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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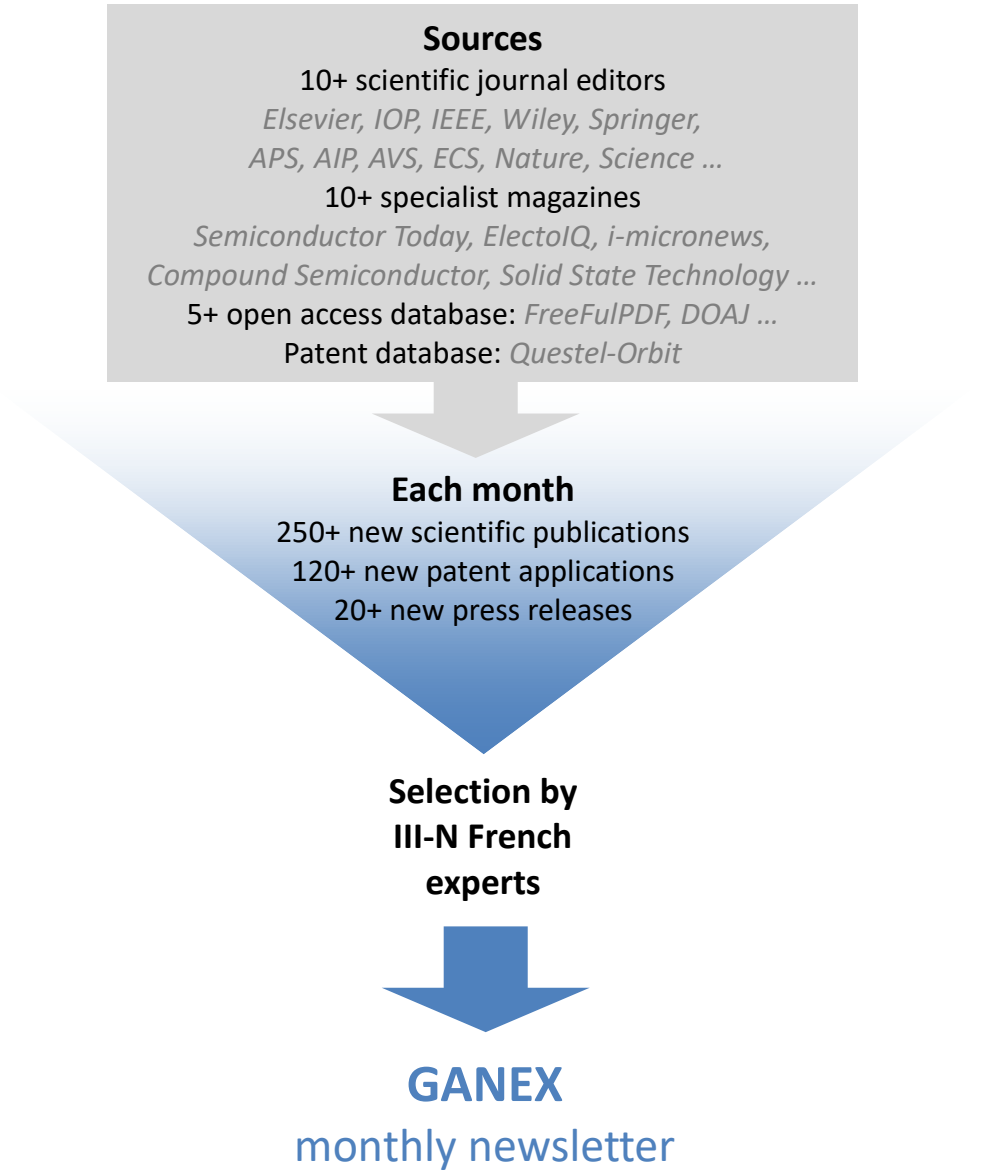
METHODOLOGY



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SCIENTIFIC PUBLICATION

Selection of new scientific articles

GROUP 1 - LEDs and Lighting

Group leader: Benjamin Damilano (CRHEA-CNRS)

Information selected by Benjamin Damilano (CRHEA-CNRS)

Enhancing the spontaneous emission rate by modulating carrier distribution in GaN-based surface plasmon light-emitting diodes

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Optics Express
https://doi.org/10.1364/OE.25.009617

Based on the nanorod structure, we have fabricated GaN-based surface plasmon light-emitting diodes with Ag nanoparticles deposited laterally proximity to the multiple quantum wells (MQWs) region, which allows us to investigate the quantum well – surface plasmon (QW-SP) coupling effect. Our results show that the QW-SP coupling effect increases significantly when the SP resonant wavelength of Ag nanoparticles is close to the QW emission wavelength, especially by using a shorter wavelength light source, which will further enhance the spontaneous emission rate. Combined with the simulations, we find that the enhancement is due to the decreased excitation light penetration depth into the active region, which can modulate the carrier distribution and increase the proportion of SP-coupled carriers in the MQWs of LEDs. To increase the spontaneous emission rate for the electrical QW-SP coupled LEDs, we can use single QW or MQW structure to confine the carriers in the topmost QW, which will effectively increase the proportion of SP-coupled carriers. Our findings pave a way to design the ultrafast LED light source for the application of visible light communication (VLC).

Enhancement of Emission Efficiency of Deep-Ultraviolet AlGaN Quantum Wells Through Surface Plasmon Coupling with an Al Nanograting Structure

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Plasmonics
http://dx.doi.org/10.1007/s11468-017-0582-5

The enhancement of the internal quantum efficiency (IQE) of deep-ultraviolet AlxGa1-xN/AlyGa1-yN (x < y) quantum wells (QWs) by fabricating one-dimensional Al nanogratings on a QW structure for inducing surface plasmon (SP) coupling is demonstrated. Through temperature-dependent photoluminescence (PL) measurement, the enhancements of IQE in different emission polarizations are illustrated. Due to the small difference in energy band level between the heavy/light hole and split-off valence bands, the IQEs of the transverse electric- (TE-) and transverse magnetic- (TM-) polarized emissions are about the same. When emission polarization is perpendicular to Al-grating ridges, the SP resonance mode for coupling with the QWs is dominated by localized surface plasmon (LSP). When emission polarization is parallel with Al-grating ridges, the coupled SP resonance mode may mix LSP and SP polariton. In this polarization, LSP can be excited because of the width fluctuation of a grating ridge. When the excitation laser polarization is perpendicular to Al-grating ridges, the strong LSP resonance at the excitation laser wavelength leads to stronger excitation and hence higher IQE levels.

Analysis of junction temperatures for groups III–V semiconductor materials of light-emitting diodes

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Optical and Quantum Electronics
http://dx.doi.org/10.1007/s11082-017-1015-6

This study utilizes the Shockly equation and Fourier's law with the optical, electrical and thermal properties of LEDs to predict the variation of the junction

temperature with the injection current. It is shown that the relationship of the junction temperature with the injection current can be determined by the effective thermal conductivity, temperature coefficient of junction voltage, series resistance, integral constant (forward voltage at the initial forward current and junction temperature), ambient temperature and external quantum efficiency. The effective thermal conductivity, temperature coefficient of junction voltage, and series resistance are calculated from the material properties based on the structures of LEDs instead of measurements in this study. The junction temperature of AlGaInP/GaInP MQW red LED predicted from this study agrees with the available experimental data and the junction temperatures of GaInN UV LED and AlGaN UV LED calculated by this work are also consistent with these obtained from the emission peak shift method. The elevated temperatures of AlGaN and GaInN are larger than that of AlGaInP/GaInP MQW red LED due to the difference of the thermal conductivity for the LED substrate. This study also presents the effects of the parameters on the variation of the junction temperature with the injection current. The effective thermal conductivity and ambient temperature significantly affect the junction temperature of LEDs.

Efficiency enhancement in AlGaN deep ultraviolet light-emitting diodes by adjusting Mg doped staggered barriers

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Superlattices and Microstructures
http://doi.org/10.1016/j.spmi.2017.03.055

Ultraviolet light-emitting diodes (UVLEDs) with staggered barriers have been studied. The energy band diagrams, internal quantum efficiency, total output power and radiative recombination rate are investigated by APSYS software. The simulation results show that the UVLED with staggered barriers get a little enhancement comparing to the conventional one, on the contrary the structure with p-doped staggered barriers has higher efficiency and power due to enhancement of the holes' injection and the electrons' confinement. Then structures with different Al content in the Mg-doped barriers have been studied numerically and that confirmed the best.

Fabrication and Characterization of Si Substrate-Free InGaN Light-Emitting Diodes and Their Application in Visible Light Communications

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IEEE Photonics Journal
https://doi.org/10.1109/JPHOT.2017.2683481

Visible light communications with InGaN-based light-emitting diodes (LEDs) grown on large-diameter (6-inch) and cost-effective Si (111) substrates are investigated experimentally. During epitaxial growth, the transition layers consisted of the step-graded AlGaN buffers incorporated with three low-temperature-grown (~900 °C) AlN interlayers on AlN/Si substrates that are used to compensate for thermally induced tensile stress and to maintain a reasonable crystalline quality of GaN-on-Si LEDs. Strong light absorption from Si can be prevented by fabricating a Si substrate-free InGaN LED with a composite metal coating of Al/Ag/Al multilayer, providing improved adhesive strength and reflectivity comparable to the unitary Ag film. In comparison with GaN-on-Si LEDs, stripping Si substrates combined with the use of a highly reflective bottom mirror (Al/Ag/Al multilayer) reflected a more intense emission pattern corresponding to a 2.2 times (@ 190 mA) increase in light output power in thin-film LEDs. In addition, a 1.8 times (@ 160 mA) increase in optical channel bandwidth is achieved by using thin-film LEDs as optical transmitters. A direct line-of-sight optical link using the proposed thin-film LEDs achieved data transmission rates of up to 100 Mb/s over a distance of 100 cm, indicating that the proposed LEDs have potential for use as optical transmitters in indoor visible light communications."

Monolithic cyan – violet InGaN/GaN LED array

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Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600815

In the case of InGaN alloys grown by metalorganic vapour phase epitaxy on a c-plane GaN, indium content decreases as the substrate miscut is increased. This phenomenon has been previously used to fabricate laser diodes with variable wavelength on one chip [Appl. Phys. Express 5, 021001 (2012)]. In that work, however, wavelength variation was only 5 nm. In the present work we show independent, electrically driven array of light emitting diodes (LED), covering 40 nm emission wavelength range on one chip. This is achieved by a particular patterning technique, which enables the change in the local miscut of the substrate by introducing large enough slopes for practical devices. This technological approach offers a new degree of freedom for InGaN/GaN bandgap modification and device engineering. It can be applied to freestanding GaN as well as to GaN/sapphire templates used for mass production of LEDs. Once optimized, this approach could eventually lead to truly monolithic RGB LEDs.

Phosphor-based light conversion for miniaturized optical tools

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Applied Optics
https://doi.org/10.1364/AO.56.003654

This paper describes the application of phosphor-based light conversion for its use in optogenetic experiments to tailor the wavelength of light emitted from implantable miniaturized light sources. Gallium-nitride-based blue light-emitting diodes are used in combination with orthosilicate phosphor immersed in an epoxy matrix and emitting in the yellow wavelength range. The miniaturization of the phosphor-containing polymer droplets toward diameters as small as 300 µm provides the compatibility with implantable optical probes. The parameter study applied here varied the concentration of the phosphor material in the polymer matrix as well as the droplet height in order to tailor the characteristics of blue-to-yellow light conversion.

150 mW deep-ultraviolet light-emitting diodes with large-area AlN nanophotonic light-extraction structure emitting at 265 nm

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4978855

High-power 265 nm deep-ultraviolet (DUV) AlGaN-based light-emitting diodes (LEDs) with large-area AlN nanophotonic light-extraction structures that were fabricated by a nanoimprint lithography process are presented. Each DUV-LED has a large active area (mesa size of ~0.35 mm2) and a uniform current spreading design that allows high injection current operation. We have shown that these DUV-LEDs with their large-area nanoimprinted AlN nanophotonic structures exhibit wider near-field emitting areas, stronger far-field extracted light intensities, and an approximately 20-fold increase in output power when compared with a conventional flat-surface DUV-LED. A large-area nanoimprinted single-chip DUV-LED operating in the UV-C wavelength regime has demonstrated a record continuous-wave output power in excess of 150 mW for an injection current of 850 mA at a peak emission wavelength of 265 nm.

Carrier capture in InGaN/GaN quantum wells: Role of electron-electron scattering

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Journal of Applied Physics
http://dx.doi.org/10.1063/1.4979010

The competition of electron-electron interband scattering (ee) and longitudinal optical phonon emission (e-ph) as electron capture mechanisms is theoretically investigated in III-nitride quantum wells. The non-trivial separation of their scattering probabilities is discussed, and compact expressions for capture time are obtained in the framework of the quantum many-body formalism. At the typical operating conditions of light emitting diodes (LEDs), the model predicts an increasing importance of ee scattering as a capture mechanism with increasing

carrier density. Verifications against recent experiments are presented to support this finding and confirm the need for population-dependent capture time expressions including both ee and e-ph mechanisms for an accurate description of LED carrier dynamics and efficiency.

All metalorganic chemical vapor phase epitaxy of p/n-GaN tunnel junction for blue light emitting diode applications

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4978268

We report on III-Nitride blue light emitting diodes (LEDs) comprising a GaN-based tunnel junction (TJ) all realized by metalorganic vapor phase epitaxy in a single growth process. The TJ grown atop the LED structures consists of a Mg-doped GaN layer and subsequently grown highly Ge-doped GaN. Long thermal annealing of 60 min at 800 °C is important to reduce the series resistance of the LEDs due to blockage of acceptor-passivating hydrogen diffusion through the n-type doped top layer. Secondary ion mass spectroscopy measurements reveal Mg-incorporation into the topmost GaN:Ge layer, implying a non-abrupt p-n tunnel junction and increased depletion width. Still, significantly improved lateral current spreading as compared to conventional semi-transparent Ni/Au p-contact metallization and consequently a more homogeneous electroluminescence distribution across $1 \times 1\ mm^2$ LED structures is achieved. Direct estimation of the depletion width is obtained from electron holography experiments, which allows for a discussion of the possible tunneling mechanism.

Time dependent and temperature dependent properties of the forward voltage characteristic of InGaN high power LEDs

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AIP Advances
http://dx.doi.org/10.1063/1.4978265

Estimating the junction temperature and its dynamic behavior in dependence of various operating conditions is an important issue, since these properties influence the optical characteristics as well as the aging processes of a light-emitting diode (LED). Particularly for high-power LEDs and pulsed operation, the dynamic behavior and the resulting thermal cycles are of interest. The forward voltage method relies on the existence of a time-independent unique triple of forward-voltage, forward-current, and junction temperature. These three figures should as well uniquely define the optical output power and spectrum, as well as the loss power of the LED, which is responsible for an increase of the junction temperature. From transient FEM-simulations one may expect an increase of the temperature of the active semiconductor layer of some 1/10 K within the first 10 µs. Most of the well-established techniques for junction temperature measurement via forward voltage method evaluate the measurement data several dozens of microseconds after switching on or switching off and estimate the junction temperature by extrapolation towards the time of switching. In contrast, the authors developed a measurement procedure with the focus on the first microseconds after switching. Besides a fast data acquisition system, a precise control of the switching process is required, i.e. a precisely defined current pulse amplitude with fast rise-time and negligible transient by-effects. We start with a short description of the measurement setup and the newly developed control algorithm for the generation of short current pulses. The thermal characterization of the LED chip during the measurement procedures is accomplished by an IR thermography system and transient finite element simulations. The same experimental setup is used to investigate the optical properties of the LED in an Ulbricht-sphere. Our experiments are performed on InGaN LED chips mounted on an Al based insulated metal substrate (IMS), giving a comprehensive picture of the transient behavior of the forward voltage of this type of high power LED.

MOCVD growth of GaN on SEMI-spec 200 mm Si

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Semiconductor Science and Technology
https://doi.org/10.1088/1361-6641/aa681c

We describe the results produced from our research on integrating GaN devices with Si CMOS integrated circuits. High quality, low bow and robust 200 mm GaN on SEMI-spec epitaxial Si (725 µm) wafers are achieved by using a unique shaped susceptor and careful control of buffer design. High brightness InGaN/GaN MQW LEDs emitting at 450 nm with total III-N stack thickness of 3.6 µm have also been demonstrated. The growth technology of GaN on SEMI-spec 200 mm leads to new wafer/device platforms such as GaN-OI and CMOS + GaN that will open new avenues in device performance and integration of III-N devices with Si CMOS.

Self-assembled indium tin oxide nanoball-embedded omnidirectional reflectors for high photon extraction efficiency in III-nitride ultraviolet emitters

Semi Oh et al.

Nanoscale
http://dx.doi.org/10.1039/C7NR00957G

The control of refractive index and electrical conductivity in dielectric layer of onmidirectional reflectors (ODRs) is essential to improve the low efficiency of AlGaN-based UV emitters. Here, we report self-assembled indium tin oxide (ITO) nanoball-embedded omnidirectional reflectors (NODRs) for use in high-efficiency AlGaN-based UV emitters of 365 nm. This NODRs consisted of a reflective Al layer, self-assembled conducting ITO nanoball layer for current injection and spreading, and nanovoids that provided a low refractive index to achieve a highly efficient UV emitters. The NODR was able to realize both high electrical conductivity and reflectivity by decreasing the average refractive index of the ITO nanoball layers. We observed diffuse reflection as well as omnidirectional reflection from the NODR UV emitters because of the corrugated interfaces of the nanovoids, ITO nanoball layer, and Al layer. These structural and optical properties of the NODRs remarkably increased the output power of a UV emitter by a Lambertian enhancement factor of 57% at an injection current of 50 mA at all emission angles compared with that of an ITO film/Al UV emitter.

A comparative study of efficiency droop and internal electric field for InGaN blue lighting-emitting diodes on silicon and sapphire substrates

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Scientific Reports
http://dx.doi.org/10.1038/srep44814

We investigated the efficiency droop and polarization-induced internal electric field of InGaN blue light-emitting diodes (LEDs) grown on silicon(111) and c-plane sapphire substrates. The efficiency droop of the LED sample grown on silicon substrates was considerably lower than that of the identically fabricated LED sample grown on sapphire substrates. Consequently, the LED on silicon showed higher efficiency at a sufficiently high injection current despite the lower peak efficiency caused by the poorer crystal quality. The reduced efficiency droop for the LED on silicon was attributed to its lower internal electric field, which was confirmed by reverse-bias electro-reflectance measurements and numerical simulations. The internal electric field of the multiple quantum wells (MQWs) on silicon was found to be reduced by more than 40% compared to that of the MQWs on sapphire, which resulted in a more homogenous carrier distribution in InGaN MQWs, lower Auger recombination rates, and consequently reduced efficiency droop for the LEDs grown on the silicon substrates. Owing to its greatly reduced efficiency droop, the InGaN blue LED on silicon substrates is expected to be a good cost effective solution for future lighting technology.

