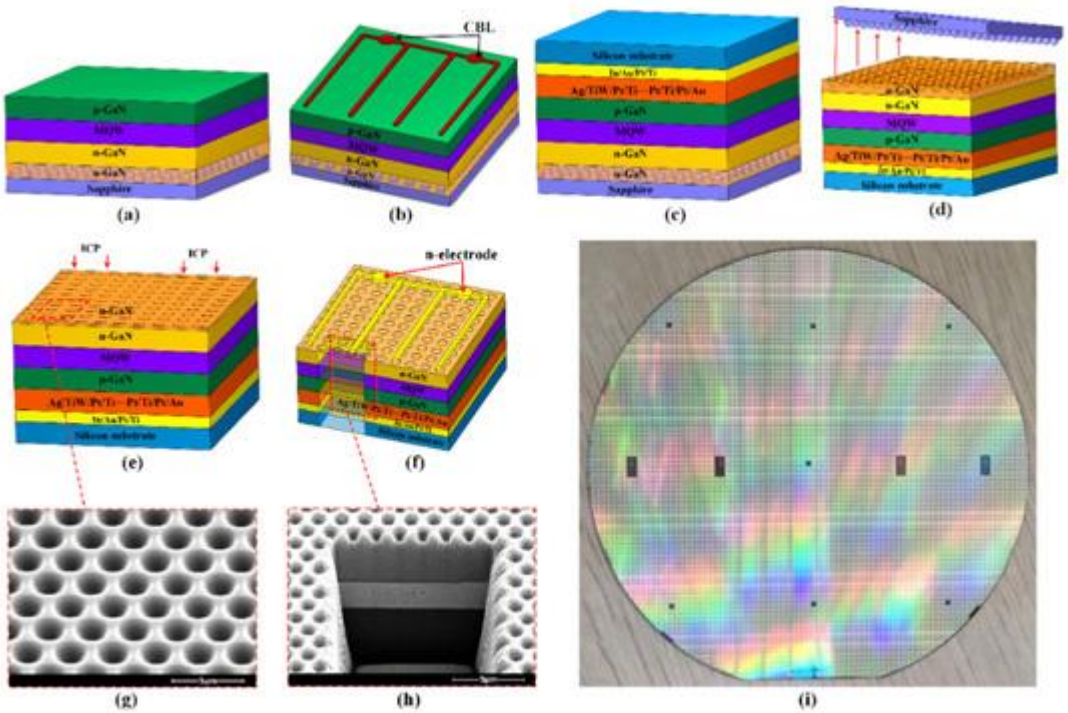


Figure 2: Fabrication process of LEDs: (a) MOCVD growth; (b) defining SiO2 CBL; (c) metal deposition and bonding to Si wafer; (d) laser lift-off (LLO) removal of sapphire substrate; (e) ICP etch to n-GaN contact; (f) deposition of p- and n- electrodes. (g) Scanning electron microscope (SEM) image of exposed n-GaN surface with hemispherical dimples after LLO and ICP etching. (h) Cross-sectional SEM image of LEDs bonded to Si wafer. (i) Photograph of LEDs on 4-inch Si wafer; colors arise from thin-film interference effects.

Ion-beam sputtering applied a 100nm silver film as reflector, followed by titanium/tungsten as a diffusion barrier. After electron-beam deposition of a platinum/titanium cap, rapid thermal annealing at 600°C was used to improve the GaN/silver ohmic contact.

The 4-inch-diameter p-Si final device substrate was prepared by adding multi-layers of titanium/platinum/gold and a titanium/platinum cap. A 2.5µm layer of indium was applied to the p-Si substrate before thermal compression bonding at 230°C. One feature of the titanium adhesion layer was that it also acted as a barrier against poisoning of the p-Si with gold. Platinum contamination of the p-Si was also avoided, according to energy-dispersive x-ray analysis.

A 248nm krypton-fluoride excimer laser was used to perform lift-off separation of the sapphire growth substrate. This was followed by ICP etch down to the n-GaN contact layer.

The n-GaN was treated with potassium hydroxide (KOH) or phosphoric acid (H3PO4) solution to texture the surface for improved light extraction. Chromium/platinum/gold was used to form the p- and n-electrodes for the LED. The n-contact metals were formed into 12µm-wide fingers.

The SiO2 CBL around the opaque electrodes directed current away from this region and made for more uniform current density in the light-emitting areas, according to simulations. Along with the vertical structure, it was hoped the CBL would reduce self-heating, making for more efficient performance over lateral structure devices. Current crowding increase leading to self-heating is a major problem in conventional lateral structure LEDs.

The vertical LED structure enabled much lower forward voltages for a given current injection – 2.87V at 350mA, compared with 3.52V with a conventional lateral LED structure (Figure 3). Lower forward voltage indicates lower input power and hence higher power efficiency. The light output power (LOP) for a given current injection was also higher in the vertical LED: lateral LED output saturated at ~320mA, while the vertical device increased in light power up to 1300mA. “The absence of premature LOP saturation in V-LEDs was attributed to reduced current crowding and enhanced heat dissipating compared to L-LEDs,” the team writes.

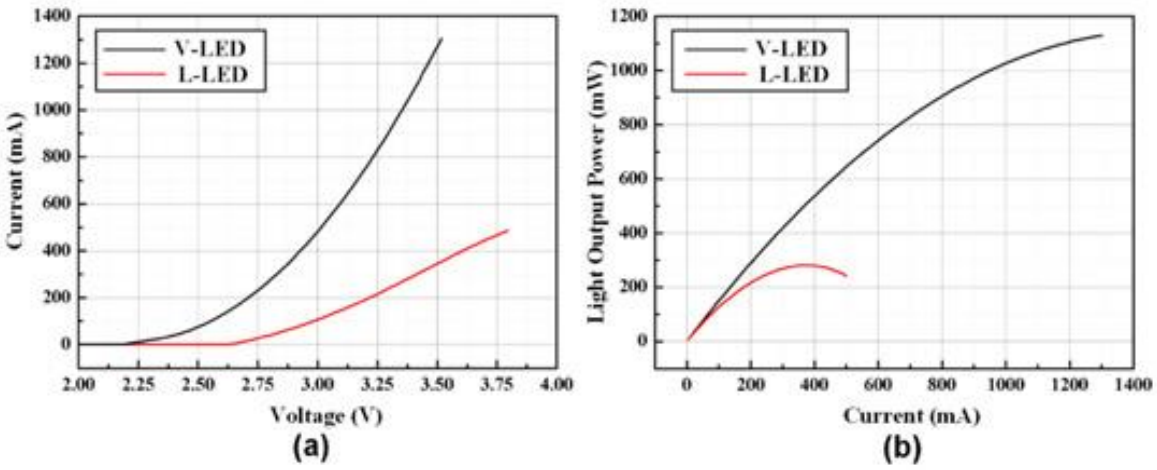


Figure 3: (a) Current-voltage profiles of lateral (L-) and vertical (V-)LEDs. (b) Light output power-current characteristics.