Indium gallium nitride-based ultraviolet, blue, and green light-emitting diodes functionalized with shallow periodic hole patterns

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Scientific Reports
http://dx.doi.org/10.1038/srep45726

In this study, we investigated the improvement in the light output power of indium gallium nitride (InGaN)-based ultraviolet (UV), blue, and green light-emitting diodes (LEDs) by fabricating shallow periodic hole patterns (PHPs) on the LED surface through laser interference lithography and inductively coupled plasma etching. Noticeably, different enhancements were observed in the light output powers of the UV, blue, and green LEDs with negligible changes in the electrical properties in the light output power versus current and current versus voltage curves. In addition, confocal scanning electroluminescence microscopy is employed to verify the correlation between the enhancement in the light output power of the LEDs with PHPs and carrier localization of InGaN/GaN multiple quantum wells. Light propagation through the PHPs on the UV, blue, and green LEDs is simulated using a three-dimensional finite-difference time-domain method to confirm the experimental results. Finally, we suggest optimal conditions of PHPs for improving the light output power of InGaN LEDs based on the experimental and theoretical results.

GROUP 2 - Laser and Coherent Light

Group leader: Bruno Gayral (CEA)

Information selected by Knowmade

Performance of InGaN based green laser diodes improved by using an asymmetric InGaN/InGaN multi-quantum well active region

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Optics Express
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Series of green laser diodes (LDs) with different (In)GaN barrier layers are investigated. It is found that the optical confinement factor of multi-quantum well (MQW) always increases with increasing indium content of InGaN barrier layer, which results in a decrease of threshold current when indium content of InGaN barrier layer increases from 0 to 5%. However, when a high In content InGaN barrier is used (> 5%), both threshold current and slop efficiency of LDs deteriorate. It may be attributed to the waste of carriers in the potential well at the interface between the last barrier (LB) and the upper waveguide (UWG) layers, which is induced by the piezoelectric polarization effect in high In content InGaN LB layer. Therefore, a new LD structure using a thin thickness of the LB layer to reduce the effect of polarization shows a low threshold current and a high output power even when the In content of barrier layers is as large as 7%.

Thermal lensing effects on lateral leakage in GaN-based vertical-cavity surface-emitting laser cavities

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Optics Express
https://doi.org/10.1364/OE.25.009556

Lateral leakage of light has been identified as a detrimental loss source in many suggested and experimentally realized GaN-based VCSELs. In the present work we include thermal effects to realistically account for the substantial Joule heating in these devices. In contrast to what could be expected from the previous results, the induced thermal lensing does not make antiguided cavities more positively guided, so that they approach the unguided regime with extremely high lateral leakage. Rather, thermal lensing strongly suppresses lateral leakage for both antiguided and guided cavities. This is explained in terms of lowered launch of power from the central part of the cavity and/or lower total internal reflection in the peripheral part; the former effect is active in all cavities whereas the latter only contributes to the very strongly reduced leakage in weakly antiguided cavities. Thermal lensing suppresses lateral leakage both for the fundamental and the first higher order mode, but a strong modal discrimination is still achieved for the antiguided cavities. Thus, strongly antiguided cavities could be used to achieve single-mode devices, but at the cost of slightly higher threshold gain and stronger temperature dependent performance characteristics.

The effect of AlGaN bulk and AlGaN/GaN superlattice cladding layers on performance characteristics of deep violet InGaN DQW lasers

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Vacuum
http://doi.org/10.1016/j.vacuum.2017.04.002

This paper reports performance characteristics of InGaN-based DQW laser diodes with different SLS cladding layer (CL) structures using the ISE TCAD software. LDs with SLSs as CLs were shown to have superior optical and electrical properties compared to LDs with bulk AlGaN CLs.The simulation results show the variation of output power, threshold current, slope efficiency, and differential quantum efficiency (DQE) from 13.51 to 10.88 mA, 20.92 to 41.27 mW, 1.83 to 1.87 W/A and 57.88 to 59.10%, for bulk to SLS CLs. Results show the increased operating

current, electron and hole carrier densities and radiative recombination which enhanced output power and reduced threshold current for the structure with the SLS down CL. Using SLS in upper CL doesn't have significant effect on operating current, it increase the slope efficiency and DQE. Using SLS structure simultaneously in up and down CLs enhances the output power, DQE and slop efficiency, and decreases the threshold current.

Enhancement of optical gain by controlling waveguide modes in semipolar InGaN quantum well laser diodes

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Physica status solidi (b)
http://dx.doi.org/10.1002/pssb.201600746

Waveguide modes in semipolar InGaN quantum-well (QW) laser diodes (LDs) with cleaved-facet cavity mirrors have been theoretically investigated using a 4×4 transfer matrix technique. It is shown that the waveguide mode can be controlled by changing the refractive-index contrast in the waveguide structures, although previous studies suggest that the waveguide modes are either ordinary or extraordinary due to the birefringence of the material itself, and that optical gain cannot be fully utilized for lasing because the polarization direction which determines optical gain in the devices does not coincide with the polarization direction in the waveguide mode. This behavior can be explained based on the competition between the layer-structural effect and the material birefringence. From the results of our calculations, it is concluded that the utilization of a high refractive-index-contrast waveguide structure is effective in enhancing the optical gain in semipolar LDs with cleaved-facet cavity mirrors.

Ultrafast all-optical modulation in Fe-doped GaN at 1.31 and 1.55 µm with high contrast and ultralow power

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4980090

We demonstrate the possibility of all-optical modulation at 1.31 and 1.55 µm optical communication wavelengths by interband pumping of Fe-doped GaN crystals using femtosecond pump-probe techniques. Considering the lower photon energy of near-infrared probe pulses, switching time was well controlled by Fe doping from the nanosecond range to a value as fast as 10 ps for Fe concentration of 1×1019 cm−3 arising from the carrier trapping effect of deep Fe acceptors, which suggests a modulation speed performance of ∼50 GHz. Simultaneously, about 50% of modulation contrast was achieved by means of optical excitation at an ultralow pump fluence of 0.5 mJ/cm2. Moreover, almost no degradation of the modulation contrast and speed was observed due to Fe doping.

Stimulated emission from semi-polar (11-22) GaN overgrown on sapphire

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AIP Advances
http://dx.doi.org/10.1063/1.4981137

(11-22) semi-polar GaN is expected to exhibit major advantages compared with current c-plane polar GaN in the fabrication of long wavelength such as green and yellow emitters. However, all the III-nitride based semi-/non- polar laser diodes (LDs) reported so far have been achieved exclusively based on homo-epitaxial growth on extremely expensive free-standing GaN substrates with a very limited size. In this paper, we have observed a stimulated emission at room temperature achieved on our semi-polar (11-22) GaN overgrown on a micro-rod arrayed template with an optimized design on m-plane sapphire. This has never been achieved previously on any semi-polar GaN grown on sapphire. Furthermore, an optical gain of 130cm−1 has been measured by means of performing a standard laser stripe-length dependent optical measurement. The values of the threshold and the optical gain obtained are comparable to those of the c-plane GaN reported so far, further validating the satisfactory crystal quality of our overgrown semi-polar (11-22) GaN on sapphire. This represents a major step towards the development of III-nitride semi-polar based LDs on sapphire, especially in the long wavelength regime.

Study of intersubband transitions in GaN-ZnGeN2 coupled quantum wells

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Journal of Applied Physics
http://dx.doi.org/10.1063/1.4977696

In this work, we design and analyze a closely lattice-matched wide bandgap GaN-ZnGeN2 coupled quantum well (QW) structure targeting for near-infrared (IR) ($\lambda \leq 3$ um) intersubband transition for quantum cascade laser applications. The coupled quantum well structure comprised two GaN wells separated by a thin ZnGeN2 barrier layer. The QW active region is surrounded by thick ZnGeN2 layers as barriers. The computations of the electron-phonon and electron-photon scattering rates are carried out by employing the Fermi's golden rule for transitions. The calculation takes into consideration the conservation of energy and momentum in scattering processes. The coupled QW structure is optimized through tuning the confined subband energy levels in the conduction band to achieve (1) electron-LO phonon resonant scattering when the energy separation between the first and second conduction subband levels matches the phonon energy of GaN (92 meV); and (2) dominant electron-photon transition in near-IR between the third and second conduction subband levels.

Efficient continuous-wave nonlinear frequency conversion in high-Q gallium nitride photonic crystal cavities on silicon

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APL Photonics
http://dx.doi.org/10.1063/1.4974311

We report on nonlinear frequency conversion from the telecom range via second harmonic generation (SHG) and third harmonic generation (THG) in suspended gallium nitride slab photonic crystal (PhC) cavities on silicon, under continuous-wave resonant excitation. Optimized two-dimensional PhC cavities with augmented far-field coupling have been characterized with quality factors as high as 4.4 × 104, approaching the computed theoretical values. The strong enhancement in light confinement has enabled efficient SHG, achieving a normalized conversion efficiency of 2.4 × 10−3 W−1, as well as simultaneous THG. SHG emission power of up to 0.74 nW has been detected without saturation. The results herein validate the suitability of gallium nitride for integrated nonlinear optical processing.

Effect of hydrogen treatment temperature on the properties of InGaN/GaN multiple quantum wells

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Nanoscale Research Letters
http://dx.doi.org/10.1186/s11671-017-2109-6

InGaN/GaN multiple quantum wells (MQWs) were grown with hydrogen treatment at well/barrier upper interface under different temperatures. Hydrogen treatment temperature greatly affects the characteristics of MQWs. Hydrogen treatment conducted at 850 °C improves surface and interface qualities of MQWs, as well as significantly enhances room temperature photoluminescence (PL) intensity. In contrast, the sample with hydrogen treatment at 730 °C shows no improvement, as compared with the reference sample without hydrogen treatment. On the basis of temperature-dependent PL characteristics analysis, it is concluded that hydrogen treatment at 850 °C is more effective in reducing defect-related non-radiative recombination centers in MQWs region, yet has little impact on carrier localization. Hence, hydrogen treatment temperature is crucial to improving the quality of InGaN/GaN MQWs.

Effect of compositional interlayers on the vertical electrical conductivity of Si-doped AlN/GaN distributed Bragg reflectors grown on SiC

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Applied Physics Express
https://doi.org/10.7567/APEX.10.055501

We have investigated the effect of strain-compensating interlayers on the vertical electrical conductivity of Si-doped AlN/GaN distributed Bragg reflectors (DBRs). Samples with 10.5 mirror pairs were grown through plasma-assisted molecular beam epitaxy on SiC. Room-temperature current–voltage characteristics were measured vertically in mesas through 8 of the 10.5 pairs. The sample with no interlayers yields a mean specific series resistance of 0.044 Ω cm2 at low current densities, while three samples with 5/5-Å-thick, 2/2-nm-thick, and graded interlayers have resistivities between 0.16 and 0.34 Ω cm2. Thus, interlayers impair vertical current transport, and they must be designed carefully when developing conductive DBRs.

Near-infrared waveguide in gallium nitride single crystal produced by carbon ion implantation

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Japanese Journal of Applied Physics
https://doi.org/10.7567/JJAP.56.050306

We report on the fabrication of planar waveguides in gallium nitride by 5 MeV carbon ion implantation with different fluences at room temperature. The waveguides are characterized by prism coupling, Rutherford backscattering/channeling, and high-resolution X-ray diffraction analysis. A positive change in ordinary refractive index is confirmed in the waveguide region at a near-infrared waveband. The thermal stability of the ion-implanted GaN waveguides is investigated by annealing the samples at different temperatures.

Effect of compositional interlayers on the vertical electrical conductivity of Si-doped AlN/GaN distributed Bragg reflectors grown on SiC

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GROUP 3 - Power Electronics

Group leader: Frédéric Morancho (LAAS-CNRS)

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

Low cost high voltage GaN polarization superjunction field effect transistors

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Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600834

A comprehensive overview of the novel high voltage GaN field effect transistors (FETs) based on the Polarization Superjunction (PSJ) concept, and a cost-effective approach towards manufacturing these high performance devices are presented. Current challenges impeding wider adoption of GaN power switching transistors in applications, and the latest results of the scaled-up PSJ-FETs from POWDEC KK, are also discussed. The article also presents hard-switching characteristics of 400–800 V boost converter, constructed using a PSJ-FET grown on sapphire substrate, and the future direction of GaN power semiconductor technology based on monolithic integration for advanced power electronics.

Effects of Post-Deposition Annealing on ZrO2/n-GaN MOS Capacitors with H2O and O3 as the Oxidizers

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Nanoscale Research Letters
http://dx.doi.org/10.1186/s11671-017-2024-x

GaN-based metal-oxide-semiconductor capacitors with ZrO2 as the dielectric layer have been prepared by atomic layer deposition. The accumulation and depletion regions can be clearly distinguished when the voltage was swept from −4 to 4 V. Post-annealing results suggested that the capacitance in accumulation region went up gradually as the annealing temperature increased from 300 to 500 °C. A minimum leakage current density of 3 × 10−9 A/cm2 at 1 V was obtained when O3 was used for the growth of ZrO2. Leakage analysis revealed that Schottky emission and Fowler-Nordheim tunneling were the main leakage mechanisms.

Comparative studies of normally-off Al0.26Ga0.74N/AlN/GaN/Si high electron mobility transistors with different gate structures

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Materials Science in Semiconductor Processing
http://doi.org/10.1016/j.mssp.2017.03.034

Systematic designs to achieve normally-off operation and improved device performance for Al0.26Ga0.74N/AlN/GaN high electron mobility transistors (HEMTs) grown on a Si substrate are investigated in this work. The step-by-step approach includes: (1) devising a thin AlGaN/AlN composite barrier, (2) introducing fluoride ions within the active region by using CF4 plasma treatment, (3) growing the Al2O3 oxide passivation layers within gate-drain/source regions by using a cost-effective ozone water oxidization technique, and (4) integrating a metal-oxide-semiconductor gate (MOS-gate) design with high-k Al2O3 gate dielectric. Devices with four different evolutionary gate structures have been compared and studied. Variations of threshold voltage (Vth), Hooge coefficients (αH), maximum drain-source current density (IDS, max), maximum extrinsic transconductance (gm, max), gate-voltage swing (GVS) linearity, two-terminal gate-drain breakdown/turn-on voltages (BVGD/Von), on/off current ratio (Ion/Ioff), and high-temperature characteristics up to 450 K are also investigated.

Effect of AlN spacer layer thickness on AlGaN/GaN/Si Schottky barrier diodes

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Materials Science in Semiconductor Processing
http://doi.org/10.1016/j.mssp.2017.04.001

AlGaN/GaN Schottky barrier diodes (SBDs) are popularly demonstrated on 6-in. silicon substrate for next generation motor drive and power supply applications. The epitaxial structures with various inserted AlN spacer layer thicknesses have been investigated using the device DC, reverse recovery time and low-frequency noise (LFN) characteristics. The fabricated SBD with 2.0 nm AlN spacer layer realized the highest breakdown voltage of 274 V without edge termination together with the lowest on-resistance (RON) of 2.75 mΩ-cm2 than the SBDs with AlN 0.0 nm and AlN 1.5 nm designs. The fabricated SBD with 2.0 nm AlN spacer layer also demonstrated the fast reverse recovery time of 22.6 nS and lower reverse recovery charge of 4.2 nC. Additionally, lower level of LFN characteristic was obtained in SBD with 2.0 nm AlN spacer layer at 300 K and 500 K due to the better carrier confinement in two dimensional electron gas (2DEG) channel. These results suggest that the SBD with 2.0 nm AlN spacer layer is one of the most promising designs for high speed and high-power rectifier circuit applications.

All-GaN Integrated Cascode Heterojunction Field Effect Transistors

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IEEE Transactions on Power Electronics
https://doi.org/10.1109/TPEL.2016.2643499

All-GaN integrated cascode heterojunction field effect transistors were designed and fabricated for power switching applications. A threshold voltage of +2 V was achieved using a fluorine treatment and a metal-insulator-semiconductor gate structure on the enhancement mode part. The cascode device exhibited an output current of 300 mA/mm by matching the current drivability of both enhancement and depletion mode parts. The optimisation was achieved by shifting the threshold voltage of the depletion mode section to a more negative value with the addition of a dielectric layer under the gate. The switching performance of the cascode was compared to the equivalent GaN enhancement-mode-only device by measuring the hard switching speed at 200 V under an inductive load in a double pulse tester. For the first time, we demonstrate the switching speed advantage of the cascode over equivalent GaN enhancement-mode-only devices, due to the reduced Miller-effect and the unique switching mechanisms. These observations suggest that practical power switches at high power and high switching frequency will benefit as part of an integrated cascode configuration.

Extraction of net acceptor type trap density in semi-insulating GaN layers grown on Si substrate by DC I–V measurement

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Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600925

A simple quantitative method is proposed to estimate net acceptor-type trap density (NT–ND, where NT denotes a gross acceptor-type trap density, and ND denotes a donor density) in semi-insulating GaN layers, widely used as the electron channel layer in AlGaN/GaN heterojunction field-effect-transistors. The DC current–voltage characteristics of a semi-insulating GaN layer on a Si wafer have a threshold voltage (VTH). Band diagram simulation reveals that NT–ND determines VTH, and hence, the NT–ND in semi-insulating GaN films can be experimentally estimated by measuring VTH.

Dynamics of carrier transport via AlGaN barrier in AlGaN/GaN MIS-HEMTs

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Appl. Phys. Lett.
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Exchange of carriers between the GaN channel and the dielectric/AlGaN interface in AlGaN/GaN metal insulator semiconductor high electron mobility transistors was recently attributed to a serial process of electron transport through the AlGaN barrier and electron trapping/emission at the interface. In this paper, the time constant related to barrier transport is evaluated from the measurements of time onset of threshold voltage drift in stress-recovery experiments. Temperature and forward gate bias dependent studies reveal an activation energy of 0.65 eV for the electron transport at zero bias being consistent with the estimated potential barrier of 0.75 eV at the dielectric/AlGaN interface. Thermo-ionic emission and defect assisted tunneling to near interface states are considered as transport mechanisms.

Thin-film GaN Schottky diodes formed by epitaxial lift-off

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4982250

The performance of thin-film GaN Schottky diodes fabricated using a large-area epitaxial lift-off (ELO) process is reported in this work. Comparison of the device characteristics before and after lift-off processing reveals that the Schottky barrier height remains unchanged by the liftoff processing and is consistent with expectations based on metal-semiconductor work function differences, with a barrier height of approximately 1 eV obtained for Ni/Au contacts on n− GaN. However, the leakage current in both reverse and low-forward-bias regimes is found to improve significantly after ELO processing. Likewise, the ideality factor of the Schottky diodes also improves after ELO processing, decreasing from n = 1.12–1.18 before ELO to n = 1.04–1.10 after ELO. A possible explanation for the performance improvement obtained for Schottky diodes after substrate removal by ELO processing is the elimination of leakage paths consisting of vertical leakage along threading dislocations coupled with lateral conduction through the underlying n+ buffer layer that is removed in the ELO process. Epitaxial liftoff with GaN may enable significant improvement in device performance and economics for GaN-based electronics and optoelectronics.

On the physical operation and optimization of the p-GaN gate in normally-off GaN HEMT devices

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4978690

In this study, an investigation is undertaken to determine the effect of gate design parameters on the on-state characteristics (threshold voltage and gate turn-on voltage) of pGaN/AlGaN/GaN high electron mobility transistors (HEMTs). Design parameters considered are pGaN doping and gate metal work function. The analysis considers the effects of variations on these parameters using a TCAD model matched with experimental results. A better understanding of the underlying physics governing the operation of these devices is achieved with a view to enable better optimization of such gate designs.

Hot electron assisted vertical leakage/breakdown in AlGaN/GaN heterostructures on Si substrates

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Superlattices and Microstructures
https://doi.org/10.1016/j.spmi.2017.03.058

We present a hot electron assisted vertical leakage/breakdown mechanism in AlGaN/GaN heterostructures on Si substrates by a combination of applying vertical and lateral bias conditions. Beyond a critical bias point, the vertical leakage current under the combined bias condition is larger than that under a pure vertical bias condition which results in a lower breakdown voltage. The critical bias has a positive temperature dependence. A model is proposed that highly energetic hot electrons can release trapped electrons from defects and even ionize them. The model is proved by investigating the detrapping and ionization mechanisms by changing hot electron energy.

Study on the electrical degradation of AlGaN/GaN MIS-HEMTs induced by residual stress of SiNx passivation

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Solid-State Electronics
https://doi.org/10.1016/j.sse.2017.03.013

In this paper, we report a new phenomenon in C-V measurement of different gate length MIS-HEMTs, which can be associated with traps character of the AlGaN/GaN interface. The analysis of DC measurement, frequency dependent capacitance-

voltage measurements and simulation show that the stress from passivation layer may induce a decrease of drain output current Ids, an increase of on-resistance, serious nonlinearity of transconductance gm, and a new peak of C-V curve. The value of the peak is reduced to zero while the gate length and measure frequency are increasing to 21 µm and 1 MHz, respectively. By using conductance method, the SiNx/GaN interface traps with energy level of EC−0.42 eV to EC−0.45 eV and density of 3.2 × 1012 ∼ 5.0 × 1012 eV−1 cm−2 is obtained after passivation. According to the experimental and simulation results, formation of the acceptor-like traps with concentration of 3 × 1011 cm−2 and energy level of EC−0.37 eV under the gate on AlGaN barrier side of AlGaN/GaN interface is the main reason for the degradation after the passivation.

Normally OFF Trench CAVET With Active Mg-Doped GaN as Current Blocking Layer

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2016.2632150

A normally OFF trench current aperture vertical electron transistor (CAVET) was designed and successfully fabricated with Mg-doped p-GaN current blocking layers. The buried Mg-doped GaN was activated using a postregrowth annealing process. The source-to-drain body diode showed an excellent p-n junction characteristics, blocking over 1 kV, sustaining a maximum blocking electric field of 3.8 MV/cm. Three-terminal breakdown voltages of trench-CAVETs, measured up to 225 V, were limited by dielectric breakdown. This paper highlights the achievement of the well-behaved buried p-n junction that has been a formidable challenge in the success of vertical GaN devices.

Investigation of the p-GaN Gate Breakdown in Forward-Biased GaN-Based Power HEMTs

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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2016.2631640

In this letter, we report a detailed experimental investigation of the time-dependent breakdown induced by forward gate stress in GaN-based power HEMTs with a p-type gate, controlled by a Schottky metal/p-GaN junction. When a high stress voltage is applied on the gate, a large voltage drop and an electric field occur in the depletion region of the p-GaN close to the metal interface, promoting the formation of a percolation path. We have investigated the mechanisms underlying the gate breakdown by adopting different stress conditions, analyzing the influence of the temperature, and investigating the activation energy of the traps. In addition, thanks to this approach, the device lifetime has been evaluated and an original empirical model, representing the relationship between the gate leakage current and the time to failure, has been proposed.

In Situ Oxide, GaN Interlayer-Based Vertical Trench MOSFET (OG-FET) on Bulk GaN substrates

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IEEE Electron Device Letters
https://doi.org/10.1109/LED.2017.2649599

In this letter, we report on high breakdown voltage in situ oxide, GaN interlayer-based vertical trench MOSFETs (OG-FETs) on bulk GaN substrates. Following our previous work on OG-FETs on GaN on sapphire, utilizing a low damage gate-trench etch and using bulk GaN substrates, a breakdown voltage of 990 V with an ON-resistance 2.6 mQ · cm2, was achieved. Without edge termination, a high breakdown field of 1.6 MV/cm was achieved in these devices.

A New Differential Amplitude Spectrum for Analyzing the Trapping Effect in GaN HEMTs Based on the Drain Current Transient

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IEEE Transactions on Electron Devices
https://doi.org/10.1109/TED.2017.2654481

The reliability of GaN high-electron-mobility transistors remains limited by trapping, and a new way to characterize traps is through the drain current transient. In this paper, we report a differential amplitude spectrum (DAS) from which we could extract the exact amount that a trap contributes to charging/discharging from the current transient. We compared the time constant spectrum and the DAS in extracting traps' amplitudes theoretically and experimentally. Using the DAS, we investigated the trapping effect and systematically identified the positions and mechanisms of traps with Ea values of 0.10, 0.38, 0.45, and 0.61 eV in our samples. In particular, we demonstrated that the semi-ON state with high-drain voltage in the filling process can maximize the charge trapping in both the AlGaN layer and GaN buffer. In addition, we experimentally proved that measured voltage in the linear region was the best choice for these samples.

Nearly ideal vertical GaN Schottky barrier diodes with ultralow turn-on voltage and on-resistance

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Applied Physics Express
https://doi.org/10.7567/APEX.10.051001

Vertical Schottky barrier diodes (SBDs) were fabricated from the metal–organic chemical vapor deposition (MOCVD)-grown GaN epitaxial layer on free-standing GaN substrates. It was found that the quality of GaN drift layers and SBD properties were strongly dependent on the growth rates. The step-flow surface morphology, near-unity ideality factor (n ~ 1.04), and high Schottky barrier height (~0.97 eV) were achieved at a relatively low growth rate of 2.61 μm/h. An extremely low turn-on voltage (0.73 V), together with a low on-resistance of 0.72 mΩcenterdotcm2, was obtained.

GROUP 4 - Advanced Electronics and RF

Group leader: Jean-Claude Dejaeger (IEMN)

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

RF loss mechanisms in GaN-based high-electron-mobility-transistor on silicon: Role of an inversion channel at the AlN/Si interface

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Physica status solidi (a)
http://dx.doi.org/10.1002/pssa.201600944

One of the epitaxial issues pertaining to the growth of AlGaN/GaN HEMTs on Si is the decrease of parasitic losses that can adversely impact the RF device performances. We characterized the microwave losses in coplanar waveguides (CPWs) on GaN-based high-electron-mobility-transistors (HEMTs) and their buffer layers on Silicon substrate, up to 40 GHz. The RF losses depend not only on the crystalline quality but also on the residual tensile stress in AlN buffer, as well as its thickness. The mechanism of interfacial lossy channel induced by the piezoelectric field is discussed. Adopting a thin high-low-high temperature (HLH) AlN buffer can help to reduce the tensile stress leading to a reduction of RF losses. We suggest that a thinner p-type AlN and/or p-AlGaN-on-thin AlN near the interface can suppress the electron interfacial lossy channel, which helps the GaN-HEMT-on-HR Si to remain in a high frequency range and at high-temperature operation.

Current transport mechanisms in Pt/Au Schottky contacts to AlInGaN using AlGaN/InGaN short-period superlattices

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Applied Physics A
http://dx.doi.org/10.1007/s00339-017-0938-x

High-quality AlInGaN film grown by metal organic chemical vapor deposition is realized by fabricating the AlGaN/InGaN short-period superlattices, and then, Schottky contacts are fabricated on the AlInGaN superlattices. The crystal quality of AlInGaN superlattice samples is characterized by X-ray diffraction and scanning electron microscopy, and the correlation between the compositions of AlInGaN and growth condition is further clarified. The current transport mechanisms of the Pt/Au Schottky contacts to AlInGaN superlattice samples with different background carrier concentrations are studied by current–voltage (I–V) characteristics and theory analysis based on the thermionic emission (TE) and thermionic field emission (TFE) models. It is found that the results obtained from the TE and TFE models are almost identical for the Schottky contact to strain-balanced AlInGaN sample with low background carrier concentration, indicating that the thermionic emission is a dominant current transport mechanism. However, the Schottky contacts fabricated using high background carrier concentration AlInGaN samples demonstrate degraded barrier characteristics due to an occurrence of donor-like defects which result in the defect-assisted tunneling current, and thus, the combination of tunneling transport and thermionic emission constitutes the current transport mechanisms in Schottky contacts.

Comparative studies of normally-off Al0.26Ga0.74N/AlN/GaN/Si high electron mobility transistors with different gate structures

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Materials Science in Semiconductor Processing
http://doi.org/10.1016/j.mssp.2017.03.034

Systematic designs to achieve normally-off operation and improved device performance for Al0.26Ga0.74N/AlN/GaN high electron mobility transistors (HEMTs) grown on a Si substrate are investigated in this work. The step-by-step approach includes: (1) devising a thin AlGaN/AlN composite barrier, (2) introducing fluoride ions within the active region by using CF4 plasma treatment, (3) growing the Al2O3 oxide passivation layers within gate-

drain/source regions by using a cost-effective ozone water oxidization technique, and (4) integrating a metal-oxide-semiconductor gate (MOS-gate) design with high-k Al2O3 gate dielectric. Devices with four different evolutionary gate structures have been compared and studied. Variations of threshold voltage (Vth), Hooge coefficients (αH), maximum drain-source current density (IDS, max), maximum extrinsic transconductance (gm, max), gate-voltage swing (GVS) linearity, two-terminal gate-drain breakdown/turn-on voltages (BVGD/Von), on/off current ratio (Ion/Ioff), and high-temperature characteristics up to 450 K are also investigated.

A novel approach to the design of a broadband high efficiency Class-E power amplifier with over 87% bandwidth

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RF/Microwave Power Amplifiers for Radio and Wireless Applications (PAWR), 2017 IEEE Topical Conference on
https://doi.org/10.1109/PAWR.2017.7875564

A systematic methodology for designing and implementing a broadband high-efficiency Class-E GaN power amplifier (PA) is proposed. The non-linear model of the GaN device is utilized to prescribe the optimal output impedance for broadband Class-E operation. The impedance of the output-matching network at the fundamental and harmonic frequencies is considered and optimized to cover broadband operation, maximum output power, and high efficiency. Simulated and experimental results of the amplifier demonstrate Class-E PA performance that covers a 0.9 GHz to 2.3 GHz band (i.e. 87% bandwidth) with a measured efficiency of 57-88%, and an output power of 12 W-30 W and an average gain of 10.5 dB.

Power adaptive decomposed vector rotation based digital predistortion for RF power amplifiers in dynamic power transmission

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RF/Microwave Power Amplifiers for Radio and Wireless Applications (PAWR), 2017 IEEE Topical Conference on
https://doi.org/10.1109/PAWR.2017.7875559

In this paper, a power adaptive digital predistortion (DPD) model is proposed to linearize RF power amplifiers (PAs) operated in dynamic power transmissions. By employing the decomposed vector rotation (DVR) based nonlinear weighting technique to adjust the DPD coefficients dynamically, the distortion induced by the dynamic power operation can be effectively compensated. Experimental test results with a high power Gallium Nitride (GaN) Doherty PA confirm that higher linearization performance can be achieved by employing this model, compared to that using the existing approaches.

3.0–3.6 GHz wideband, over 46% average efficiency GaN Doherty power amplifier with frequency dependency compensating circuits

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RF/Microwave Power Amplifiers for Radio and Wireless Applications (PAWR), 2017 IEEE Topical Conference on
https://doi.org/10.1109/PAWR.2017.7875563

A wideband GaN Doherty power amplifier (DPA) for 4G/LTE-Advanced base stations is presented. To break the inherent narrow band limitation of conventional DPA, a frequency dependency compensating circuit and a modified λ/4 inverter incorporating package parasitic elements are proposed. Measured DPA achieves 45.9-50.2 % drain efficiency with -50 dBc ACLR at 3.0-3.6 GHz under 20 MHz LTE signal after digital pre-distortion (DPD), which is very suitable for multiband radio and carrier aggregation in 4G. The use of the wideband efficient GaN DPA can reduce the complexity and energy consumption of radio, which further helps reducing the total cost of ownership (TCO) of base stations.

Growth of 10 nm-thick AlIn(Ga)N/GaN heterostructure with high electron mobility and low sheet resistance

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Physica status solidi (b)
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We have grown an AlIn(Ga)N/GaN heterostructure which is a promising alternative to the AlGaN/GaN heterostructure. The mobility and the carrier concentration of the two-dimensional electron gas (2DEG) formed at the AlIn(Ga)N/GaN heterointerface were strongly dependent on both the growth temperature and pressure. Two optimized growth conditions for the heterostructure with a low sheet resistance less than 300 Ω/sq were obtained by varying the growth temperature and pressure from 750 to 1070 °C and 100 to 300 torr, respectively: (i) AlIn(Ga)N/GaN heterostructure with high 2DEG carrier concentration of 2.4×1013 cm−2 with mobility of 1010 cm2 V−1s−1 (grown at 900 °C and 100 torr); (ii) AlIn(Ga)N/GaN heterostructure with high 2DEG mobility of 1910 cm2 V−1s−1 with carrier concentration of 1.13×1013 cm−2 (grown at 900 °C and 300 torr). Both structures would be useful for different purpose of device application.

An AlGaN/GaN field effect diode with a high turn-on voltage controllability

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Physica status solidi (a)
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In this paper, an AlGaN/GaN Field Effect Diode (FED) with high turn-on voltage (VON) controllability is proposed. The structural feature of a δ-doped GaN cap, an AlGaN barrier, and a GaN channel (GaN/AlGaN/GaN), and selective dry-etching of the GaN cap, ensure the precise control of VON which can be modulated by AlGaN barrier layer thickness. The VON as low as 0.3 V is obtained at the remained AlGaN thickness of 4-nm with an extremely low estimated VON deviation.

Characterization of nanostructure ferrite material on gallium nitride on SiC substrate for millimeter wave integrated circuit

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AIP Advances
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In this paper, for the first time, the characterization of spin-casted thick Barium nano-hexaferrite film on GaN-on-SiC substrate over a broad frequency range of 30-110 GHz is presented. Real and imaginary parts of both permittivity and permeability of the ferrite/polymer film are computed from transmittance data obtained by using a free space quasi-optical millimeter wave spectrometer. The spin-casted composite film shows strong resonance in the Q band, and mixing the powder with polymer slightly shifts the resonance frequency lower compared to pure powder. The high temperature compatibility of GaN substrate enables us to run burn-out tests at temperatures up to 900°C. Significant shortening phenomenon of resonance linewidth after heat treatment was found. Linewidth is reduced from 2.8 kOe to 1.7 kOe. Experiment results show that the aforementioned film is a good candidate in applications of non-reciprocal ferrite devices like isolators, phase shifters, and circulators.

Electrical and optical characteristics of gamma-ray irradiated AlGaN/GaN high electron mobility transistors

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Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomen
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A comparative study on the direct-current (dc) electrical performance and optical characteristics of unirradiated and 120 MRad 60Co-gamma-ray (γ-ray) irradiated AlGaN/GaN high electron mobility transistors (HEMTs) was performed. The devices fabricated on an irradiated HEMT epilayer structure show slight degradation/alteration in the dc characteristics such as source–drain current–voltage (IDS-VDS), transfer (IDS-VGS), transconductance, and gate current–voltage, indicating the presence of radiation-induced defects. Also, a shift in flat band voltage was observed from the capacitance-voltage measurements. Micro-Raman spectroscopy and photoluminescence (PL) spectroscopy were used to compare the crystal quality of the heterojunction. No shift in the Raman peak frequency position was observed in both the unirradiated and irradiated samples, which implies that the irradiation did not produce an additional strain to the HEMT layers. However, the full width at half maximum of the

Raman and near-band-edge PL peaks has increased after irradiation, which suggests the degradation of crystal quality. The spectroscopic photocurrent–voltage study with sub-bandgap and above bandgap illumination confirmed the pre-existence of sub-bandgap defects in the heterostructure and revealed the possibility of their rearrangement or the introduction of new defects after the irradiation. It was concluded that AlGaN/GaN HEMTs are relatively resistant to high dose (120 MRad) gamma-ray irradiation, but they can introduce additional traps or reconfigure the pre-existing traps, influencing the electrical and optical characteristics of AlGaN/GaN HEMTs.

Enhanced transport properties in InAlGaN/AlN/GaN heterostructures on Si (111) substrates: The role of interface quality

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We have investigated the structural and transport properties of InAlGaN/AlN/GaN heterostructures grown on Si substrates. By depositing the AlN spacer layer at a low temperature after the growth interruption, the surface morphology and interface quality have been significantly improved. Electron mobilities of 1620 cm2/Vs at room temperature and 8260 cm2/Vs at 77 K are achieved while delivering a high electron sheet density of about 2.0 × 1013 cm−2, resulting in an extremely low sheet resistance of 186 Ω/□ at room temperature and 37 Ω/□ at 77 K. The experimental results evidence that it is the high interface quality that contributes to the improvement of electron transport properties. Our results provide an effective approach to obtain high quality InAlGaN/GaN heterostructures.

Tunable Schottky barrier in van der Waals heterostructures of graphene and g-GaN

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Using first-principles calculations, we systematically investigated the electronic properties of graphene/g-GaN van der Waals (vdW) heterostructures. We discovered that the Dirac cone of graphene could be quite well preserved in the vdW heterostructures. Moreover, a transition from an n-type to p-type Schottky contact at the graphene/g-GaN interface was induced with a decreased interlayer distance from 4.5 to 2.5 Å. This relationship is expected to enable effective control of the Schottky barrier, which is an important development in the design of Schottky devices.

Ultrafast all-optical modulation in Fe-doped GaN at 1.31 and 1.55 μm with high contrast and ultralow power

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Appl. Phys. Lett.
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We demonstrate the possibility of all-optical modulation at 1.31 and 1.55 μm optical communication wavelengths by interband pumping of Fe-doped GaN crystals using femtosecond pump-probe techniques. Considering the lower photon energy of near-infrared probe pulses, switching time was well controlled by Fe doping from the nanosecond range to a value as fast as 10 ps for Fe concentration of 1 × 1019 cm−3 arising from the carrier trapping effect of deep Fe acceptors, which suggests a modulation speed performance of ∼50 GHz. Simultaneously, about 50% of modulation contrast was achieved by means of optical excitation at an ultralow pump fluence of 0.5 mJ/cm2. Moreover, almost no degradation of the modulation contrast and speed was observed due to Fe doping.