With 350mA, the vertical LED output power was 501mW, beating a previous report of a GaN vertical blue LED of ~450mW at the same injection. The researchers comment: “The higher LOP demonstrated in this work confirmed that integrating the optimized metallization scheme, SiO2 CBL and surface texturing by KOH wet etching is an effective approach to higher-performance V-LEDs.”

The researchers also developed a platinum/titanium protective wrap-around layer for the silver/titanium-tungsten alloy structure. The wrap-around structure protected the mirror contact from humidity degradation. Operation at 85°C and 85% relative humidity degrade the performance of LEDs without lateral wrap-around protection over 1000 hours. By contrast, the LEDs with wrap-around platinum/titanium showed "negligible optical degradation even after an aging time of 1008h," according to the researchers.

BluGlass launches direct-to-market GaN laser business unit to capture downstream manufacturing value

SemiconductorToday

BluGlass Ltd of Silverwater, Australia – which was spun off from the III-nitride department of Macquarie University in 2005 – has launched a new direct-to-market business unit to leverage its unique remote-plasma chemical vapor deposition (RPCVD) technology in the high-value, high-margin gallium nitride (GaN) laser diode market. High-brightness GaN laser diodes are used in applications including industrial lasers (cutting and welding), automotive and general lighting, displays, and life sciences.

Compared with the industry's incumbent technology, BluGlass says that its patented RPCVD platform and unique tunnel-junction capabilities offers laser diode manufacturers performance and cost advantages including: higher-performing devices and reduced optical loss; productivity and cost improvements; and unique laser diode design.

BluGlass' is developing GaN laser diode prototypes and expects to deliver its first laser diode product in 2020. The new products are expected to deliver a clear path to significant revenues from 2021.

The new business unit will be headed by VP of business development Brad Siskavich out of BluGlass' US office. Siskavich has over 20 years of experience in laser diode business management. "This new business stream fits well with our strategy of commercializing the competitive advantages of the RPCVD technology to maximise returns," he says. "This highly customizable, end-to-end approach will enable BluGlass to generate revenue in this high-value market and build our leadership in the manufacture of novel GaN laser diodes."

The total market for laser applications is forecasted to reach US$27bn by 2025. The GaN laser diode segment is an emerging market opportunity, expected to grow to a US$658m serviceable addressable market for BluGlass by 2025. GaN lasers require a higher-performance, lower-cost technology solution to help address significant unmet needs in the industry, says BluGlass. The firm will hence initially focus on industrial laser diodes for welding and cutting applications, targeting an initial market share of 6-10% (US$40-65m) of this SAM by 2025.
"BluGlass is entering the laser diode market as a result of our success in demonstrating tunnel junctions as a building block for high-performance cascade LEDs," says managing director Giles Bourne. "Our RPCVD tunnel-junction technology has unique, compelling advantages to drive performance and cost improvements for the GaN laser diode market," he believes. "LEDs and laser diodes are, in their physics and material growth, very similar, which allows us to accelerate our entry into this new market space without diluting our activities on other RPCVD applications.''

BluGlass notes that, with the opening of its Paul Dunnigan Laboratories in August, it now has the pre-installed RPCVD capacity onsite in Silverwater to accrue significant laser diode revenues and build a profitable business unit.

Extremely thin gallium nitride wells enable deep ultraviolet lasing

SemiconductorToday

Researchers in China have presented a deep ultraviolet (DUV) 249nm optically pumped III-nitride laser structure based on gallium nitride rather than the more usual wider-bandgap aluminium gallium nitride (AlGaN) quantum wells (QWs) [Maocheng Shan et al, ACS Photonics, published online 20 September 2019]. The very short wavelength of 249nm was enabled by the extreme confinement of very thin GaN wells in thin AlN barriers. The corresponding photon energy was 5.0eV, a couple of eV higher than the 3.3eV bandgap of bulk GaN.

The team, from Huazhong University of Science and Technology in China, King Abdullah University of Science and Technology (KAUST) in Saudi Arabia and Ningbo Institute of Materials Technology and Engineering in China, see potential applications for sub-280nm DUV lasers in sterilization, communication, optical storage, spectral analysis, and biochemical detection.

The researchers report that previously only spontaneous emission has been achieved in GaN/AlN multiple quantum well (MQW) systems, adding: "To date, there has not been any report of lasing which, if demonstrated, would truly demonstrate that the potentials of the AlN/GaN MQWs are on par with the AlGaN MQWs for high-performance DUV emitters."

Among the problems for AlGaN DUV lasers are strong quantum-confined Stark effects (QCSEs) arising from electric fields, based in ionic charge polarization, that pull electrons away from holes, inhibiting recombination into photons. Also, high-Al-content AlGaN tends to emit radiation optically polarized in a transverse-magnetic mode, which is more difficult to use efficiently in light-emitting diode and edge-emitting laser structures.

Metal-organic chemical vapor deposition (MOCVD) on 2-inch c-plane sapphire resulted in an AlN/GaN MQW laser structure. The 750°C low-temperature (LT) AlN buffer was 15nm thick. The 3µm AlN template layer was grown at 1230°C. X-ray rocking curve analysis suggested that the AlN template was of higher crystalline quality than previously used for AlGaN DUV laser structures.

A somewhat lower growth temperature of 1040°C was chosen for the MQW to ensure high-quality wells, avoiding evaporation of the more volatile GaN material. The GaN wells were designed to be 4 monolayers (MLs) thick, while the AlN barriers were 6MLs. In metric measurements, according to x-ray analysis, the wells and barriers were 1.0nm and 1.5nm thick, respectively.

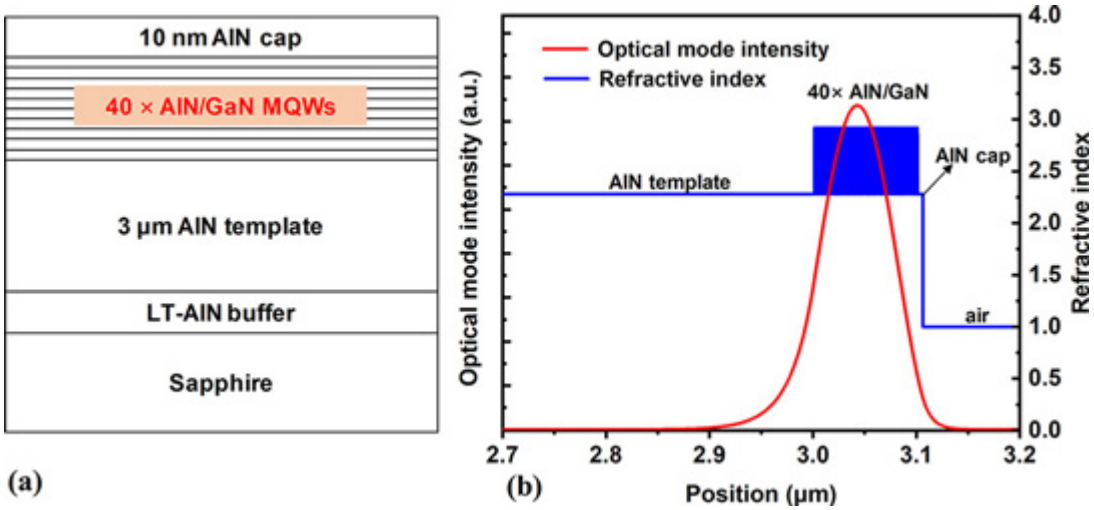


Figure 1: (a) Schematic diagram of AlN/GaN MQW DUV laser grown on sapphire substrate; (b) simulated optical mode profile and refractive index distribution.

The similarity of the quantum well (QW) and barrier (QB) thicknesses was expected to lead to a higher refractive index, compared with the usual situation with significantly thicker barriers. The researchers explain the use of 40 wells as being "due to comprehensive considerations of the lateral optical confinement, penetration depth of the excitation laser beam, gain medium volume, strain relaxation, and material and interface quality."

The final 10nm AlN cap was to provide surface passivation. The team says that ideally the top AlN layer would be thicker to provide a more symmetric waveguide effect coupled with the underlying AlN template. The reason for the thinness was to enable pumping from a 193nm argon fluoride (ArF) excimer laser with minimal absorption losses.

Optical simulations of the structure suggested a 35.4% confinement factor. The researchers explain: "The large factor was partially attributed to the use of high-index GaN QWs and large MQW pair number of 40. Also, it is partially caused by the comparable thicknesses between the GaN QWs and the AlN QBs, resulting in a larger average index."

The material was prepared into 1mm-long cavity laser bars by thinning the sapphire substrate, and laser scribing and cleaving. No optical coating was applied to the facet.

The laser pump was pulsed at 50Hz with 5ns duration. The emission peak was at 249nm with little shift between spontaneous and lasing operation (Figure 2). The researchers attribute this to a minimal QCSE, resulting from the thinness of the GaN QWs.

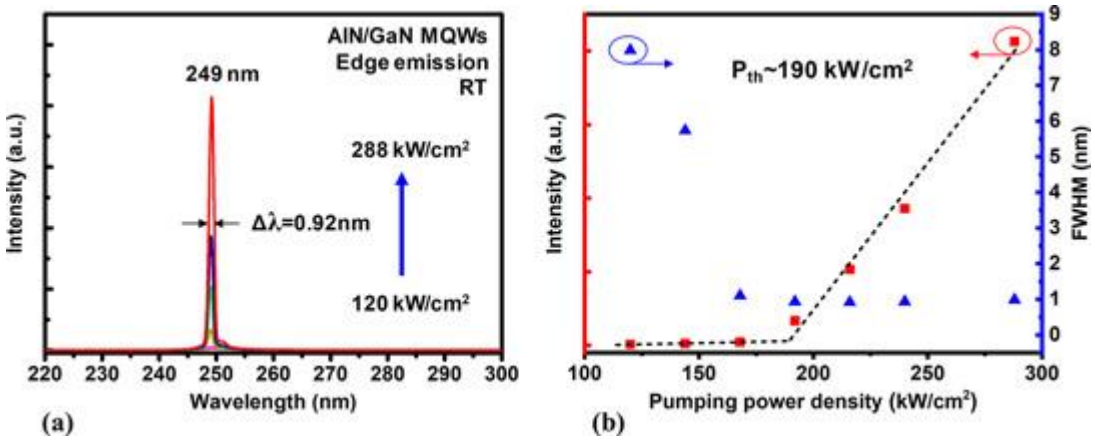


Figure 2: (a) Laser emission spectra and (b) peak intensity and line width of spectra as a function of pumping power density.

The team puts the lasing threshold at 190kW/cm2 pumping power density. The researchers report that this is comparable to AlGaN-based DUV laser structures on sapphire or AlN substrates. "Such a threshold can be mostly attributed to the high material and interface quality, large quantum and optical confinement, and smooth cleaved facet," they write.

As the system passed through the laser threshold, the linewidth reduced from 8nm to 0.2nm full-width at half-maximum (FWHM). Above and below threshold the degree of optical polarization was 0.92 and 0.48, respectively. The polarization here was the ratio of the transverse electric intensity excess over the transverse magnetic to the total intensity (that is, (ITE-ITM)/(ITE+ITM)).

The researchers explain the favoring of TE polarization: "The TE dominance is caused by the topmost position of the heavy hole (HH) band of GaN and thereby the optical transition between the conduction band and the HH band."

The even greater favoring of TE emission above laser threshold is attributed to a large TE-to-TM gain ratio in stimulated operation.

AquiSense's PearlAqua Micro first UV-C LED product certified to NSF/ANSI 55-2019 Standard

SemiconductorToday

Nikkiso Group company AquiSense Technologies LLC of Erlanger, KY, USA (which designs and manufactures water, air and surface disinfection systems based on UV-C LEDs) has claimed the first NSF Component Certification to the newly updated NSF/ANSI 55-2019 Standard for its PearlAqua Micro range, certified by NSF International in compliance with the new NSF/ANSI 55 Standard for Material Safety and Structural Integrity.

With tens of thousands of units shipped this year, the PearlAqua Micro is claimed to be the smallest UV-C LED water treatment system. Manufactured to ISO-9001:2015 quality standards, the range includes five discrete model sizes offering flow rates of up to 8lpm and third-party validation disinfection performance of up to 6-log (99.9999%) pathogen reduction. The range is designed to be integrated at the point of use and offers 12VDC or 24VDC input voltage, automatic on/off control, multiple sensing/alarm options, and customizable housing options.

The NSF/ANSI 55-2019 Standard has recently been updated to address the unique technical differences of LED technology compared with traditional mercury gas-discharge lamp technology. Following very soon will be microbiological performance certification by NSF. This will provide additional verification to the already completed third-party microbiological validation completed on the PearlAqua Micro range, showing supplemental bacterial treatment of drinking water supplies. This provides a strong final barrier and 'last-mile' protection to many applications.

"Prior to September 2019, there was no specific standard for LED technology in water treatment applications," notes CEO Oliver Lawal. "Our team has worked for years supporting NSF International to ensure the new 55 Standard is robust and future-proof," he adds.

Seoul Semiconductor's SunLike Series natural-spectrum LEDs adopted by lighting brand REMEZ

SemiconductorToday

South Korean LED maker Seoul Semiconductor Co Ltd says that its SunLike Series natural-spectrum LEDs have been adopted for lighting brand 'REMEZ' by RemiLicht GmbH for the Russian lighting market. The LED light bulbs feature a human-centric lighting design enabled by the SunLike Series LEDs.