Parasitic channel induced by an on-state stress in AlInN/GaN HEMTs

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In this paper, we have highlighted that an on-state stress can induce a parasitic channel in AlInN/GaN HEMTs. The devices have been stressed during 216 h with a drain-to-source voltage (VDS) of 20 V and a gate-to-source voltage (VGS) of 0 V. A decrease in the drain current (IDS max) of 43%, an increase in the access resistance (RON) of 100%, and a drop in the maximum extrinsic transconductance (gm max) from 234 mS/mm down to 144 mS/mm have been observed after the ageing test. Moreover, a double peak feature is shown in the gm (VGS) characteristic 4 months after the end of the on-state stress. Consequently, we can conclude that a parasitic channel has been created by the on-state stress in the AlInN/GaN transistors. At the same time, no degradation of the Schottky contact has been highlighted after the ageing test.

Quantum electronic transport in polarization-engineered GaN/InGaN/GaN tunnel junctions

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We theoretically investigate GaN/InGaN/GaN tunnel junctions grown along the wurtzite c-axis. We developed a dedicated quantum electronic transport model based on an 8-band k.p Hamiltonian coupled to the non-equilibrium Green's function formalism. We first show that the transmission is dominated by quantum states localized at the heterojunction. We also confirm that, for a thin InGaN layer, current strongly increases with doping. On the other hand, for thick InGaN layers (>8 nm), our results show an unexpected low impact of doping on current. In this latter case, the spontaneous and the piezoelectric polarizations reduce the tunnel-barrier width to the InGaN layer thickness. We conclude that quantum electronic transport in such tunnel junctions is mainly controlled by interfaces with both polarizations and localized states.

Suppression of gate leakage current in in-situ grown AlN/InAlN/AlN/GaN heterostructures based on the control of internal polarization fields

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This paper investigates the gate leakage characteristics of in-situ AlN capped InAlN/AlN/GaN heterostructures grown by metal-organic vapor phase epitaxy. It was revealed that the leakage characteristics of AlN capped InAlN/AlN/GaN heterostructures are strongly dependent on the growth temperature of the AlN cap. For an AlN capped structure with an AlN growth temperature of 740 °C, the leakage current even increased although there exists a large bandgap material on InAlN/AlN/GaN heterostructures. On the other hand, a large reduction of the gate leakage current by 4–5 orders of magnitudes was achieved with a very low AlN growth temperature of 430 °C. X-ray diffraction analysis of the AlN cap grown at 740 °C indicated that the AlN layer is tensile-strained. In contrast to this result, the amorphous structure was confirmed for the AlN cap grown at 430 °C by transmission electron microscopy. Furthermore, theoretical analysis based on one-dimensional band simulation was carried out, and the large increase in two-dimensional electron gas (2DEG) observed in Hall measurements was well reproduced by taking into account the spontaneous and piezo-electric polarization in the AlN layer grown at 740 °C. For the AlN capped structure grown at 430 °C, it is believed that the reduced polarization field in the AlN cap suppressed the penetration of 2DEG into the InAlN barrier layer, resulting in a small impact on 2DEG mobility and density. We believe that an in-situ grown AlN cap with a very low growth temperature of 430 °C is a promising candidate for high-frequency/high-power GaN-based devices with low gate leakage current.

Investigation of thin InN/GaN heterostructures with in situ SiNx dielectric grown by plasma-assisted molecular beam epitaxy

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The effects of InN layer thickness (4/7/10 nm) in metal–insulator–semiconductor Ni/SiNx/InN structures have been evaluated. The 7 nm thick SiNx layer is deposited in situ, by plasma assisted molecular beam epitaxy, on the surface of InN grown on GaN (0001) buffer layers. Metal–insulator–semiconductor capacitors (MISCAPs) and InN channel field-effect transistors (MISFETs) were fabricated and the electrical characteristics of the devices were studied and discussed. Room temperature current versus voltage analysis of the MISCAPs suggested ohmic conduction by hopping at low electric fields, while field emission was prevailed for high electric fields with an extracted trap barrier height in the range of 1.1–1.3 eV for all the structures. The output characteristics of the fabricated MISFETs showed modulation of the drain–source current with the highest current density of 0.8 A/mm for the 10 nm InN layer, but the channel could not fully pinch-off.

AlN/GaN/AlN resonant tunneling diodes grown by rf-plasma assisted molecular beam epitaxy on freestanding GaN

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The authors report the growth by rf-plasma assisted molecular beam epitaxy of AlN/GaN/AlN resonant tunneling diodes which exhibit stable, repeatable, and hysteresis-free negative differential resistance (NDR) at room temperature for more than 1000 bias sweeps between −2.5 and +5.5 V. The device layers were grown on freestanding, Ga-polar GaN substrates grown by hydride vapor phase epitaxy and having a density of threading dislocations between 106 and 107 cm−2. The authors speculate that the repeatable NDR is facilitated by the low-dislocation density substrates.

A Scalable Large-Signal Multiharmonic Model of AlGaN/GaN HEMTs and Its Application in C-Band High Power Amplifier MMIC

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IEEE Transactions on Microwave Theory and Techniques
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A scalable electrothermal large-signal AlGaN/GaN HEMTs model for both fundamental and multiharmonics is presented based on the modified Angelov model. To obtain accurate scalability of the electrothermal model, a simple empirical expression is proposed for the geometric and power-dissipation-dependent nonlinear thermal resistance Rth. Only one additional parameter with linear scaling rule is needed in the drain-source current (Ids) model for a scalable large-signal multiharmonic model. The proposed model has been validated by different AlGaN/GaN HEMTs characterized by on-wafer measurements. It shows that the presented scalable model can well predict the dc I-V, pulsed I-V, scattering (S) parameters, and large-signal performance up to third harmonic. Furthermore, to further validation, a C-band power amplifier is designed. The amplifier is realized using the second-harmonic tuned approach to enhance the efficiency. Measurement results show that the GaN high power amplifier (HPA) microwave monolithic integrated circuit (MMIC) exhibits more than 40% power-added efficiency and 60-W output power (Pout) with associated gain of 25 dB in 5-6 GHz measured at 28-V drain voltage and pulse signal with 100-µs pulsewidth and 10% duty cycle. The area of the chip is 3.2 mm x 5.3 mm (16.96 mm²). These results show that the proposed model will be useful for high-efficiency HPA MMIC design.

1/f-Noise in AlGaN/GaN Nanowire Omega-FinFETs

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IEEE Electron Device Letters
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The low-frequency noise (LFN) characteristics of AlGaN/GaN FinFETs with omega-gate and combined two-dimensional electron gas (2DEG) and MOS conduction are investigated. It is found that LFN is dominated by carrier number fluctuations whatever the width of the fin. Charge trapping in narrow devices is one order of magnitude lower than in wide fin device. In narrow devices, the sidewall conduction prevails and the noise mainly stems from the carrier trapping in the sidewall Al2O3 gate dielectric. Instead, in wide fin devices, the top gate AlGaN/GaN HEMT structure dominates and the LFN is mostly governed by the carrier trapping in the GaN layer close to 2DEG channel.

Optimization of Small-Signal Model of GaN HEMT by Using Evolutionary Algorithms

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IEEE Microwave and Wireless Components Letters
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In this letter, a new evolutionary algorithm-based method for the optimization of intrinsic elements of small-signal model (SSM) of GaN HEMT devices is presented. The method uses a unique search space exploration strategy for evolutionary algorithms to obtain an optimized compact SSM from the extracted parameter and measured S-parameters. The validity of the method is verified by comparing the measured S-parameter data of a 2×0.1×50µm2 GaN/Si HEMT and a 4×0.1×75µm2 GaN/SiC HEMT in the frequency range of 1 to 30 GHz. The modeled data and measured data are in good agreement.

Comparative studies on AlGaN/GaN/Si MOS-HFETs with Al2O3/TiO2 stacked dielectrics by using an ultrasonic spray pyrolysis deposition technique

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Semiconductor Science and Technology
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Al0.26Ga0.74N/GaN metal-oxide-semiconductor heterostructure field-effect transistors (MOS-HFETs) grown on a Si substrate with Al2O3/TiO2 stacked gate dielectrics formed by using non-vacuum ultrasonic spray pyrolysis deposition (USPD) technique are investigated. High permittivity (k) values of Al2O3 and TiO2 were characterized to be 9 and 46.1, respectively, with an equal layer thickness of 10 nm. The present MOS-HFET (Schottky-gate HFET) design has demonstrated enhanced device characteristics at 300 K, including maximum drain–source current density (I DS,max) of 725 (530) mA/mm, I DS at V GS = 0 V (I DSS0) of 471 (383) mA/mm, gate-voltage swing (GVS) of 2.5 (1.6) V, two-terminal gate-drain breakdown voltage (BV GD) of −182 (−121) V, turn-on voltage (V on) of 4.9 (3.2) V, three-terminal off-state drain-source breakdown voltage (BV DS) of 174 (103) V, on/off current ratio (I on/I off) of 5.6 × 107 (3.7 × 103), unity-gain cut-off frequency (f T) of 10.3 (6.8) GHz, maximum oscillation frequency (f max) of 14.8 (8.6) GHz, and power-added efficiency (P.A.E.) of 38.5% (31.7%) at 2.4 GHz. High temperature device characteristics up to 450 K are also discussed.

Investigation of enhancement-mode AlGaN/GaN nanowire channel high-electron-mobility transistor with oxygen-containing plasma treatment

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Applied Physics Express
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A novel enhancement-mode (E-mode) AlGaN/GaN high-electron-mobility transistor (HEMT) has been fabricated, by combining nanowire channel (NC) structure fabrication and N2O (or O2) plasma treatment. A comparison of two NC-HEMTs with different plasma treatments has been made. The NC-

HEMT with N2O plasma treatment shows an output current of 610 mA/mm and a peak transconductance of 450 mS/mm. The DIBL of the NC-HEMT with N2O plasma treatment is as low as 2 mV/V, and an SS of 70 mV/decade is achieved. The device exhibits an intrinsic current gain cutoff frequency f T of 19 GHz and a maximum oscillation frequency f max of 58 GHz.

Hot Electron Transistor with van der Waals Base-Collector Heterojunction and High-Performance GaN Emitter

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Nano Lett.
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Single layer graphene is an ideal material for the base layer of hot electron transistors (HETs) for potential terahertz (THz) applications. The ultrathin body and exceptionally long mean free path maximizes the probability for ballistic transport across the base of the HET. We demonstrate for the first time the operation of a high-performance HET using a graphene/WSe2 van der Waals (vdW) heterostructure as a base-collector barrier. The resulting device with a GaN/AlN heterojunction as emitter, exhibits a current density of 50 A/cm2, direct current gain above 3 and 75% injection efficiency, which are record values among graphene-base HETs. These results not only provide a scheme to overcome the limitations of graphene-base HETs toward THz operation but are also the first demonstration of a GaN/vdW heterostructure in HETs, revealing the potential for novel electronic and optoelectronic applications.

High Temperature Terahertz Detectors Realized by a GaN High Electron Mobility Transistor

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Scientific Reports
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In this work, a high temperature THz detector based on a GaN high electron mobility transistor (HEMT) with nano antenna structures was fabricated and demonstrated to be able to work up to 200 °C. The THz responsivity and noise equivalent power (NEP) of the device were characterized at 0.14 THz radiation over a wide temperature range from room temperature to 200 °C. A high responsivity Rv of 15.5 and 2.7 kV/W and a low NEP of 0.58 and 10 pW/Hz0.5 were obtained at room temperature and 200 °C, respectively. The advantages of the GaN HEMT over other types of field effect transistors for high temperature terahertz detection are discussed. The physical mechanisms responsible for the temperature dependence of the responsivity and NEP of the GaN HEMT are also analyzed thoroughly.

GROUP 5 – MEMS and Sensors

Group leader: Marc Faucher (IEMN)

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A Highly Responsive Self-Driven UV Photodetector Using GaN Nanoflowers

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Advanced Electronic Materials
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The rising demand for optoelectronic devices to be operable in adverse environments necessitates the sensing of ultraviolet (UV) radiation. Here, a self-driven, highly sensitive, fast responding GaN nanoflower based UV photodetector is reported. By developing unique structures, the light absorption increases efficiently and a maximum responsivity of 10.5 A W−1 is achieved at 1 V bias. The reported responsivity is the highest among the GaN UV photodetectors on Si substrates and commercially available Si-based UV photodetectors. Under self-driven condition, the photodetector exhibits very low dark current (≈nA) with a very high responsivity (132 mA W−1) and detectivity (2.4 × 1010 Jones). A remarkably high light-to-dark current ratio of ≈260 signifies extremely high photodetection gain compared to planar GaN-based photodetectors. The self-driven and biased photodetector device yields highly stable rise and decay time response. A model based on band theory elucidates the origin of self-driven photodetectors. Implementation of the innovative growth design structures assures an exceptionally high sensitivity toward UV signal, which is capable of substituting the existing technology of UV photodetectors. High responsivity and detectivity from devices based on the GaN nanoflower-like structure with the advantage of high surface/volume ratio can have numerous applications in fabrication of nanoscale optoelectronic high performance devices such as self-driven UV photodetectors.

Hexagonal boron nitride pattern embedded in AlN template layer for visible-blind ultraviolet photodetectors

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We introduced the use of solution-processed few-layer hexagonal boron nitride (h-BN) stripe patterns embedded in the lateral epitaxial overgrowth (LEO) of AlN grown on sapphire substrates using high temperature metal organic chemical vapor deposition (MOCVD). This straightforward usage of h-BN film contributes to reducing the lattice mismatch and almost entirely terminates the threading dislocations originating from the AlN/sapphire interface, which results in a low pit density and the absence of air-voids in the AlN template. Compared with AlN templates grown on conventional sapphire substrates, the full width at half maximum of the AlN template grown on the h-BN pattern in the (0002) and (10-12) planes decreased from 376 arcsec to 227 arcsec and from 495 arcsec to 398 arcsec, respectively. For device applications, AlGaN-based visible-blind UV photodetectors fabricated using the as-obtained high quality AlN templates show one order of magnitude reduction of the dark leakage current and 50% increase in the responsivity. Our results suggest that the h-BN pattern plays a promising role in the growth of a high quality AlN template, leading to the improvement of performance of AlGaN-based optoelectronic devices.

InGaN/GaN nanowires as a new platform for photoelectrochemical sensors – detection of NADH

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Biosensors and Bioelectronics
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InGaN/GaN nanowire heterostructures are presented as nanophotonic probes for the light-triggered photoelectrochemical detection of NADH. We demonstrate that photogenerated electron-hole pairs give rise to a stable anodic photocurrent whose potential- and pH-dependences exhibit broad applicability. In addition, the simultaneous measurement of the photoluminescence provides an additional tool for the analysis and evaluation of light-triggered reaction processes at the nanostructured interface. InGaN/GaN nanowire ensembles can be excited over a wide wavelength range, which avoids interferences of the photoelectrochemical response by absorption properties of the compounds to be analyzed by adjusting the excitation wavelength. The photocurrent of the nanostructures shows an NADH-dependent magnitude. The anodic current increases with rising analyte concentration in a range from 5 µM to 10 mM, at a comparatively low potential of 0 mV vs. Ag/AgCl. Here, the InGaN/GaN nanowires reach high sensitivities of up to 91 µA mM−1 cm−2 (in the linear range) and provide a good reusability for repetitive NADH detection. These results demonstrate the potential of InGaN/GaN nanowire heterostructures for the defined conversion of this analyte paving the way for the realization of light-switchable sensors for the analyte or biosensors by combination with NADH producing enzymes.

Pt-AlGaN/GaN Hydrogen Sensor with Water-blocking PMMA Layer

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IEEE Electron Device Letters
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One of the biggest issues with GaN-based hydrogen sensors is their sensitivity to humidity in the ambient. We demonstrate that encapsulation of Pt-AlGaN/GaN Schottky diode with poly(methyl methacrylate) (PMMA) provides effective mitigation of the effects of water. Without PMMA encapsulation, the absolute current signal for detection of 500 ppm of H 2 was decreased by a factor of 8 in the presence of water. By sharp contrast, encapsulated diodes show no decrease in response in the presence of water. The relative current changes are of the order 2.8 x10 5 % when 500 ppm H 2 is introduced to the surface of bare or PMMA encapsulated diodes in the absence of water or to encapsulated diode in the presence of water. Detection limits of ~100 ppm H 2 (0.01% by volume) were obtained with standard forward bias detection mode at 1.3 V.

AlN wideband energy harvesters with wafer-level vacuum packaging utilizing three-wafer bonding

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Micro Electro Mechanical Systems (MEMS), 2017 IEEE 30th International Conference on
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This paper experimentally demonstrates an aluminum nitride (AlN) based piezoelectric MEMS energy harvester (EH) with an operation bandwidth of 64.6Hz (859.9Hz-924.5Hz, 7.24%), peak output open-circuit voltage of 4.43V, and an output power of 82.24µW that yields a high power density of 0.734mW/cm3 with its size of 0.8×0.8×0.175cm3. The in-house microfabricated wideband EH is packaged using a novel wafer-level vacuum packaging scheme which employs two times of eutectic AlGe bonding to bond the device wafer to both the top cap wafer and the bottom cap wafer. In addition, Ti is employed as the getter material to enhance the vacuum level inside the cavity, hence reducing the air damping experienced by the cantilevers and increasing the quality factor (Q-factor) and output voltage. The reported EH is a promising candidate in the application of Internet of Things (IoT) to for powering various wireless sensor nodes (WSN) which are located in environment with a wide range of vibration frequencies.

Persistent Photoconductivity, Nanoscale Topography, and Chemical Functionalization Can Collectively Influence the Behavior of PC12 Cells on Wide Bandgap Semiconductor Surfaces

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Small
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Wide bandgap semiconductors such as gallium nitride (GaN) exhibit persistent photoconductivity properties. The incorporation of this asset into the fabrication of a unique biointerface is presented. Templates with lithographically defined regions with controlled roughness are generated during the semiconductor growth process. Template surface

functional groups are varied using a benchtop surface functionalization procedure. The conductivity of the template is altered by exposure to UV light and the behavior of PC12 cells is mapped under different substrate conductivity. The pattern size and roughness are combined with surface chemistry to change the adhesion of PC12 cells when the GaN is made more conductive after UV light exposure. Furthermore, during neurite outgrowth, surface chemistry and initial conductivity difference are used to facilitate the extension to smoother areas on the GaN surface. These results can be utilized for unique bioelectronics interfaces to probe and control cellular behavior.

Microsensors based on a whispering gallery mode in AlGaN microdisks undercut by hydrogen-environment thermal etching

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Applied Optics
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AlGaN microdisks were fabricated via a top-down process using electron-beam lithography, inductively coupled plasma reactive-ion etching, and hydrogen-environment thermal etching from commercial epitaxial wafers with a 100–300 nm thick AlGaN layer grown on a *c*c-plane GaN layer by metal-organic chemical vapor deposition. The hydrogen-environment thermal etching performed well in undercutting the AlGaN microdisks owing to the selective etching for the GaN layer. The AlGaN microdisks acted as the whispering gallery mode (WGM) optical microresonators, exhibiting sharp resonant peaks in room temperature photoluminescence spectra. The evanescent component of the whispering gallery mode (WGM) is influenced by the ambient condition of the microdisk, resulting in the shift of the resonant peaks. The phenomenon is considered to be used for microsensors. Using the WGM in the AlGaN microdisks, we demonstrated microsensors and a microsensor system, which can potentially be used to evaluate biological and chemical actions in a microscale area in real time.

Transducer design for AlN Lamb wave resonators

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Journal of Applied Physics
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AlN Lamb wave resonators enjoy advanced and attractive properties for enabling the next-generation single-chip radio frequency front-end, but their moderate effective electromechanical coupling coefficient (k2eff) poses a limit to their application in filters and multiplexers. Despite the fact that the reported k2eff enhancement techniques of doped AlN thin films which are expensive and trade off the quality factor (Q), the transducer topology itself extensively impacts the k2eff value. Although an AlN cross-sectional Lame mode resonator exhibiting a k2eff of 6.34% has been demonstrated without the need for changing the piezoelectric material, a detailed study of transducer design for AlN Lamb wave resonators has not been conducted. In this work, we investigate the impact of (i) transducer configurations, (ii) electrode materials, (iii) electrode thicknesses, and (iv) interdigital transducer duty factors on the k2eff dispersive characteristics of one-port AlN Lamb wave resonators by using the finite element analysis approach. By properly designing and optimizing the transducers, the k2eff of one-port AlN Lamb wave resonators can be boosted to as high as 7.7%, showing great potential for applications of cellular frequency selection.

Competitive adsorption of air constituents as observed on InGaN/GaN nano-optical probes

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Sensors and Actuators B: Chemical
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The photoluminescence properties of InGaN/GaN nanowire arrays were used to probe the adsorption of H2O, O2, NO2 and O3 on III-nitride surfaces. Upon

adsorption these gases either enhance (H2O) or quench (O2, NO2, O3) the photoluminescence intensity which allows the related adsorption processes to be evaluated. An analysis of the experimental data in terms of the Langmuir Adsorption and Recombination model reveals that – at room temperature – the Langmuir energy of adsorption Eads increases in the order H2O, O2, NO2, and O3 and that for each gas species Eads increases linearly with increasing surface temperature. We show that this behaviour can be explained by a competition of these air constituents for the same kind of Ga(In) adsorption sites. In contrast, exploratory experiments with H2 and simple hydrocarbons reveal that these reducing species neither quench nor enhance the native photoluminescence response, which indicates that these do not compete for the same adsorption sites as the background air constituents.

An innovative piezo-MEMS channel-select filter design based on non-monotonic coupled modes

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We propose a novel mechanically-coupled filter design which for the first time combines two distinct physical vibration modes, including length-extensional (LE) and degenerate in-plane shear (IPS) modes excited in a single filter structure, fabricated using InvenSense AlN-on-silicon platform. By taking advantage of typical LE-based (LE-LE) and IPS-based (IPS-IPS) monotonic filter designs but without their inherent constraints, the proposed non-monotonic coupled mode (IPS-LE) filter simultaneously features a nodal-point positioned filter coupler and a differential operation, hence enabling narrow-band filtering and significant feedthrough reduction toward channel-select applications. Notably, the proposed filter topology is also capable of addressing the fly-back issue observed from IPS-based filter. As a result, the designed 34.8-MHz piezo-MEMS filter is successfully demonstrated with a flat passband, 0.18%-bandwidth (63 kHz), and 30-dB stopband rejection under proper termination resistances (RQ).

Ultraviolet photoresponse of surface acoustic wave device based on Fe-doped high-resistivity GaN

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Japanese Journal of Applied Physics
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The ultraviolet (UV) photoresponse of a surface acoustic wave (SAW) device fabricated on an Fe-doped high-resistivity GaN epitaxial film grown by hydride vapor phase epitaxy is investigated. The SAW device exhibits large variations in transmission characteristics under UV illumination, but shows a very low recovery rate after ceasing the illumination. Through the characterization of photocurrent and the simulation of the displacement field of Rayleigh wave, it is suggested that the persistent photoconductivity of the Fe-doped GaN is the origin of the retarded photoresponse of the SAW device, and that the wide surface depletion layer contributes to the large photoresponse of the SAW device.

Group III nitride nanomaterials for biosensing

Xiao Li and Xinyu Liu

Nanoscale
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Biosensing has found its wide applications in biological and medical research, and in real-world diagnoses, environmental monitoring and other analytical tasks. Being recognized as novel and outstanding transducing materials because of their superior and unique physical/chemical properties, group III nitride (III–nitride) nanomaterials have been introduced to biosensor development with remarkable advancements achieved in the past decades. This paper presents the first comprehensive review on biosensor development with III–nitride nanomaterials. The review starts by introducing the material properties and biocompatibility of III–nitrides that are useful to biosensing. The focus is then placed on surface treatments which lay the foundation for biosensing, and on biosensing mechanisms where the exceptional properties of III–nitride nanomaterials lead to superior biosensing performance. From a practical point of view, techniques for biosensor fabrication are reviewed. Finally, existing biosensing applications and future directions are discussed.

Giant UV photoresponse of a GaN nanowire photodetector through effective Pt nanoparticle coupling

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High performance ultraviolet (UV) photodetectors based on semiconducting nanowires are expected to have extensive applications in UV-ray detection, optical communication and environmental monitoring. In this work, GaN nanowire photodetectors have been fabricated and giant UV photoresponse has been achieved with Pt nanoparticle (NP) modification. The peak responsivity and external quantum efficiency (EQE) of the GaN nanowire UV photodetector were increased from 773 to 6.39 × 104 A W−1 and from 2.71 × 105% to 2.24 × 107%, respectively, and the response time and sensitivity were improved greatly after Pt NP decoration on the GaN nanowire surface. Moreover, the Pt–GaN nanowire photodetector still presents its spectrum selectivity in the UV region. Our results reveal that Pt nanoparticles play a key role in enhancing the photodetection performance of the nanodevice due to the strong absorption and scattering of incident light induced by localized surface plasmon resonance (LSPR) and the improvement of interfacial charge separation owing to the special device configuration. These findings offer an efficient avenue toward the performance enhancement of GaN nanowire and related optoelectronic devices or systems.

Non-Reciprocal Acoustic Transmission in a GaN Delay Line Using the Acoustoelectric Effect

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IEEE Electron Device Letters
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This letter reports on first-time demonstration of non-reciprocal acoustic transmission in a gallium nitride (GaN) delay line structure. The split of forward (S21) and backward (S12) transmissions is observed by applying a dc electric field through the active area with a two-dimensional electron gas (2DEG) sheet. The non-reciprocity (~20.7 dB/mm max. in this work) varies by tuning the gate voltage to deplete the 2DEG sheet carrier density, which agrees with model prediction for the interaction between 2DEG and surface acoustic waves (SAWs). Our preliminary results prove the feasibility of implementing chip-scale non-reciprocal acoustic devices in a GaN platform through acoustoelectric amplification.

GROUP 6 - Photovoltaics and Energy harvesting

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Information selected by Knowmade

Polarization compensation at low p-GaN doping density in InGaN/GaN p-i-n solar cells: Effect of InGaN interlayers

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Superlattices and Microstructures
http://doi.org/10.1016/j.spmi.2017.04.014

The effectiveness of polarization matching layer (PML) between i-InGaN/p-GaN is studied numerically for Ga-face InGaN/GaN p-i-n solar cell at low p-GaN doping (∼5e17 cm−3). The simulations are performed for four InxGa1-xN/GaN heterostructures (x = 10%, 15%, 20% and 25%), thus investigating the impact of PML for low as well as high indium containing absorber regions. Use of PML presents a suitable alternative to counter the effects of polarization-induced electric fields arising at low p-GaN doping density especially for absorber regions with high indium (>10%). It is seen that it not only mitigates the negative effects of polarization-induced electric fields but also reduces the high potential barriers existing at i-InGaN/p-GaN heterojunction. The improvement in photovoltaic properties of the heterostructures even at low p-GaN doping validates this claim.

Influence of electronic and optical properties of GaN nanoparticles as potential electrocatalyst in hydrogen production

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Materials Science in Semiconductor Processing
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Due the high electron density of the anion lattice found in nitrides, these compounds have been used for such applications as high power devices, photonics and, more recently, hydrogen production. Among nitride compounds, GaN is well known for its thermal stability, while the different physical techniques used for its synthesis have been reported to obtain different physicochemical properties. However, these techniques are not designed for the mass production of GaN. For these reasons, two different methods for both the chemical synthesis of GaN and its physical chemical characterization are reported in this study, with both synthesis methods presenting wurtzite phase crystallization. Furthermore, both samples presented agglomerates formed by similar sized nanoparticles (~20 nm). Despite the similarity in the particle size, higher pore volume and surface area as well as carbon traces are promoted by the solvothermal route. In contrast, structural and photoluminescence (PL) characterization revealed that Ga vacancies and interstitial N formed in those samples synthesized by the nitridation method, promoting higher intensity in ~2.8 eV PL band. Finally, based on cathodic linear sweep voltammetry, the samples prepared in this study can be considered good candidates for use in hydrogen production.

Enhancing the efficiency of the intermediate band solar cells by introducing: carrier losses, alloying and strain

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IET Optoelectronics
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A detailed balance model is used to determine the efficiency of intermediate band solar cell including carrier losses from the intermediate band. The effect of the energy gap of the host semiconductor is examined as a function of the intermediate band position in the energy gap and the host semiconductor energy gap. Generally the optimal intermediate band level decreases within the energy gap to mitigate the carrier losses, and carrier losses are less detrimental to small energy gap materials. We therefore focus on the role of carrier losses in wide bandgap semiconductor intermediate band solar cell systems, such as the GaN semiconductor with an Mn impurity band. Experimentally Mn acceptor level in the GaN energy gap is 1.8 eV above the valence band, which is 199 meV off the ideal intermediate band and reduces the efficiency to 21.36%. We demonstrate how carrier losses can be introduced into the system to shift the optimum IB

position. Introducing carrier losses shifts the optimal intermediate band position to 1.8 eV above the valence band and increases the efficiency to 23.41%. We compare this to the effect of alloying GaN and introducing biaxial strain to shift the effective position of the Mn impurity band on the efficiency.

Photorechargeable High Voltage Redox Battery Enabled by Ta3N5 and GaN/Si Dual-Photoelectrode

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Advanced Materials
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Solar rechargeable battery combines the advantages of photoelectrochemical devices and batteries and has emerged as an attractive alternative to artificial photosynthesis for large-scale solar energy harvesting and storage. Due to the low photovoltages by the photoelectrodes, however, most previous demonstrations of unassisted photocharge have been realized on systems with low open circuit potentials (<0.8 V). In response to this critical challenge, here it is shown that the combined photovoltages exceeding 1.4 V can be obtained using a Ta3N5 nanotube photoanode and a GaN nanowire/Si photocathode with high photocurrents (>5 mA cm–2). The photoelectrode system makes it possible to operate a 1.2 V alkaline anthraquinone/ferrocyanide redox battery with a high ideal solar-to-chemical conversion efficiency of 3.0% without externally applied potentials. Importantly, the photocharged battery is successfully discharged with a high voltage output.

Nonpolar and semipolar InGaN/GaN multiple-quantum-well solar cells with improved carrier collection efficiency

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Appl. Phys. Lett.
http://dx.doi.org/10.1063/1.4980139

We demonstrate the nonpolar and semipolar InGaN/GaN multiple-quantum-well (MQW) solar cells grown on the nonpolar m-plane and semipolar (202—1)(202¯1) plane bulk GaN substrates. The optical properties and photovoltaic performance of the nonpolar and semipolar InGaN solar cells were systematically studied, and the results were compared to the conventional polar c-plane devices. The absorption spectra, current density–voltage (J–V) characteristics, external quantum efficiency (EQE), and internal quantum efficiency (IQE) were measured for nonpolar m-plane, semipolar (202—1)(202¯1) plane, and polar c-plane InGaN/GaN MQW solar cells. Nonpolar m-plane InGaN/GaN MQW solar cells showed the best performance across all devices, with a high open-circuit voltage of 2.32 V, a low bandgap-voltage offset of 0.59 V, and the highest EQE and IQE. In contrast, the polar c-plane device showed the lowest EQE despite the highest absorption spectra. This huge difference is attributed to the better carrier transport and collection on nonpolar m-plane devices due to the reduced polarization effects, which were further confirmed by bias-dependent EQE measurements and energy band diagram simulations. This study demonstrates the high potential of nonpolar and semipolar InGaN solar cells and can serve as guidance for the future design and fabrication of high efficiency III-nitride solar cells.

Surface treatment and profile characterization of p-type graded band gap AlGaN material for preparing high performance photocathode

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Applied Surface Science
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Ar+ sputtering was applied for exploring the graded band gap profile and the effectiveness of surface contaminations removal, especially the oxide, of the AlGaN material for preparing high performance photocathodes. The X-ray photoelectron spectroscopy scan(XPS) and spectral curves fitting indicated that after conventional chemical cleaning, there were still large amount of carbon and oxygen on surface, where the oxide mainly included gallium oxide and aluminum oxide. After Ar+ sputtering for 0.5 min and 1 min, these carbon and oxygen were both completely removed from surface and the

proportion of Al changed from original 29.8% to 36.7% and 37.8%, respectively, more suitable to the solar blind detection. The variation trend of Al and Ga from surface to bulk confirmed the graded band gap profile of this AlGaN material, which would introduce built-in electric field for preparing high performance photocathode.

Effects of structural defects and polarization charges in InGaN-based double-junction solar cell

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Superlattices and Microstructures
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The performance of a double heterojunction solar cell based on Indium Gallium Nitride (InGaN) including a tunnel junction was simulated. The most challenging aspects of InGaN solar cells development being the crystal polarization and structural defects detrimental effects, their impact on the solar cell performances has been investigated in detail. The solar cell simulation was performed using physical models and InGaN parameters extracted from experimental measurements. The optimum efficiency of the heterojunction solar cell was obtained using a multivariate optimization method which allows to simultaneously optimize eleven parameters. The optimum defect free efficiency obtained is 24.4% with a short circuit current JSC=12.92mA/cm2, an open circuit voltage VOC=2.29V and a fill factor FF=82.55%. The performances evolution as functions of the polarization and the defects types and parameters was studied from their maximum down to as low as a 2% efficiency.

Improved photoelectrochemical performance of GaN nanopillar photoanodes

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Nanotechnology
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In this work, we report on the photoelectrochemical (PEC) investigation of n-GaN nanopillar (NP) photoanodes fabricated using metal organic chemical vapour deposition and the top-down approach. Substantial improvement in photocurrents is observed for GaN NP photoanodes compared to their planar counterparts. The role of carrier concentration and NP dimensions on the PEC performance of NP photoanodes is further elucidated. Photocurrent density is almost doubled for doped NP photoanodes whereas no improvement is noticed for undoped NP photoanodes. While the diameter of GaN NP is found to influence the onset potential, carrier concentration is found to affect both the onset and overpotential of the electrodes. Optical and electrochemical impedance spectroscopy characterisations are utilised to further explain the PEC results of NP photoanodes. Finally, improvement in the photostability of NP photoanodes with the addition of NiO as a co-catalyst is investigated.

A study on GaN based converters for the application of power conditioning of photovoltaic systems

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Electrical Engineering (ICEE), 2017 International Conference on
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The increase in solar system installation worldwide has forced engineers to improve the overall efficiency of the system. The system consists of a power conditioning unit mostly which compromises of converters and filters in addition to panels themselves. The paper presents the simulations and discussions upon the improvement of hard switching using GaN transistors with various loads and frequencies at 100v, ignoring the conduction losses.

GROUP 7 - Materials, Technology and Fundamental

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Selective-area growth of doped GaN nanorods by pulsed-mode MOCVD: Effect of Si and Mg dopants

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Physica status solidi (b)
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Injecting current with a uniform carrier concentration is important for applications with three-dimensional architectures such as vertical power devices or displays. In III-nitride nanostructures, dopants not only incorporate differently depending on the surface orientation but can also seriously affect the kinetic equilibrium shapes of the nanorods. Herein, we report selective-area growth of doped GaN nanorods grown by pulsed-mode metalorganic chemical vapor deposition. Two dopants, Si and Mg, were employed as donor and acceptor atoms, respectively, for a mono-doping approach. Furthermore, a mixed flow of Si and Mg was supplied for a co-doping approach. We compared the morphological effects and growth rates of each doped GaN nanorod array. Then, we proposed appropriate growth mechanisms for the doped GaN nanorods on the basis of our structural characterizations. These results might extend the morphological functionality of GaN nanorods by including doping and may also provide an appropriate foundation for the design of nanostructure-based electronic or photonic devices.

Growth of InN Nanowires with Uniform Diameter on Si(111) Substrates: Competition Between Migration and Desorption of In Atoms

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Small
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The effects of the growth parameters on the uniformity and the aspect ratio of InN nanowires grown on Si(111) substrates have been studied systematically, and a modified quasi-equilibrium model is proposed. The growth temperature is of great importance for both the nucleation of the nanowires and the migration of In and N atoms, thus affecting the uniformity of the InN nanowires. In order to improve the uniformity of the InN nanowires, both traditional substrate nitridation and pre-In-droplet deposition have been implemented. It is found that the substrate nitridation is favorable for the nucleation of InN nanowires. However, the initial In atoms adhered to the substrate are insufficient to sustain the uniform growth of the InN nanowires. We have found that the initial In droplet on the substrate is not only advantageous for the nucleation of the InN nanowire, but also favorable for the In atom equilibrium between the initial In droplets and the direct In flux. Therefore, InN nanowires with a uniform aspect ratio and optimal diameter can be achieved. The results reported herein provide meaningful insights to understanding the growth kinetics during the InN nanowires growth, and open up great possibilities of developing high-performance group III-nitride-based devices.

Structural impact on the nanoscale optical properties of InGaN core-shell nanorods

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III-nitride core-shell nanorods are promising for the development of high efficiency light emitting diodes and novel optical devices. We reveal the nanoscale optical and structural properties of core-shell InGaN nanorods formed by combined top-down etching and regrowth to achieve non-polar sidewalls with a low density of extended defects. While the luminescence is uniform along the non-polar {1–100} sidewalls, nano-cathodoluminescence shows a sharp reduction in the luminescent intensity at the intersection of the non-polar {1–100} facets. The reduction in the luminescent intensity is accompanied by a reduction in the emission energy localised at the apex of the corners. Correlative compositional analysis reveals an increasing indium content towards the corner except at the apex itself. We propose that the observed variations in the structure and chemistry are responsible for the changes in the optical properties at the corners of the nanorods. The insights revealed by nano-cathodoluminescence will aid in the future development of higher efficiency core-shell nanorods.