The SunLike Series LEDs adopted by RemiLicht (for LED light bulbs for residential lighting and desk lamps) achieved warm-white (3000K) and cold-white (5700K) correlated color temperatures (CCTs), optimized to natural light spectra by reaching lower blue light peak similar to sunlight's spectral curve in order to reduce scattered reflection and glare common in conventional LEDs.

Seoul says that its SunLike Series natural-spectrum LEDs have been identified as a key light source for promoting human well-being, based on the results of a recent comprehensive sleep study conducted by professor Christian Cajochen and his team at the University of Basel in Switzerland ('Effect of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance, and Sleep', Journal of Lighting and Research Technology, on 24 March).

"We have evidence that a daylight [natural spectrum] LED solution has beneficial effects on visual comfort, daytime alertness, mood, and sleep intensity in healthy volunteers," Cajochen says.

Light sources with SunLike Series LEDs are said to more accurately show the color of objects as they would appear in natural sunlight. Optimized to natural light spectra and color rendering index of CRI-97 (close to the CRI-100 of sunlight, and higher than the CRI-80 of conventional LEDs), it is claimed that SunLike Series LEDs deliver significant benefits in vivid color, contrast detail, and quality of light consistency.

"We have sought LED light sources to replicate the qualities of natural sunlight for indoor environments to deliver beneficial effects on eye comfort and human health," says RemiLicht's CEO Igor Remez. "We were able to create LED light bulbs for human-centric lighting with Seoul Semiconductor's innovative SunLike Series LEDs, which will deliver healthy light that were not possible to achieve using conventional LED technology," he adds.

"Even if different sources of white light look identical to the naked eye, they may contain different levels of the crucial wavelength in the blue spectrum that triggers the body's hormonal response," says Carlo Romiti, Europe sales VP at Seoul Semiconductor. "A truly human-centric lighting source must not only closely match the spectrum of natural sunlight but it also must have the correct level of blue-wavelength light for the time of day," he adds. "Our SunLike Series LEDs enable truly human-centric lighting design that closely matches the spectrum of natural sunlight. It has also achieved the highest level of eye safety certification from the International Commission on Illumination as an RG-1 level light source with no photo-biological risks."

Seoul Semiconductor developed SunLike Series natural-spectrum LEDs in collaboration with Toshiba Materials' TRI-R spectrum technology in 2017 as the first LED light source to closely match the spectrum of natural sunlight.

Cree's LED revenue down 22% year-on-year due to soft market and China trade and tariff concerns

SemiconductorToday

For its fiscal first-quarter 2020 (ended 29 September 2019), Cree Inc of Durham, NC, USA has reported revenue of $242.8m, down 3% on $251.2m last quarter and 11% on $274.2m a year ago, after excluding (as discontinued operations) the Lighting Products business unit (LED lighting fixtures, lamps and corporate lighting for commercial, industrial and consumer applications), which Cree sold on 13 May to IDEAL Industries Inc of Sycamore, IL, USA.

Fiscal	Q1/2019	Q2/2019	Q3/2019	Q4/2019	Q1/2020
Revenue	$408.3m	$413m	$274m	$251.2m	$242.8m

The drop in continuing business was because LED Products revenue of $115.1m (47.4% of total revenue) was down 22% on $146.8m (54% of total revenue) a year ago due to soft market conditions and the ongoing trade and tariff concerns with China. However, this is down only 1.6% on $117m last quarter (better than the expected 2-4% decline) and an increase from 46.6% of total revenue.

Revenue for Cree's Wolfspeed silicon carbide (SiC) materials, power and gallium nitride (GaN) RF device business was $127.7m (52.6% of total revenue), up fractionally on $127.4m (46% of total revenue) a year ago, but down 5% on $134.2m (53.4% of total revenue) last quarter, as Cree continues to see softness in China related to the change in electric vehicle (EV) subsidies earlier this year. "This marks the third consecutive month of weaker automotive sales trends in China," notes chief financial officer Neill Reynold. "In our RF business, in addition to Huawei, we are seeing some push outs and delays in purchasing activity as it relates to the rollout of 5G networks," he adds. Read more

OTHER

IQE acquires full ownership of CSDC joint venture

SemiconductorToday

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has announced the acquisition of third-party shareholdings in its CSDC joint venture in Singapore, giving it is 100% ownership.

Established in March 2015, CSDC was a joint venture between IQE's Singaporean subsidiary MBE Technology Pte Limited (51%), WIN Semiconductors Corp (25%), Nanyang Technological University (18%) and individuals of the NanYang University (6%). It was formed to develop and commercialise compound semiconductor technologies for academic and industrial customers based on Molecular Beam Epitaxy (MBE) technologies in Asia.

According to IQE, the geopolitical landscape in Asia has changed significantly this year, with the localisation of Asian technology supply chains rapidly becoming evident and the development of opportunities for the China 5G market.

"In the current geopolitical context, Singapore represents a strategically significant site for IQE," says IQE's CEO Dr Drew Nelson. "The capabilities of the CSDC team and skills availability in that location, coupled with proximity to Asian chip customers and OEMs, provide a strong opportunity to contribute to IQE's global growth opportunities," he adds. "With 100% control, IQE will be best positioned to address the current financial position and secure the strategic direction of the operation."

Revenue recognised by IQE and its Singaporean subsidiary will be unaffected by the transaction, says the firm. It is anticipated that post acquisition adjusted EBITDA and adjusted Operating Profit in the consolidated group accounts for fiscal year 2019 will be adversely affected by about £0.5m.

IQE says that the acquisition is for a nominal fee of US$1 to WIN Semiconductors Corp and SGD$1 to each of the other third party shareholders, to be settled in cash. The non-cash balance sheet impacts will be finalised as part of the completion of acquisition accounting for the shareholdings. For the year ended 31 December 2018, CSDC recorded net losses of SGD$8.9m. The net liabilities attributable to CSDC as at 31 December 2018 were SGD$15.4m. The acquisition constitutes a related party transaction under AIM Rule 13 by virtue of WIN Semiconductors Corp and Nanyang Technological University being substantial shareholders in CSDC hence they are related parties under the AIM Rules.

IQE's CEO Dr Drew Nelson will remain as a director of CSDC and LG Yeap, general manager for MBE Technology Pte Ltd, will become a director of CSDC.

Riber's growth in Systems and Services revenues offsets 91% drop for Evaporators

SemiconductorToday

For third-quarter 2019, Riber S.A. of Bezons, France – which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells – has reported revenue of €6.8m, down on €7.2m last quarter but up 39% on €4.9m a year ago.

However, for the nine months to end-September, revenue is still down 4% year-on-year from €21.6m to €20.7m.

Specifically, Evaporators sales dropped by 91%, from €10.6m to €1m, following completion of the previous investment cycle for organic light-emitting diode (OLED) screen production equipment.

However, the contraction in the Evaporators business linked to the general economic environment has been offset by the development of Systems and Services activities.