Controlling color emission of InGaN/AlGaN nanowire light-emitting diodes grown by molecular beam epitaxy

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Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena
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The authors report on the achievement of full-color nanowire light-emitting diodes (LEDs), with the incorporation of InGaN/AlGaN nanowire heterostructures grown directly on the Si (111) substrates by molecular beam epitaxy. Multiple color emission across nearly the entire visible wavelength range can be realized by varying the In composition in the InGaN quantum dot active region. Moreover, multiple AlGaN shell layers are spontaneously formed during the growth of InGaN/AlGaN quantum dots, leading to the drastically reduced nonradiative surface recombination, and enhanced carrier injection efficiency. Such core–shell nanowire structures exhibit significantly increased carrier lifetime and massively enhanced photoluminescence intensity compared to conventional InGaN/GaN nanowire LEDs. A high color rendering index of ∼98 was recorded for white-light emitted from such phosphor-free core–shell nanowire LEDs.

Ultraclean Single Photon Emission from a GaN Quantum Dot

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Nano Lett.
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Wide bandgap III-nitride quantum dots (QDs) are promising materials for the realization of solid-state single-photon sources, especially operating at room temperature. However, so far a large degree of inhomogeneous broadening induced by spectral diffusion has compromised their use. Here, we demonstrate the ultraclean emission from single GaN QDs formed at macrostep edges in a GaN/AlGaN quantum well. As a likely consequence of the high growth temperature and hence a reduced defect density, spectral diffusion is heavily suppressed to levels at least 1 order of magnitude lower than conventional GaN QDs. A record narrow line width of as small as 87 μeV is obtained, while the low inhomogeneous broadening enables us to assess an upper limit of homogeneous broadening in the QDs (27 μeV). Furthermore, the uncontaminated emission facilitates the generation of ultraviolet single-photons with unprecedented purity (g(2)(0) = 0.02). The realization of high-quality GaN QDs will enable exploration of optoelectronic properties of III-nitrides, opening up

the possibility of realizing single-photon quantum information systems operating at room temperature.

Thin-Wall GaN/InAlN Multiple Quantum Well Tubes

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Thin-wall tubes composed of nitride semiconductors (III-N compounds) based on GaN/InAlN multiple quantum wells (MQWs) are fabricated by metal–organic vapor-phase epitaxy in a simple and full III-N approach. The synthesis of such MQW-tubes is based on the growth of N-polar c-axis vertical GaN wires surrounded by a core–shell MQW heterostructure followed by in situ selective etching using controlled H2/NH3 annealing at 1010 °C to remove the inner GaN wire part. After this process, well-defined MQW-based tubes having nonpolar m-plane orientation exhibit UV light near 330 nm up to room temperature, consistent with the emission of GaN/InAlN MQWs. Partially etched tubes reveal a quantum-dotlike signature originating from nanosized GaN residuals present inside the tubes. The possibility to fabricate in a simple way thin-wall III-N tubes composed of an embedded MQW-based active region offering controllable optical emission properties constitutes an important step forward to develop new nitride devices such as emitters, detectors or sensors based on tubelike nanostructures.

NON/SEMI POLAR

Information selected by
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Nonpoar and semipolar InGaN/GaN multiple-quantum-well solar cells with improved carrier collection efficiency

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Appl. Phys. Lett.
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We demonstrate the nonpolar and semipolar InGaN/GaN multiple-quantum-well (MQW) solar cells grown on the nonpolar m-plane and semipolar (202—1)(202¯1) plane bulk GaN substrates. The optical properties and photovoltaic performance of the nonpolar and semipolar InGaN solar cells were systematically studied, and the results were compared to the conventional polar c-plane devices. The absorption spectra, current density–voltage (J–V) characteristics, external quantum efficiency (EQE), and internal quantum efficiency (IQE) were measured for nonpolar m-plane, semipolar (202—1)(202¯1) plane, and polar c-plane InGaN/GaN MQW solar cells. Nonpolar m-plane InGaN/GaN MQW solar cells showed the best performance across all devices, with a high open-circuit voltage of 2.32 V, a low bandgap-voltage offset of 0.59 V, and the highest EQE and IQE. In contrast, the polar c-plane device showed the lowest EQE despite the highest absorption spectra. This huge difference is attributed to the better carrier transport and collection on nonpolar m-plane devices due to the reduced polarization effects, which were further confirmed by bias-dependent EQE measurements and energy band diagram simulations. This study demonstrates the high potential of nonpolar and semipolar InGaN solar cells and can serve as guidance for the future design and fabrication of high efficiency III-nitride solar cells.

Polarization imaging of imperfect m-plane GaN surfaces

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APL Photonics
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Surface polar states in m-plane GaN wafers were studied using a laser terahertz (THz) emission microscope (LTEM). Femtosecond laser illumination excites THz waves from the surface due to photocarrier acceleration by local spontaneous polarization and/or the surface built-in electric field. The m-plane, in general, has a large number of unfavorable defects and unintentional polarization inversion created during the regrowth process. The LTEM images can visualize surface domains with different polarizations, some of which are hard to visualize with photoluminescence mapping, i.e., non-radiative defect areas. The present study demonstrates that the LTEM provides rich information about the surface polar states of GaN, which is crucial to improve the performance of GaN-based optoelectronic and power devices.

Stimulated emission from semi-polar (11-22) GaN overgrown on sapphire

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(11-22) semi-polar GaN is expected to exhibit major advantages compared with current c-plane polar GaN in the fabrication of long wavelength such as green and yellow emitters. However, all the III-nitride based semi-/non- polar laser diodes (LDs) reported so far have been achieved exclusively based on homo-epitaxial growth on extremely expensive free-standing GaN substrates with a very limited size. In this paper, we have observed a stimulated emission at room temperature achieved on our semi-polar (11-22) GaN overgrown on a micro-rod arrayed template with an optimized design on m-plane sapphire. This has never been achieved previously on any semi-polar GaN grown on sapphire. Furthermore, an optical gain of 130cm−1 has been measured by means of performing a standard laser stripe-length dependent optical measurement. The values of the threshold and the optical gain obtained are comparable to those of the c-plane GaN reported so far, further validating the satisfactory crystal quality of our overgrown semi-polar (11-22) GaN on sapphire. This represents a major step towards the development of III-nitride semi-polar based LDs on sapphire, especially in the long wavelength regime.

Fabriction of non-polar GaN based highly responsive and fast UV photodetector

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We report the fabrication of ultraviolet photodetector on non-polar (11–20), nearly stress free, Gallium Nitride (GaN) film epitaxially grown on r-plane (1–102) sapphire substrate. High crystalline film leads to the formation of two faceted triangular islands like structures on the surface. The fabricated GaN ultraviolet photodetector exhibited a high responsivity of 340 mA/W at 5 V bias at room temperature which is the best performance reported for a-GaN/r-sapphire films. A detectivity of 1.24 × 109 Jones and noise equivalent power of 2.4 × 10−11 WHz−1/2 were also attained. The rise time and decay time of 280 ms and 450 ms have been calculated, respectively, which were the fastest response times reported for non-polar GaN ultraviolet photodetector. Such high performance devices substantiate that non-polar GaN can serve as an excellent photoconductive material for ultraviolet photodetector based applications.

Anisotropic electrical conductivity of surface-roughened semipolar (11-22) GaN films by photochemical etching

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We studied the anisotropy of electrical conductivity in surface-roughened semipolar $(11\bar{2}2)$ GaN (s-GaN) films. Highly crystalline s-GaN films were obtained using asymmetric lateral epitaxy on oxide-patterned m-plane sapphire substrates. The in-plane structural anisotropy of the s-GaN films was confirmed by anisotropic peak broadening in X-ray rocking curves (XRC) with the in-beam orientations. The XRC full-width at half maximum (FWHM) values were measured to be 454 and 615 arcsec along the $[11\bar{2}3]$ GaN and $[1\bar{1}00]$ GaN directions, respectively. The s-GaN surface was roughened using photo-chemical etching, and the electrical anisotropy was then investigated as a function of azimuth angles with the transmission line method. The Ohmic contact properties on the roughened s-GaN surface did not depend on the azimuth angle or annealing temperatures between 750 and 950 °C. The sheet resistances parallel to the $[1\bar{1}00]$ GaN direction on roughened s-GaN were found to be approximately half of the resistance parallel to the $[11\bar{2}3]$ GaN direction, showing that anisotropic electrical conductivity is maintained for surface-roughened s-GaN due to charged carrier scattering induced by basal-plane stacking faults

Photoluminescence and lasing characteristics of single nonpolar GaN microwires

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Nonpolar a-axial GaN MWs were fabricated on a patterned Si substrate via metal–organic chemical vapor deposition (MOCVD) without the assistance of any catalyst. The temperature-dependent photoluminescence (PL) properties of a single GaN MW were discussed comprehensively. Below the temperature of 90 K, the neutral donor-bound exciton (D0X) line dominates in the spectrum, while the free–exciton transition dominates at temperatures above 90 K. The optical properties of GaN MWs exhibit a multiple-mode-stimulated-amplified emission with a peak around 375 nm and a corresponding lasing threshold of about 120 kW cm−2. In addition, the lasing characteristics of GaN MWs were explored by the finite-difference time-domain (FDTD) method.

MATERIAL / CHARACTERIZATION / EQUIPMENT / NUMERICAL SIMULATION

Information selected by
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Origin of high hole concentrations in Mg-doped GaN films

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Physica status solidi (b)
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The origin for high hole concentration in Mg-doped GaN films grown by metal-modulated epitaxy has been explored. We observe a Mg acceptor band characterized by a broad emission without phonon replicas and a high energy tail that overlaps with the valence band of GaN, giving rise to a reduced effective Mg activation energy. We attribute the high hole concentrations to the reduction of compensating nitrogen vacancy concentration and to effectively dispersed Mg atoms, which are incorporated into the lattice as single substitutional atoms. This has been achieved by a low temperature growth, a decrease in the III/V ratio, and a planar growth interface that results from the layer-by-layer approach using the metal-modulated epitaxial technique.

Comparison of wurtzite GaN/AlN and ZnO/MgO short-period superlattices: Calculation of band gaps and built-in electric field

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Physica status solidi (b)
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The group-III nitride and the group-II oxide semiconductors have direct band gaps, which cover the ultraviolet to infrared energy range. In this work we calculate the band gaps and built-in electric field of the polar wurtzite GaN/AlN and ZnO/MgO Short Period Superlattices (SPSLs). In many respects GaN and AlN are similar to ZnO and MgO, respectively, especially regarding the band gaps and the lattice parameters. To realize the wider band gap based materials the superlattices (SLs) with GaN and ZnO as quantum wells and AlN and MgO as quantum barriers, that is, GaN/AlN and ZnO/MgO, are created. We found similar evolution of the GaN/AlN and ZnO/MgO band gaps with varying number of atomic layers constituting these SPSLs. Band gap bowings and strength of the internal electric field existing in these two families of SPSLs differ significantly.

Hexagonal boron nitride pattern embedded in AlN template layer for visible-blind ultraviolet photodetectors

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We introduced the use of solution-processed few-layer hexagonal boron nitride (h-BN) stripe patterns embedded in the lateral epitaxial overgrowth (LEO) of AlN grown on sapphire substrates using high temperature metal organic chemical vapor deposition (MOCVD). This straightforward usage of h-BN film contributes to reducing the lattice mismatch and almost entirely terminates the threading dislocations originating from the AlN/sapphire interface, which results in a low pit density and the absence of air-voids in the AlN template. Compared with AlN templates grown on conventional sapphire substrates, the full width at half maximum of the AlN template grown on the h-BN pattern in the (0002) and (10-12) planes decreased from 376 arcsec to 227 arcsec and from 495 arcsec to 398 arcsec, respectively. For device applications, AlGaN-based visible-blind UV photodetectors fabricated using the as-obtained high quality AlN templates show one order of magnitude reduction of the dark leakage current and 50% increase in the responsivity. Our results suggest that the h-BN pattern plays a promising role in the growth of a high quality AlN template, leading to the improvement of performance of AlGaN-based optoelectronic devices.

Investigation of Si and O Donor Impurities in Unintentionally Doped MBE-Grown GaN on SiC(0001) Substrate

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Journal of Electronic Materials
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We have investigated the unintentional n-type background doping in GaN(0001) layers grown on semi-insulating 4H-SiC(0001) substrate by plasma-assisted molecular beam epitaxy under Ga-rich conditions at growth temperatures from 780°C and 900°C. All layers exhibited very smooth surface morphology with monolayer steps as revealed by atomic force microscopy. Hall-effect measurements showed that the sample grown at 900°C had carrier concentration of 9.8 × 1017 cm−3 while the sample grown at 780°C had resistivity too high to obtain reliable measurements. Secondary-ion mass spectroscopy revealed O and Si concentrations of <1017 cm−3 in the sample grown at 900°C but >1017 cm−3 in the sample grown at 780°C. The trend for the atomic concentrations of O and Si, which are common donor impurities in GaN, was thus contrary to the trend of the carrier concentration. The full-width at half-maximum for x-ray rocking curves obtained across the GaN(0002)

and GaN(10 1¯1¯ 5) reflections for the sample grown at 900°C was 62 arcsec and 587 arcsec, respectively. The half-width increased with decreasing growth temperature. The atomic concentrations of O and Si are too low to account for the unintentional background doping levels. A possible explanation proposed in early reports for the background doping is N-vacancies.

Structural and magnetic properties of Dy-implanted GaN films

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GaN:Dy films were prepared by implanting Dy ions into c-plane (0001) GaN films and a subsequent rapid thermal annealing process. The structural and magnetic properties of samples were investigated by means of X-ray diffraction (XRD), Raman and Physical Property Measurement System (PPMS). The XRD and Raman studies showed that lattice damage and dislocation caused by ion implantation can be effectively recovered by rapid thermal annealing. The PPMS results showed ferromagnetism at room temperature. The average value of the moment per Dy ion (Ms/Dy) is increased after thermal annealing. The available vacancies and formation of bound magnetic poloron as a result of implantation and thermal annealing are assigned responsible for observed ferromagnetism.

Influence of nitridation process on characteristics of N-polar AlGaN films grown by MOCVD

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Materials Science in Semiconductor Processing
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The N-polar AlGaN epi-layers with an Al composition of ~10% were grown on (0001)-oriented c-plane sapphire substrates by metal-organic chemical vapor deposition (MOCVD) technology. Special attention was paid on the nitridation process in the epitaxial growth of N-polar AlGaN films. The optical microscope (OM) measurement results demonstrated that the size of hexagonal defects on the surface of N-polar AlGaN epi-layer decreased dramatically with our improved nitridation process. Furthermore, the structural, electrical, and optical properties of N-polar AlGaN epi-layers were characterized extensively by means of X-ray rocking curves (XRCs), Hall effect, and photoluminescence (PL) spectroscopy. It was found that the defects-related blue-band (BB) emission was greatly suppressed and the threading dislocation (TD) density was significantly reduced by the optimized nitridation process. These characterization results reveal that the reformed nitridation process plays a vital role in the improvement in the crystalline quality as well as the electrical and optical properties of the N-polar AlGaN epi-layers.

Nature of intensive defect-related broadband luminescence of heavily doped Al x Ga1-x N:Si layers

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We report photoluminescence investigations of heavily doped Al x Ga1-x N:Si films grown by molecular beam epitaxy on sapphire substrates. The wide intensive defect-related band dominates in the photoluminescence spectra of Al x Ga1-x N:Si films with the Al content higher than 0.46 covering the whole visible spectral range. This band is attributed to donor-acceptor transitions. The acceptor ionization energy of about 1.87 eV for heavily doped AlN:Si was obtained, decrease of Al content leads to decrease of the acceptor ionization energy. The donor was assigned to the Si atom on the Ga/Al site; the acceptor might be the (2-/3-) transition level of the V Al.

Effect of compositional interlayers on the vertical electrical conductivity of Si-doped AlN/GaN distributed Bragg reflectors grown on SiC

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We have investigated the effect of strain-compensating interlayers on the vertical electrical conductivity of Si-doped AlN/GaN distributed Bragg reflectors (DBRs). Samples with 10.5 mirror pairs were grown through plasma-assisted molecular beam epitaxy on SiC. Room-temperature current–voltage characteristics were measured vertically in mesas through 8 of the 10.5 pairs. The sample with no interlayers yields a mean specific series resistance of 0.044 Ω cm2 at low current densities, while three samples with 5/5-Å-thick, 2/2-nm-thick, and graded interlayers have resistivities between 0.16 and 0.34 Ω cm2. Thus, interlayers impair vertical current transport, and they must be designed carefully when developing conductive DBRs.

MOVPE growth of GaN on 6-inch SOI-substrates: effect of substrate parameters on layer quality and strain

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Semiconductor Science and Technology
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We demonstrate that higher crystalline quality, lower strain and improved electrical characteristics can be achieved in gallium nitride (GaN) epitaxy by using a silicon-on-insulator (SOI) substrate compared to a bulk silicon (Si) substrate. GaN layers were grown by metal–organic vapor phase epitaxy on 6-inch bulk Si and SOI wafers using the standard step graded AlGaN and AlN approach. The GaN layers grown on SOI exhibited lower strain according to x-ray diffraction analysis. Defect selective etching measurements suggested that the use of SOI substrate for GaN epitaxy reduces the dislocation density approximately by a factor of two. Furthermore, growth on SOI substrate allows one to use a significantly thinner AlGaN buffer compared to bulk Si. Synchrotron radiation x-ray topography analysis confirmed that the stress relief mechanism in GaN on SOI epitaxy is the formation of a dislocation network to the SOI device Si layer. In addition, the buried oxide layer significantly improves the vertical leakage characteristics as the onset of the breakdown is delayed by approximately 400 V. These results show that the GaN on the SOI platform is promising for power electronics applications.

Low-temperature (≤600 °C) growth of high-quality In x Ga1− x N (x ~ 0.3) by metalorganic vapor phase epitaxy using NH3 decomposition catalyst

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In x Ga1− x N (x ~ 0.3) films on GaN/sapphire templates were grown by NH3 decomposition catalyst-assisted metalorganic vapor phase epitaxy (CA-MOVPE). NiO-based pellets were used as a catalyst. Even at a temperature lower than 500 °C, single-crystal In0.3Ga0.7N films were grown without the incorporation of metallic components (In, Ga) or the cubic phase. In contrast with the case of InN growth using the same catalyst [A. Yamamoto et al., Jpn. J. Appl. Phys. 55, 05FD04 (2016)], no marked grain growth or hydrogen etching was observed in In0.3Ga0.7N. Samples grown at a temperature ≤500 °C showed a full-width at half-maximum of the (0002) X-ray rocking curve as small as 10 arcmin or smaller. The carrier

concentration in nominally undoped In0.3Ga0.7N grown using the catalyst was higher by about 4 orders of magnitude than that in conventional MOVPE samples. Secondary ion mass spectroscopy analysis revealed that such a higher carrier concentration was due to the marked reduction in carbon contamination level in the films.

Impact of wet-oxidized Al2O3/AlGaN interface on AlGaN/GaN 2-DEGs

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Semiconductor Science and Technology
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We investigated the impact of wet-oxidation of AlGaN in an AlGaN/GaN heterostructure by selectively probing the metal/AlGaN interface. The two-dimensional electron gas (2-DEG) characteristics show improved mobility with increasing oxidation time and Al2O3 thickness. The change is attributed to an interplay of the interface trap density (D it) and the oxide thickness. D it is found to reduce progressively for thicker gate oxides as determined by selectively probing the Al2O3/AlGaN interface and employing frequency dependent capacitance and conductance spectroscopy on these devices. The energies of the interface traps are found to be in the range of 0.35–0.45 eV below the conduction band edge. The D it is found to reduce from 2 × 1013 cm−2 eV−1 for 2.3 nm of Al2O3 to 5 × 1012 cm−2 eV−1 for 16 nm of Al2O3. Contrary to the earlier reports of increased 2-DEG electron density, the primary advantage is found to be a reduction in Dit leading to an increased electron mobility from 1730 to 2800 cm2V−1s−1.

Ion-assisted gate recess process induced damage in GaN channel of AlGaN/GaN Schottky barrier diodes studied by deep level transient spectroscopy

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Deep traps in AlGaN/GaN Schottky barrier diodes have been investigated using deep level transient spectroscopy. It has been found that ion-assisted gate recess process leads to the formation of electron traps. The defects related to these traps are mainly located in the two-dimensional electron gas channel below the Schottky contact, meaning that the partial etching of the AlGaN layer produces damage on the top of the underlying GaN layer. The activation energies of the electron traps, extracted from the data, range between 0.28 and 0.41 eV. We believe that these centers are complexes linked with nitrogen vacancies which may behave as extended defects.

Wafer-scale epitaxial lift-off of GaN using bandgap-selective photoenhanced wet etching

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Physica status solidi (b)
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An epitaxial lift-off (ELO) process for GaN materials has been demonstrated using bandgap-selective photoenhanced wet etching of an InGaN release layer. This process has been applied to GaN layers grown on sapphire as well as native GaN substrates using a perforation technique to scale the process up to wafers of arbitrary size. The process has the advantage of leveraging conventional MOCVD growth to form the release layer, with minimal degradation of films grown on top of the release layer. The ELO process is non-destructive and can enable cost reduction through reuse of the native GaN substrate after ELO. The GaN films have been characterized before and after ELO using AFM, SEM, XRD, TEM and by fabricating Schottky barrier diodes. The performance of Schottky diodes fabricated on GaN-on-sapphire structures was found to improve after ELO. Potential applications for this technology include GaN power and optoelectronic devices as well as flexible electronics.

Extraction of net acceptor type trap density in semi-insulating GaN layers grown on Si substrate by DC I–V measurement

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A simple quantitative method is proposed to estimate net acceptor-type trap density (NT–ND, where NT denotes a gross acceptor-type trap density, and ND denotes a donor density) in semi-insulating GaN layers, widely used as the electron channel layer in AlGaN/GaN heterojunction field-effect-transistors. The DC current–voltage characteristics of a semi-insulating GaN layer on a Si wafer have a threshold voltage (VTH). Band diagram simulation reveals that NT–ND determines VTH, and hence, the NT–ND in semi-insulating GaN films can be experimentally estimated by measuring VTH.

Substantiation of buried two dimensional hole gas (2DHG) existence in GaN-on-Si epitaxial heterostructure

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Gallium Nitride on Silicon (GaN-on-Si) devices feature a relatively thick epi buffer layer to release the stress related to the lattice constant mismatch between GaN and Si. The buffer layer is formed by several AlGaN-based transition layers with different Al contents. This work addresses the fundamental question of whether two-dimensional hole gases (2DHGs) exist at those interfaces where the theory predicts a high concentration of a negative fixed charge as a consequence of the discontinuity in polarization between the layers. In this study, we demonstrate that the presence of such 2DHGs is consistent with the measured vertical Capacitance-Votage Profiling (CV) and Technology Caomputer-Aided Design (TCAD) simulation in the whole range of measurable frequencies (10 mHz–1 MHz). N-type compensating background donor included in the epi structure in the simulation deck proves to be crucial to explain the depletion region extension consistent with the CV experimental data. For the standard range of frequencies (1 kHz–1 MHz), there was no indication of the presence of 2DHGs. A set of ultra-low frequency (10 mHz–10 Hz) measurements performed were able to reveal the existence of 2DHGs. The outcome of these ultra-low frequency experiments was matched with TCAD simulations which validated our theory.

Epitaxial ScAlN grown by molecular beam epitaxy on GaN and SiC substrates

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Appl. Phys. Lett.
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ScxAl1-xN is a promising ultra-wide bandgap material with a variety of potential applications in electronic, optoelectronic, and acoustoelectric devices related to its large piezoelectric and spontaneous polarization coefficients. We demonstrate growth of ScxAl1-xN on GaN and SiC substrates using plasma-assisted molecular beam epitaxy with x = 0.14–0.24. For metal-rich growth conditions, mixed cubic and wurtzite phases formed, while excellent film quality was demonstrated under N-rich growth conditions at temperatures between 520 and 730 °C. An rms roughness as low as 0.7 nm and 0002 rocking curve full-width at half maximum as low as 265 arc sec were measured for a Sc0.16Al0.84 N film on GaN. To further demonstrate the quality of the ScAlN material, a high-electron-mobility transistor heterostructure with a Sc0.14Al0.86 N barrier, GaN/AlN interlayers, and a GaN buffer was grown on SiC, which showed the presence of a two-dimensional electron gas with a sheet charge density of 3.4 × 1013 cm−2 and a Hall mobility of 910 cm2/V·s, resulting in a low sheet resistance of 213 Ω/□.

Kinetic Monte Carlo simulations of GaN homoepitaxy on c- and m-plane surfaces

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The surface orientation can have profound effects on the atomic-scale processes of crystal growth and is essential to such technologies as GaN-based light-emitting diodes and high-power electronics. We investigate the dependence of homoepitaxial growth mechanisms on the surface orientation of a hexagonal crystal using kinetic Monte Carlo simulations. To model GaN metal-organic vapor phase epitaxy, in which N species are supplied in

excess, only Ga atoms on a hexagonal close-packed (HCP) lattice are considered. The results are thus potentially applicable to any HCP material. Growth behaviors on c-plane (0001) and m-plane (011—0)(011¯0) surfaces are compared. We present a reciprocal space analysis of the surface morphology, which allows extraction of growth mode boundaries and direct comparison with surface X-ray diffraction experiments. For each orientation, we map the boundaries between 3-dimensional, layer-by-layer, and step flow growth modes as a function of temperature and growth rate. Two models for surface diffusion are used, which produce different effective Ehrlich-Schwoebel step-edge barriers and different adatom diffusion anisotropies on m-plane surfaces. Simulation results in agreement with observed GaN island morphologies and growth mode boundaries are obtained. These indicate that anisotropy of step edge energy, rather than adatom diffusion, is responsible for the elongated islands observed on m-plane surfaces. Island nucleation spacing obeys a power-law dependence on growth rate, with exponents of −0.24 and −0.29 for the m- and c-plane, respectively.

Indium segregation in N-polar InGaN quantum wells evidenced by energy dispersive X-ray spectroscopy and atom probe tomography

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Energy dispersive X-ray spectroscopy (EDX) in scanning transmission electron microscopy and atom probe tomography are used to characterize N-polar InGaN/GaN quantum wells at the nanometer scale. Both techniques first evidence the incorporation of indium in the initial stage of the barrier layer growth and its suppression by the introduction of H2 during the growth of the barrier layer. Accumulation of indium at step edges on the vicinal N-polar surface is also observed by both techniques with an accurate quantification obtained by atom probe tomography (APT) and its 3D reconstruction ability. The use of EDX allows for a very accurate interpretation of the APT results complementing the limitations of both techniques.

Short-wave infrared (λ = 3 µm) intersubband polaritons in the GaN/AlN system

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We demonstrate intersubband polaritons in the short-infrared wavelength range (λ < 3 µm) relying on the GaN/AlN semiconductor system. The demonstration is given for an intersubband transition centered at λ = 3.07 µm (E = 403 meV). The polaritonic dispersion is measured at room temperature: a Rabi energy of 53 meV (i.e., a minimum splitting of 106 meV), which represents 13.1% of the bare transition, is demonstrated. A metal-insulator-metal resonator architecture is employed, which proves to be efficient even at these short wavelengths.

Influence of dislocation density on internal quantum efficiency of GaN-based semiconductors

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By considering the effects of stress fields coming from lattice distortion as well as charge fields coming from line charges at edge dislocation cores on radiative recombination of exciton, a model of carriers' radiative and non-radiative recombination has been established in GaN-based semiconductors with certain dislocation density. Using vector average of the stress fields and the charge fields, the relationship between dislocation density and the internal quantum efficiency (IQE) is deduced. Combined with related experimental results, this relationship is fitted well to the trend of IQEs of bulk GaN changing with screw and edge dislocation

density, meanwhile its simplified form is fitted well to the IQEs of AlGaN multiple quantum well LEDs with varied threading dislocation densities but the same light emission wavelength. It is believed that this model, suitable for different epitaxy platforms such as MOCVD and MBE, can be used to predict to what extent the luminous efficiency of GaN-based semiconductors can still maintain when the dislocation density increases, so as to provide a reasonable rule of thumb for optimizing the epitaxial growth of GaN-based devices.

Control of unintentional oxygen incorporation in GaN

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The impact of growth temperature on the unintentional oxygen incorporation in GaN and AlGaN grown by molecular beam epitaxy and the consequences for electrical and optical properties are investigated. In particular, transistor switching characteristics, magneto-transport traces, and photoluminescence spectra of samples grown around 600 and 665 °C are compared. It is found that the incorporation of unintentional oxygen in GaN and Al0.1Ga0.9N is reduced by 1 order of magnitude upon increasing the growth temperature by ∼60 °C. A growth temperature of 665 °C results in an oxygen background concentration of 1 × 1017 cm−3 and simultaneously in electrically insulating GaN material.

Surface preparation of freestanding GaN substrates for homoepitaxial GaN growth by rf-plasma MBE

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The authors have investigated different methods for preparing the surfaces of freestanding, Ga-polar, hydride vapor-phase epitaxy grown GaN substrates to be used for homoepitaxial GaN growth by plasma-assisted molecular beam epitaxy (MBE). Cross-sectional transmission electron microscopy and secondary ion mass spectroscopy, respectively, were used to characterize the microstructure and to measure the concentrations of impurities unintentionally incorporated in the MBE-grown homoepitaxial GaN layers. Heating Ga-polar substrates to ∼1100 °C is as effective as a wet chemical clean for reducing impurity concentrations of oxygen, silicon, and carbon. The combination of an aggressive ex situ wet chemical clean with in situ Ga deposition and thermal desorption results in homoepitaxial GaN layer growth with very low residual impurity concentrations and without generating additional threading dislocations.

Effect of hydrogen treatment temperature on the properties of InGaN/GaN multiple quantum wells

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InGaN/GaN multiple quantum wells (MQWs) were grown with hydrogen treatment at well/barrier upper interface under different temperatures. Hydrogen treatment temperature greatly affects the characteristics of MQWs. Hydrogen treatment conducted at 850 °C improves surface and interface qualities of MQWs, as well as significantly enhances room temperature photoluminescence (PL) intensity. In contrast, the sample with hydrogen treatment at 730 °C shows no improvement, as compared with the reference sample without hydrogen treatment. On the basis of temperature-dependent PL characteristics analysis, it is concluded that hydrogen treatment at 850 °C is

more effective in reducing defect-related non-radiative recombination centers in MQWs region, yet has little impact on carrier localization. Hence, hydrogen treatment temperature is crucial to improving the quality of InGaN/GaN MQWs.

Adsorption of sodium dodecyl sulfate on cleaning of an N-polar GaN surface in an alkaline solution

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Materials Science and Engineering: B
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The present study investigated the removal of contaminated particles from a polished N-polar GaN surface using an alkaline cleaning solution along with sodium dodecyl sulfate (SDS) surfactant. The zeta potential, etch rate, and particle removal efficiency (PRE) of N-polar GaN surfaces were reported. A lower etch rate and smoother N-polar GaN surface were obtained when the surface is treated with a diluted NH4OH solution. However, the etch rate and PRE of the N-polar GaN surface increased as a function of the pH of the NH4OH solution. The PRE of the N-polar GaN surface reached to 96% at pH 10 with a high surface roughness of 0.5 nm. SDS was added to the ammonia solutions to control the surface roughness. The N-polar GaN surface reached 100% PRE and surface roughness shown less than 0.4 nm when cleaned in a diluted NH4OH solution with 5 mM SDS surfactant in a megasonic bath.

Band-Bending of Ga-Polar GaN Interfaced with Al2O3 through Ultraviolet/Ozone Treatment

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Understanding the band bending at the interface of GaN/dielectric under different surface treatment conditions is critically important for device design, device performance, and device reliability. The effects of ultraviolet/ozone (UV/O3) treatment of the GaN surface on the energy band bending of atomic-layer-deposition (ALD) Al2O3 coated Ga-polar GaN were studied. The UV/O3 treatment and post-ALD anneal can be used to effectively vary the band bending, valence band offset, conduction band offset, and interface dipole at the Al2O3/GaN interfaces. The UV/O3 treatment increases the surface energy of the Ga-polar GaN, improves the uniformity of Al2O3 deposition, and changes the amount of trapped charges in the ALD layer. The positively charged surface states formed by the UV/O3 treatment-induced surface factors externally screen the effect of polarization charges in the GaN, in effect, determining the eventual energy band bending at the Al2O3/GaN interfaces. An optimal UV/O3 treatment condition also exists for realizing the “best” interface conditions. The study of UV/O3 treatment effect on the band alignments at the dielectric/III-nitride interfaces will be valuable for applications of transistors, light-emitting diodes, and photovoltaics.

PRESS RELEASE

Technical and economic information selected by Knowmade

OPTOELECTRONICS

UNIQUE project to develop mass-market UV-C LEDs for industrial disinfection applications

Source: Semiconductor Today

Funded by the Bavarian Ministry for Economic Affairs, Media, Energy and Technology and sponsored by VDI/VDE/IT, the UNIQUE project (which is running from July 2016 to June 2019) aims to develop high-power UV-C LEDs (with wavelengths of 260-280nm) as mercury-free light sources for industrial disinfection processes. Potential applications span domestic water purification to industrial disinfection of food packaging.

With the LEDs based on aluminum gallium nitride (AlGaN), meeting this objective requires fundamental material, technology and system developments along the entire value-added chain. The project hence involves five Bavarian companies and research institutions, coordinated by Osram Opto Semiconductors GmbH of Regensburg, Germany.

aprotec GmbH is responsible for the design of a special installation for producing aluminum nitride (AlN) volume crystals by evaporating AlN powder at over 2000°C. The Fraunhofer Institute for Integrated Systems and Device Technology (IISB) in Erlangen, Germany is in charge of developing and optimizing a process chain for producing AlN substrates, which includes everything from the synthesis of high-purity AlN powder and the production of AlN crystals to the manufacture of AlN substrates from the AlN crystals. Osram Opto is developing the UV-C LED chip, using the associated epitaxy and processing on the basis of the AlN substrate.

UV LED chips need the protection of a gas-tight package that offers a constant vacuum and hence a stable atmosphere for the chip. Developing a permanently vacuum-tight package from inorganic UV-stable materials and evaluating the structure and connections are the tasks of SCHOTT AG of Landshut, Germany. Finally, Dr Hönle AG is responsible for integrating the UV-C modules into a new disinfection system and conducting the appropriate system tests.

By developing a small, cost-effective, energy-efficient, mercury-free, long-life UV diode the project partners aim to gain a strong position in the growing market for UV LEDs and to use the results of the project to strengthen Bavaria as a location for business. “Our many years of experience in the development of mass-market opto semiconductor components will help make the UNIQUE project a success and contribute to bringing the prototype to market at a later date in volume production,” says Dr Hans-Jürgen Lugauer, head of UV development at Osram Opto. “Osram Opto is already active in the near-UV range. UNIQUE will extend our portfolio into the deep UV range, specifically for disinfection applications.”
Read more

Osram Opto qualifies Aixtron AIX G5 C MOCVD system for GaN LED production

Source: Semiconductor Today

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says that Osram Opto Semiconductors GmbH of Regensburg, Germany has qualified the first of multiple AIX G5 C planetary systems for manufacturing gallium nitride (GaN) LEDs.

Aixtron says that, as market demand for high-quality optoelectronics is increasing due to the continually growing number of applications in the illumination, sensing and visualization sectors (including automotive, communication, display, health and food), Osram Opto is expanding production capacities, for example at its Regensburg facility.

"We have chosen the AIX G5 C as it is one of the best-in-class for high-performance applications. The system offers the lowest defect and particle level to date due to its effective in-situ cleaning system and cassette-to-cassette handler, which is essential for high yields," comments Berthold Hahn, senior director LED Chip at Osram Opto. "Furthermore, Aixtron's advanced production tools allow best wavelength uniformity for reduced binning effort and therefore enables future technologies with very demanding uniformity requirements. Overall, the AIX G5 C provides leading edge blue and green LED processes that are necessary to meet our high quality standards in volume production for various lighting applications," he adds.

"We are looking forward to the further collaboration with one of the world's leading semiconductor manufacturers," says Dr Frank Schulte, vice president of Aixtron Europe. "Our AIX G5 C platform perfectly backs Osram's product strategy since it enables the manufacturing of devices that support future-oriented technology trends in the areas of mobility, communication and energy efficiency."
Read more

Epistar files US patent infringement lawsuit against Lowe's

Source: Semiconductor Today

On 28 April, LED epitaxial wafer and chip maker Epistar Corp of Hsinchu Science-based Industrial Park, Taiwan filed a lawsuit in the US District Court for the Central District of California against Lowe's Companies Inc and Lowe's Home Centers LLC.

The complaint alleges that the Kichler Lighting's LED filament bulbs sold by Lowe's - such as the Kichler Lighting 60W Equivalent Dimmable Soft White A15 LED Decorative Light Bulb (P/N: YGA16A08-A15C-CL-5W) - infringe one or more claims of Epistar's US patent numbers 6,346,771 'High Power LED Lamp', 7,560,738 'Light-Emitting Diode Array Having An Adhesive Layer', 8,791,467 'Light Emitting Diode And Method Of Making The Same', 8,492,780 'Light-Emitting Device And Manufacturing Method Thereof', and 8,587,020 'LED Lamp'.

The complaint also alleges that Utilitech's LED bulbs sold by Lowe's - such as the Utilitech 60W Equivalent Warm White A19 LED Light Fixture Light Bulb (P/N: YGA03A41-A19-9W-830) - infringe one or more claims of Epistar's US patent numbers 8,492,780 'Light-Emitting Device And Manufacturing Method Thereof' and 8,587,020 'LED Lamp'.

The lawsuit seeks injunctive relief to halt further sale of the infringing products.

Epistar says that it has invested millions of dollars in R&D on LED technologies that have led to a portfolio consisting of over 4000 issued patents and pending patent applications, laying the foundation of its LED filament (bulb) and/or LED bulb technologies.
Read more

Soraa expands into directional luminaires

Source: Semiconductor Today

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology fabricated on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, is expanding into the directional luminaire market by launching Arc directional fixtures.