Systems sales grew by 136%, from €5.4m to €12.8m, aided by the positive market environment for production MBE, with the delivery of six systems (including five production units) compared with five (including just two production units) in the first nine months of 2018.

Revenue for Services & Accessories grew further, by 23% from €5.6m to €6.9m

Correspondingly, segmenting total revenue by geographic region, just 32% came from Asia (down from 59% in the first nine months of 2018), 44% came from Europe (up from 32%) and 24% came from North America (up from just 9%).

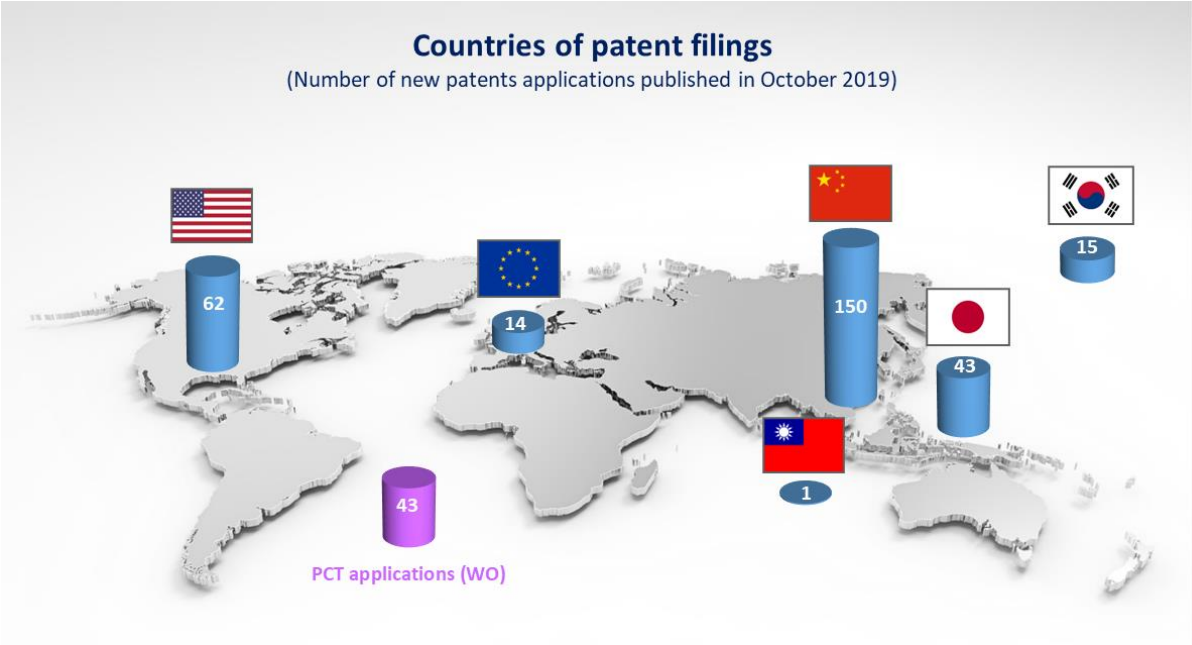
The order book at the end of September was €26.4m, down 15% on €31m a year previously. However, this was largely due to Evaporators orders dropping from €3.8m to zero. Services & Accessories orders fell by 8% from €6.6m to €6.1m. Systems orders fell by just 1% from €20.6m to €20.4m, comprising 12 systems (six production and six research), with six system (including two production units) scheduled for delivery during fourth-quarter 2019.

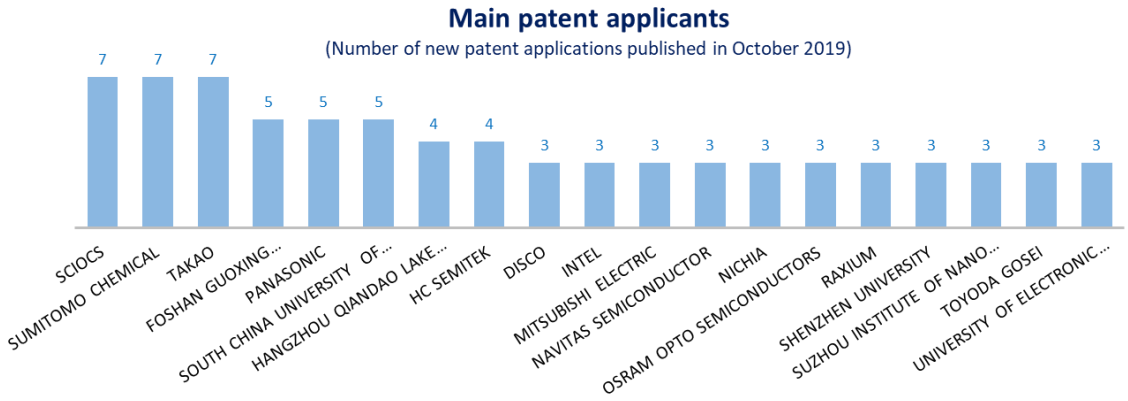
In view of these factors, for full-year 2019 Riber expects year-on-year growth in both revenue and operating income.

Riber concludes that, in a globally positive environment for the compound semiconductor market, it is moving forward with its development strategy, consolidating its market shares, expanding its portfolio of technologies and clients, and supporting the development of its service activities.

PATENT APPLICATIONS

More than 280+ **new patent families (inventions)** were published in **October 2019**.





Other patent applicants Sciocs, Sumitomo Chemical, Takao, Foshan Guoxing Semiconductor Technology, Panasonic, South China University of Technology, Hangzhou Qiandao Lake Blue Angel Industrial, HC Semitek, Disco, Intel, Mitsubishi Electric, Navitas Semiconductor, Nichia, Osram Opto Semiconductors, Raxium, Shenzhen University, Suzhou Institute of Nano Technology & Nano Bionics Chinese Academy of Sciences, Toyoda Gosei, University of Electronic Science & Technology of China, Dalian University of Technology, Fraunhofer, Fuji Electric, Globalfoundries, Globalwafers, Guangdong Bawei Biotechnology, Guangdong Institute of Semiconductor Industrial Technology, Guangdong Midea Refrigeration Equipment, Hongik University Industry Academia Cooperation Foundation, Huangshan University, Huazhong University of Science & Technology, Infineon Technologies, Institute of Semiconductors, Jiangsu Dahang Hongcheng Power Electronics, Jiangxi Zhaochi Semiconductor, Jieyi Technology, LG Innotek, Midea, Nanjing University, NGK Insulators, No 55 Institute of China Electronics Science & Technology, Shaanxi University of Science and Technology, Shanghaitech University, Shenzhen Third Generation Semiconductor Research Institute, Southeast University Nanjing, Sumitomo Electric Device Innovations, Tonghui Electronics, Toshiba, Toyota Central Research & Development Labs, University Beijing, Xiangneng Hualei Optoelectronic Corppration, 13th Research Institute of China Electronics Technology, Advanced Optoelectronic Technology, Air Liquide, Aledia, Analog Devices, Anhui University of Technology, Anhui Yijiangyuan Tea Industry, Asahi Kasei, Asti Global, Baoding Zhongchuang Yanyuan Semiconductor Technology, Beijing Institute of Remote Sensing Equipment, Beijing University of Technology, Bridgelux, British Cayman Islands Shangnachuang Technology, Cea - Commissariat à l'Energie Atomique & Aux Energies Alternatives, Chang Gung Medical Foundation Linkou Chang Gung Memorial Hospital, Chang Gung University, Changchun Institute of Optics Fine Mechanics & Physics Chinese Academy of Sciences, Chengdu RDW Technology, Chengdu Yuanwang Detection Technology, Comba Telecom Systems, Comba Telecom Systems Holdings, Comba Telecom Technology, Daegu Gyeongbuk Institute of Science & Technology, Daikin Industries, Deutsche Zentrum Fuer Luft & Raumfahrt, Dongguan Institute of Opto Electronics Peking University, Dowa Electronics Materials, Duplo Seiko, Electric Power Research Institute State Grid Jibei Electric Power, Elux, Epistar, Ericsson, Ezhou Industrial Technology Research Institute Huazhong University of Science & Technology, Facebook Technologies, Fairchild Semiconductor, Fujimi, Fujitsu, Fukuoka Industry Science & Technology Foundation, Gallium Enterprises, General Electric, Glo, Global Wafers, Gree Electric Appliances, Guangdong Electronic Information Engineering Research Institute of UESTC, Guangzhou Baifei Cosmetics, Guangzhou Jia Biological Technology, Hangzhou Haizhu Industrial, Hangzhou Sappland Microelectronics Technology, Hefei Irico Epilight Technology.

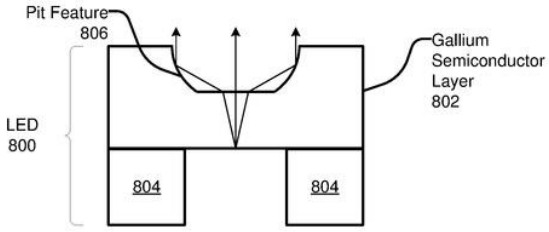
Notable new patent applications

LED surface modification with ultraviolet laser

Publication Number: US20190334058, WO2019/210291

Patent Applicant: Facebook

A laser light is used to modify the surface of the gallium semiconductor layer of an LED. The parameters of the laser are selected so that the laser interacts with the gallium semiconductor layer in a desired manner to yield the desired surface properties. For example, if a particular surface roughness is desired, the power of the laser light is selected so that the laser light penetrates the gallium semiconductor layer to a depth matching the desired surface roughness. The same principles can also be applied in a process that creates features such as trenches, pits, lenses, and mirrors on the gallium semiconductor layer of an LED. The laser projector is operated to irradiate a region of the gallium semiconductor layer to create a region of metallic gallium. The desired surface roughness and the different features can advantageously improve the beam collimation, light extraction, and other properties of the LED.

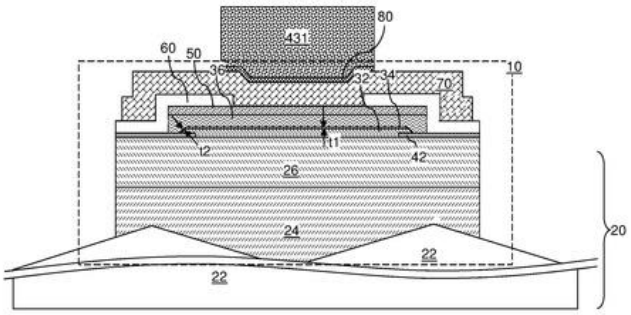


Subpixel light emitting diodes for direct view display and methods of making the same

Publication Number: US20190326478, WO2019/204748

Patent Applicant: Glo

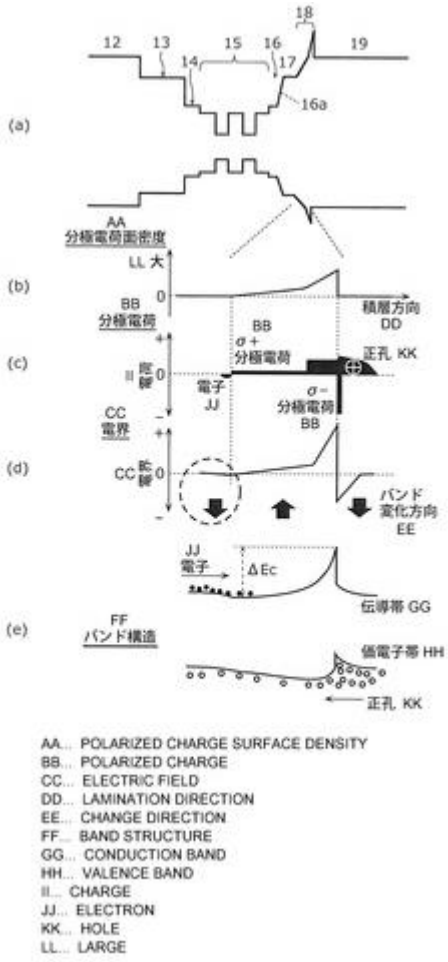
A light emitting diode (LED) includes a n-doped semiconductor material layer located over a substrate, an active region including an optically active compound semiconductor layer stack configured to emit light located over the n-doped semiconductor material layer, a p-doped semiconductor material layer located over the active region and containing a nickel doped surface region, a conductive layer contacting the nickel doped surface region of the p-doped semiconductor material, and a device-side bonding pad layer electrically connected to the conductive layer.



Semiconductor light emitting element

Publication Number: WO2019/187583
Patent Applicant: Panasonic

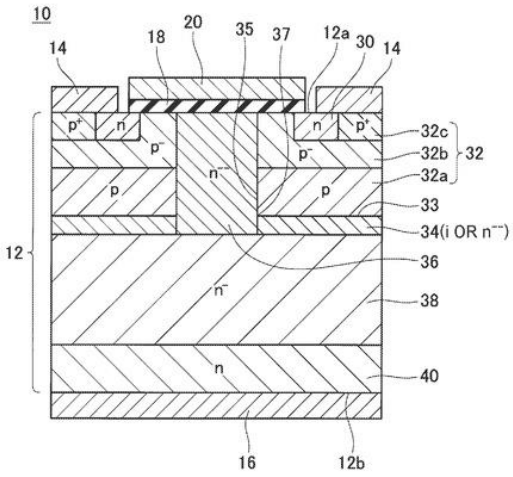
This semiconductor light emitting element (100) is provided with: a GaN substrate (11); a first semiconductor layer (12) disposed on the GaN substrate (11) and comprising a nitride-based semiconductor of a first conduction type; an active layer (15) disposed on the first semiconductor layer (12) and comprising a nitride-based semiconductor comprising Ga or In; an electron barrier layer (18) disposed on the active layer (15) and comprising a nitride-based semiconductor layer comprising at least Al; and a second semiconductor layer (19) disposed on the electron barrier layer (18) and comprising a nitride layer of a second conduction type that is different from the first conduction type. The electron barrier layer (18) has: a first area in which the content of Al changes at a first change rate; and a second area which is disposed between the first area and the second semiconductor layer (19) and in which the content of Al changes at a second change rate. In the first area and the second area, the content of Al monotonously increases in the direction from the active layer (15) toward the second semiconductor layer (19), and the second change rate is greater than the first change rate.



Semiconductor device and manufacturing method for semiconductor device

Publication Number: JP2019175908, US20190305124, DE102019107294, CN110310995
Patent Applicant: Toyota Motor, Toyota Central R&D Labs

A semiconductor device includes an n-type first drift layer, an i-type or an n-type withstand voltage layer disposed on top of the first drift layer, a p-type body layer disposed on top of the withstand voltage layer, an n-type second drift layer that is disposed on top of the first drift layer, is in contact with side surfaces of the withstand voltage layer and the body layer, an n-type source layer that is disposed on top of the body layer, is separated from the first drift layer, the second drift layer, and the withstand voltage layer by the body layer, and a gate electrode that faces the body layer through a gate insulating film, the body layer being positioned between the second drift layer and the source layer. The withstand voltage layer is made from a material having a bandgap larger than that of the first drift layer.

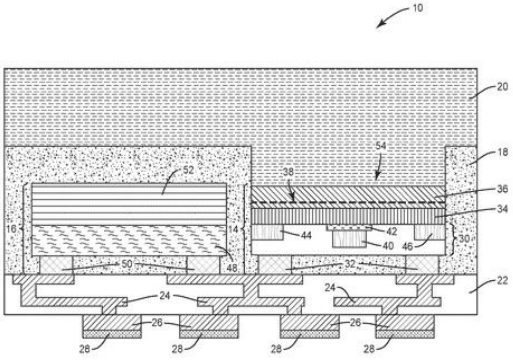


GaN-based module with enhanced electrical performance and process for making the same

Publication Number: US20190312110, WO2019/195428

Patent Applicant: Qorvo

The present disclosure relates to a Gallium-Nitride based module, which includes a module substrate, a thinned switch die residing over the module substrate, a first mold compound, and a second mold compound. The thinned switch die includes an electrode region, a number of switch interconnects extending from a bottom surface of the electrode region to the module substrate, an aluminium gallium nitride barrier layer over a top surface of the electrode region, a GaN buffer layer over the AlGaN barrier layer, and a lateral two-dimensional electron gas layer realized at a heterojunction of the AlGaN barrier layer and the GaN buffer layer. The first mold compound resides over the module substrate, surrounds the thinned switch die, and extends above a top surface of the thinned switch die to form an opening over the top surface of the thinned switch die. The second mold compound fills the opening.



Method of fabricating non-polar and semi-polar devices using epitaxial lateral overgrowth

Publication Number: WO2019/191760

Patent Applicant: University of California

A method of fabricating a semiconductor device, comprising: forming a growth restrict mask on or above a III-nitride substrate, and growing one or more island-like III-nitride semiconductor layers on the III-nitride substrate using the growth restrict mask. The III-nitride substrate has an in-plane distribution of off-angle orientations with more than 0.1 degree; and the off-angle orientations of an m-plane oriented crystalline surface plane range from about +28 degrees to about -47 degrees towards a c-plane. The island-like III-nitride semiconductor layers have at least one long side and short side, wherein the long side is perpendicular to an a-axis of the island-like III-nitride semiconductor layers. The island-like III-nitride semiconductor layers do not coalesce with neighboring island-like III-nitride semiconductor layers.

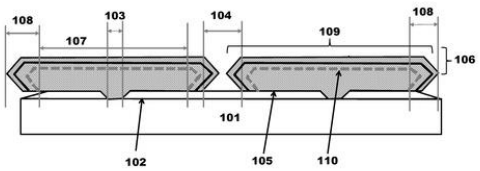


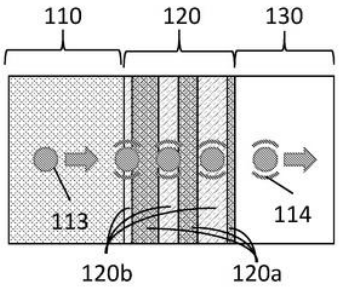
Fig. 1

Semiconductor structure with chirp layer

Publication Number: WO2019/193487

Patent Applicant: Silanna UV Technologies

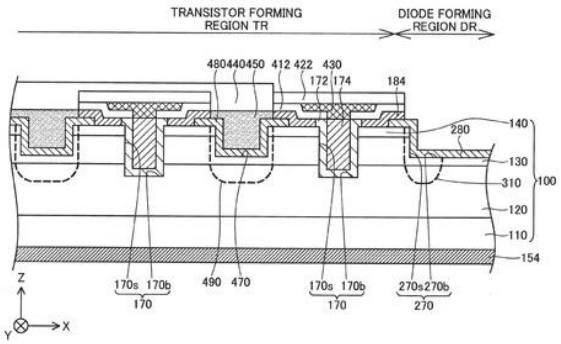
A semiconductor structure can comprise a plurality of first semiconductor layers comprising wide bandgap semiconductor layers, a narrow bandgap semiconductor layer, and a chirp layer between the plurality of first semiconductor layers and the narrow bandgap semiconductor layer. The values of overlap integrals between different electron wavefunctions in a conduction band of the chirp layer can be less than 0.05 for intersubband transition energies greater than 1.0 eV, and/or the values of overlaps between electron wavefunctions and barrier centers in a conduction band of the chirp layer can be less than 0.3 nm-1, when the structure is biased at an operating potential. The chirp layer can comprise a short-period superlattice with alternating wide bandgap barrier layers and narrow bandgap well layers, wherein the thickness of the barrier layers, or the well layers, or the thickness of both the barrier and well layers changes throughout the chirp layer.



Semiconductor device

Publication Number: US20190305126, JP2019175984
Patent Applicant: Toyoda Gosei

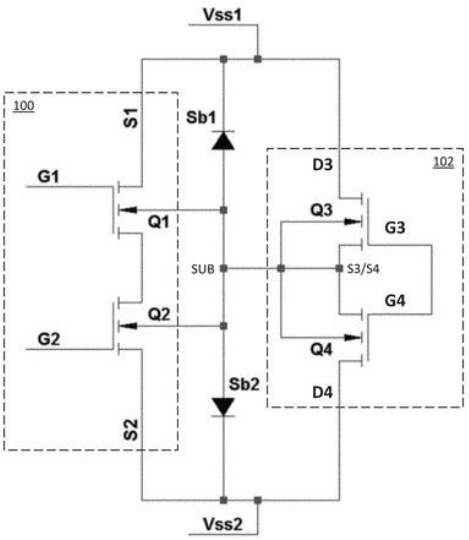
To suppress breakage of a diode. A semiconductor device comprises a stacked body and a first electrode. The stacked body includes a first nitride semiconductor layer, a second nitride semiconductor layer, a third nitride semiconductor layer, and a fourth nitride semiconductor layer that are stacked in sequence. The first electrode is in contact with a surface of the first nitride semiconductor layer that is opposite to a surface in contact with the second nitride semiconductor layer. The semiconductor device includes a transistor forming region and a diode forming region adjacent to the transistor forming region. The transistor forming region includes a first groove, a second electrode, and a third electrode. The first groove has a bottom portion located in the second nitride semiconductor layer. The second electrode is formed on a surface of the first groove. The third electrode is in contact with a surface of the fourth nitride semiconductor layer that is opposite to a surface in contact with the third nitride semiconductor layer. The diode forming region includes a second groove and a Schottky electrode. The second groove has a bottom portion located in the third nitride semiconductor layer. The Schottky electrode makes a Schottky barrier junction with the third nitride semiconductor layer and is electrically connected to the third electrode.



Semiconductor device having a bidirectional switch and discharge circuit

Publication Number: US20190326280, EP3562040, CN110391224
Patent Applicant: Infineon

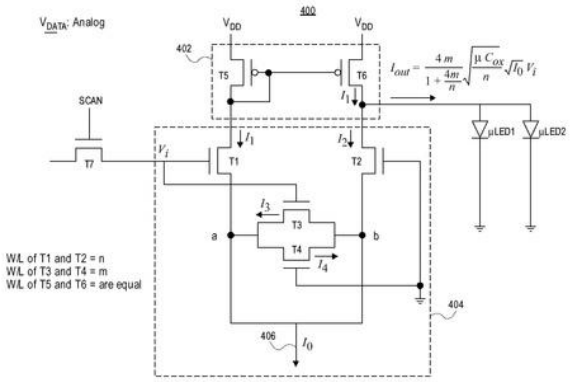
A semiconductor device includes a main bi-directional switch formed on a semiconductor substrate and having first and second gates, a first source electrically connected to a first voltage terminal, a second source electrically connected to a second voltage terminal, and a common drain. The semiconductor device further includes a discharge circuit having a plurality of individual transistors or an auxiliary bi-directional switch monolithically integrated with the main bi-directional switch and connected in a common source configuration to the semiconductor substrate. The plurality of individual transistors or the auxiliary bi-directional switch includes a first drain connected to the first source of the main bi-directional switch, a second drain connected to the second source of the main bi-directional switch, and first and second gates each decoupled from gate drive circuitry so that the first and the second gates are controlled at least passively and based on a state of the main bi-directional switch.



Micro light-emitting diode display driver architecture and pixel structure

Publication Number: US20190335553, WO2019/209411
Patent Applicant: Intel

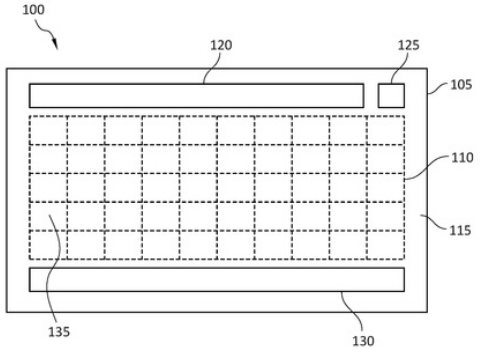
Micro light-emitting diode display driver architectures and pixel structures are described. In an example, a driver circuit for a micro light emitting diode device includes a current mirror. A linearized transconductance amplifier is coupled to the current mirror. The linearized transconductance amplifier is to generate a pulse amplitude modulated current that is provided to a set of micro LEDs connected in parallel to provide fault tolerance architecture.



Gallium nitride transistor structure

Publication Number: US20190326426, CN110391297
Patent Applicant: Navitas Semiconductor

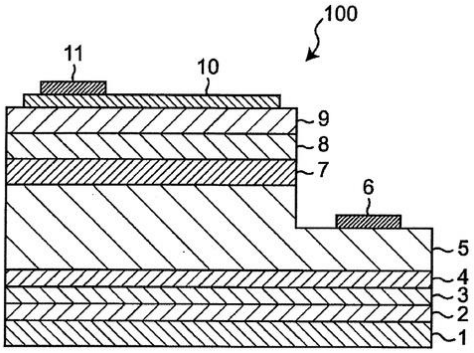
A gallium nitride transistor includes a substrate on which a source region, a drain region, a drift region and a gate region are defined. The drift region extends between the source region and the drain region. The gate region includes a combination of enhancement-mode and depletion-mode devices that are positioned across the drift region and are used together to control charge density and mobility of electrons in the drift region with a relatively low threshold voltage (Vth). Enhancement-mode devices are formed using a P-type layer disposed on the substrate and coupled to a gate electrode.



Nitride semiconductor light emitting element

Publication Number: JP2019176016, US20190305187, KR10-2019-0113647, CN110323314
Patent Applicant: Nichia

A nitride semiconductor light emitting element configured to emit deep ultraviolet light, the light emitting element comprises: an n-side contact layer comprising Al, Ga, and N; and an n-electrode disposed on the contact layer, wherein the n-electrode comprises, successively from the n-side contact layer side, a first layer consisting essentially of Ti, a second layer consisting essentially of a Si-containing Al alloy, and a third layer comprising at least one of a layer consisting essentially of Ta and/or a layer consisting essentially of W.

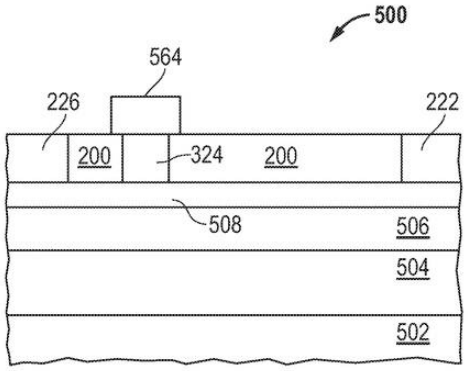


Electronic device including an enhancement-mode hemt and a method of using the same

Publication Number: US20190305123, CN110323276

Patent Applicant: Fairchild, ON Semiconductor

An electronic device can include an enhancement-mode high electron mobility transistor (HEMT) that includes a source electrode; a drain electrode; and a gate. In an embodiment, the gate can correspond to spaced-apart gate electrodes and a space disposed between the spaced-apart gate electrodes, wherein the first space has a width configured such that, a continuous depletion region forms across all of the width of the first space. In another embodiment, the gate can be a gate electrode having a nonuniform thickness along a line in a gate width direction. In another aspect, a method of using the electronic device can include, during a transient period when the HEMT is in an off-state, flowing current from the drain electrode to the source electrode when Vds>−Vth+Vgs.



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