Designed around what is claimed to be the industry's slimmest-profile die-cast heat sink, Arc is optimized for thermal management. "It's the science behind our technology that gave my team the ability to design shallow fixtures, small apertures and narrow clean beams," says Susan Larson, vice president responsible for the Fixture business and the design lead for Arc.
Read more

SoraaLaser demonstrating new dynamic laser light source technology for specialty lighting

Source: Semiconductor Today

In booth # 5807 at LightFair International in Philadelphia (9-11 May), SoraaLaser of Goleta, CA, USA (a spin-off from LED lighting firm Soraa Inc that is commercializing visible laser light sources for display, automotive and specialty applications) is demonstrating its new dynamic laser light source technology

The solid-state light sources feature fiber-delivered illumination that can be dynamically tuned from a narrow beam spotlight to a broad floodlight using a smartphone app control.

SoraaLaser claims that its solid-state laser light source technology provides advantages over LED, OLED and legacy sources in specialty lighting by enabling digital design freedom for specifiers and luminaire manufacturers in architectural, outdoor, hospitality, retail, security and entertainment lighting. In the past, dynamic beam shaping could only be accomplished by motors, manual change-out of optics, or the switching on and off of many dozens of LEDs within a large matrix, says the firm.

SoraaLaser's visible laser light sources utilize its patented semi-polar gallium nitride (GaN) laser diodes, combined with advanced phosphor technology, packaged into lighting-friendly assemblies. Compared with other light sources, they are said to provide novel properties by combining the benefits of solid-state illumination (such as minimal power consumption and long lifetime) with the highly directional output that has been possible only with legacy technology. Because the laser diodes are focused to a small spot on the phosphor and converted to white light, the SoraaLaser light sources are said to deliver high luminance and enable safe, highly collimated white light output, superior optical control with miniature optics and reflectors, along with high-efficiency fiber-optic transport and waveguide delivery.
Read more

Cree and San'an forming Hong Kong-based JV to produce mid-power lighting-class packaged LEDs

Source Semiconductor Today

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA and Xiamen-based San'an Optoelectronics Co Ltd (China's largest producer of full-color ultra-high-brightness LED epiwafers and chips) are forming a joint venture Cree Venture LED Company Ltd to produce and deliver to market mid-power lighting-class LED packaged products in an exclusive arrangement to serve the expanding markets of North and South America, Europe and Japan, and serve China and the rest of the world on a non-exclusive basis.

Located in Hong Kong, Cree Venture LED Company Ltd will be led by general manager TK Ong (who has extensive experience in the LED market) and will be governed by a board of directors with members from both firms. Cree will own 51% of the joint venture, and San'an will own 49%.

Leveraging Cree's portfolio of patents and global sales channels, the joint venture aims to bring to market a broad portfolio of mid-power products to serve the fast-growing $4bn global mid-power LED market. Cree says that its LED business is now able to serve the broader needs of the general illumination (indoor and outdoor lighting), horticultural and other evolving LED markets.

"This joint venture builds on both companies' leading product and channel capabilities to give Cree the ability to provide our LED customers a complete range of high-power and mid-power LED products to serve a broad range of markets and applications," says Cree's president & CEO Chuck Swoboda.

"The addition of the mid-power LED products in this new joint venture to Cree's industry-leading high-power products gives us an unparalleled LED portfolio," reckons Cree LEDs senior VP & general manager Dave Emerson. "With our LED systems expertise, customers are able to work with our existing channels to find the best LEDs for their applications."

Cree and San'an will be working in the coming months to incorporate, fund and commence operations of the joint venture. Initial product sales are targeted for third-quarter 2017. Cree will receive royalties from the joint venture on its patent portfolio.
Read more

LEDs rising from 60% of overall lighting market in 2016 then 80% in 2020 and 98% by 2025

Source: Semiconductor Today

The LED lighting market grew 18.1% to $47,303m in 2016, accounting for almost 60% of global lighting, according to the report 'Global LED Lighting Market (2017 Update)', part of Frost & Sullivan's Homes & Buildings Growth Partnership Service program. By 2020, LED lighting is likely to account for 80% of the total lighting market (creating an $80bn market), rising to 98% by 2025.

The residential LED lighting market in particular will see grow 16.7% year-on-year in 2017. However, although the residential, outdoor and retail sectors make the highest contributions at present, office, industrial and hospitality are expected to be future growth sectors.

LED market evolution continues with a steep decline in cost per unit, high energy-efficiency ratings, a market shift toward these lighting solutions, and favorable government initiatives driving adoption, notes the report. The Internet of Things (IoT) will disrupt the market, shifting focus from energy efficiency, product reliability and O&M costs to include controllability, connectivity and technology integration in smart buildings and smart cities.

"New technologies driven by IoT, such as light-as-a-service (Laas), will usher in connected lighting and living, enabling better energy management and new services and business models like financing and leasing," says Frost & Sullivan's Energy & Environment research analyst Sabnam Gafoor. "On the flip side, new business models and an influx of new players from the Asia-Pacific will make the future market a fragmented one."

The Asia-Pacific region contributes the most to global market revenue. Express construction in many Asian countries, government endorsement of energy-efficient lights in India and China, and the existence of a large number of LED chip and package factories in China, Japan, South Korea and Taiwan are factors driving growth. Worldwide, the regions that will see the highest growth rates are India, Asia-Pacific, Latin America and Africa.

Frost & Sullivan notes that organic LEDs (OLEDs) are gaining popularity as a solid-state lighting (SSL) technology due to their ability to emit warm light over large areas, provide color comfort, and bring improved form factors to the lighting industry.

"To remain competitive and relevant in an evolving ecosystem, LED players should seek to improve manufacturing efficiencies by adopting a larger wafer size, utilize intelligent lighting through integrated control devices, implement active and passive cooling techniques for device longevity, and replace expensive substrate materials with cheaper alternatives," concludes Gafoor.
Read more

LED materials market growing at 9.9% CAGR to $12.55bn by 2021

Source: Semiconductor Today

The LED materials market is increasing at a compound annual growth rate (CAGR) of 9.9% from 2016 to $12.55bn in 2021, forecasts a report from MarketsandMarkets.

The market is driven by the growing demand for LED materials in general lighting applications, resulting from an increase in demand for LEDs for residential and industrial facilities.

Asia-Pacific the largest market for LED materials

Asia-Pacific is currently the largest market for LED materials. China is the leading country where there is major consumption of LED materials in end-use industries such as general lighting, automotive lighting, and backlighting. Moreover, the growing population with rising disposable income in China is driving demand for better-quality LED materials.

Wafers the largest market segment

Of the LED materials market in 2016 in terms of value, the wafer segment accounted for the largest share, followed by the epitaxy segment. The wafer segment is also projected to grow at the highest CAGR to 2021.

General lighting dominating LED materials market

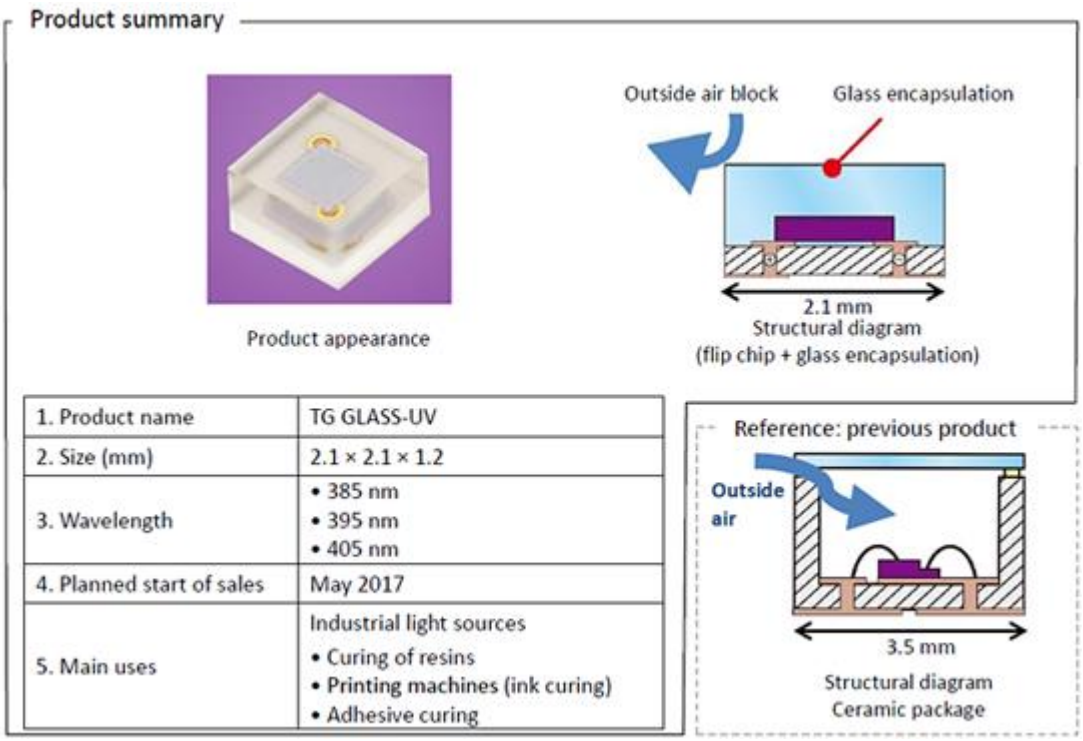
The general lighting application segment is projected to drive the LED materials market, aided by increased demand from residential LED markets to reduce overall energy costs. Industrial lighting is also expected to contribute to the growth. The use of LEDs in industrial settings has increased, as they are better than conventional lighting sources at overcoming challenges such as extreme temperature ranges and continuous or long operational hours.

Key players in the LED materials market are cited as Sumitomo Electric Industries Ltd (Japan), Hitachi Metals Ltd (Japan), Cree Inc (USA), Seoul Semiconductor Co Ltd (South Korea), Nichia Corp (Japan), Epistar Corp (Taiwan), Koninklijke Philips N.V. (Netherlands), Osram Licht AG (Germany), II-VI Inc (USA), and Akzo Nobel N.V. (The Netherlands).
Read more

Toyoda Gosei to begin sales of glass-encapsulated UV LEDs

Source: Semiconductor Today

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan is to begin sales of its glass-encapsulated ultraviolet LED products developed in March 2016 for use as an industrial light source in the curing of resins, ink and adhesives.



The firm says that the new UV LEDs maintain good reliability in high-temperature, high-humidity environments due to complete encapsulation of the LED chip in glass, minimizing the impact of gas penetration and moisture on the die. Also, an improved crystal structure boosts the light output per LED die, while the use of flip-chip technology (directly connecting the LED die to the substrate) results in smaller product size.

With these improvements, the new glass-encapsulated UV-LEDs achieve light output per unit area of 200mW/mm2, more than twice that of previous products.
Read more

LG Innotek launches UV LED module for sterilizing water purifier faucets

Source: Semiconductor Today

Seoul-based LG Innotek (a subsidiary of South Korean electronics company LG Group) says that, since the end of March, it has been mass producing an ultraviolet (UV) LED module that sterilizes the inside of water purifier faucet aerators. The module has been incorporated into LG Electronics' new direct water purifier 'PuriCare Slim Updown', launched in March.

A water purifier faucet aerator always holds a small amount of water. This part is prone to contamination due to the growth of germs that enter with the influx of air. However, it has been difficult to install a sterilizer inside a faucet aerator because the space is too narrow. The new module is 1.5cm in width and 3.7cm in length and can be mounted in the small space inside the water purifier.

The UV LED module kills 99.98% of germs when a faucet aerator is exposed to ultraviolet rays (of 278nm wavelength) for 5 minutes.It is also harmless, since it uses only ultraviolet rays for sterilization without any chemicals or heavy metals.

LG Innotek says that the new module is convenient to use as it allows quick and accurate control of ultraviolet rays. As soon as its sterilization function is activated, UV rays are released at peak performance. In contrast, a mercury UV lamp requires about 2 minutes to warm up.

LG Electronics' direct water purifier installed with this module allows instant sterilization of faucets by pressing the 'Self Care' button at any time. It also performs automatic sterilization every hour.

LG Innotek plans to actively expand the application of UV LEDs to various products. It already has a line-up of products that are optimized for different applications, including 365nm, 385nm, 395nm and 405nm UV-A LEDs for general industry and a 305nm UV-B LED for the biomedical field as well as a 280nm UV-C LED for sterilization.
Read more

Seoul Semiconductor files LED patent infringement lawsuit in Germany against Mouser

Source: Semiconductor Today

On 31 March, South Korean LED maker Seoul Semiconductor Co Ltd (SSC) filed a patent infringement lawsuit in Germany in the District Court of Düsseldorf against global electronic component distributor Mouser Electronics Inc asserting infringement of an LED patent.

According to the complaint, the accused products include LEDs for high-power light emission. Further investigation suggests that they are manufactured by multiple LED companies, including Everlight Electronics Co Ltd, a global top-10 LED maker. Seoul has sought a permanent injunction, damages, and recall and destruction of the allegedly infringing products.

The asserted patented technology serves to efficiently extract light emitted from the internal LED structure by treating LED chip surfaces, improving light intensity and brightness. This patented technology has been widely used for various high-power LED applications, such as automobile lighting, cell-phone flashlights, outdoor lighting, UV LED appliances, etc.

According to market research firm IHS, the LED penetration rate in automobile headlamps will rise sharply from the existing penetration rate of 16.4% to 32.3% by 2021. This high-power LED technology is already being used for exterior automobile lighting, including headlights and daytime running lights. Furthermore, it is expected to become a significant technology for electric vehicles and autonomous vehicles, which require high-power LED lighting with high heat dissipation for energy efficiency.

In addition, this high-power LED technology also applies to LEDs for mobile phone flashlights, which require higher light intensity. Because margins for flashlight LEDs are higher than those for backlights, the flashlight LED market has still grown steadily despite the overall decline in the IT sector LED market.

Further, the high-power LED technology is widely applicable to general lighting products for outdoor illumination and commercial or industrial use because such technology substantially enhances light efficiency and improves the brightness per unit area obtained from the LED. The technology is also widely used in manufacturing ultraviolet (UV) LEDs for sterilization, purification and curing processes. The UV LED application market is expected to grow rapidly, reaching $800m by 2020.

Beginning with this lawsuit, Seoul says that it plans to actively defend its patent assets against infringing high-power LED technologies. It has already identified infringements of other patents that it possesses related to high-power LEDs and will be considering additional infringement lawsuits.

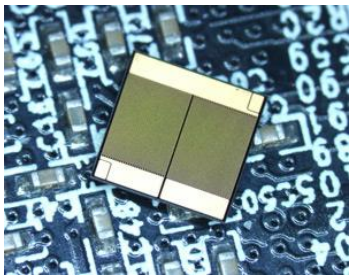
"The asserted patent is considered an essential technology for manufacturing high-power LEDs and has been widely used in various LED applications," says Ki-bum Nam, VP of Seoul Semiconductor's Lighting Business Department. "However, there are many LED products currently on the market that infringe this patented technology, so we have decided to begin enforcing our patent rights in such cases," he adds. "To create a fair market competition and promote technological innovation, we continuously take any and all actions necessary to deter such infringement and protect our intellectual property."
Read more

ELECTRONICS

Fraunhofer IAF develops first monolithically integrated half-bridge for 600V-class

Source: Semiconductor Today

Fraunhofer Institute for Applied Solid State Physics (IAF) of Freiburg, Germany has developed what is claimed to be the first half-bridge circuit for the important 600V class in which all the electronic components are monolithically integrated on one chip. Monolithically integrated half bridges are key building blocks of compact voltage converters and significantly increase the efficiency of power electronics devices.



Fraunhofer IAF's monolithically integrated half-bridge circuit. © Photo Fraunhofer IAF

Used in mains adapters and chargers for smartphones, laptops and low-voltage household appliances, voltage converters are in increasingly widespread demand as more and more electrical devices are being plugged into mains power supplies. The energy transition and e-mobility are also increasing the demand for reliable and, above all, efficient and compact voltage converters of all kinds. Half-bridge circuits are the centerpiece of many voltage converters.

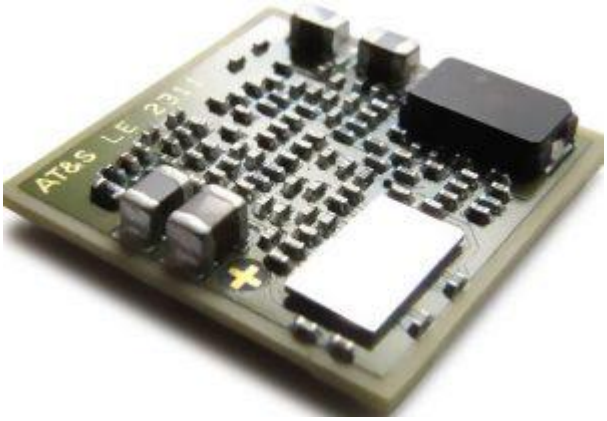
In power electronics components, 600V is the standard volt class for grid-connected electrical devices, ranging from tablets and washing machines to e-bikes and electric cars.

Besides being very compact, monolithically integrated half-bridge circuits have much better electronic properties, e.g. the switching frequency can be improved by a factor of about 10 compared with conventional voltage converters. "A switching frequency of up to 3MHz allows us to achieve a much greater power density. This is very important in areas such as e-mobility, where many converters which are as efficient as possible have to be fitted in very little space," says Richard Reiner, research associate in Fraunhofer IAF's Power Electronics business unit. Monolithically integrated half-bridges are more compact, are easier to assemble and improve reliability.
Read more

Fraunhofer IAF's GaN-on-Si monolithic multi-level power converter demonstrated using AT&S' embedded component technology

Source: Semiconductor Today

The Fraunhofer Institute for Applied Solid State Physics IAF of Freiburg, Germany has developed a fully integrated monolithic multi-level converter in high-voltage AlGaN/GaN-on-Si technology. The integrated inverter circuit is designed for maximum voltages of +/-400V and currents of 5A. The multi-level converter comprises four transistors and six diodes but covers an area of just 2mm x 3mm, suiting compact voltage-converter applications. DC/AC inverter operation has been demonstrated for US mains voltage. The circuit exhibits minimal dynamic losses at very high frequencies. The switching performance of the multi-level converter was demonstrated with a test setup based on the Embedded Component Technology (ECP) of printed-circuit board (PCB) maker AT&S (Austria Technologie & Systemtechnik) AG of Leoben, Austria.



A corresponding test setup is necessary in order to evaluate the chip, since the packaging of the die constitutes a key factor. If lateral components are employed, then the source, drain and gate pads are on one side and the back of the die is used for heat dissipation. Since the conventional approach using wirebonds imposes restrictions, the second step of the evaluation saw AT&S' ECP technology being used. The power components – like the multi-level converter – are hence embedded into the PCB material and can be connected from both sides. The chips are connected directly via copper-plated microvias. This permits low-impedance connections and significantly lower inductances compared with wirebond technology. The rear of the die is also connected by means of copper-plated microvias, ensuring excellent heat dissipation.

"We see this [AT&S ECP] mounting technology as opening up entirely new possibilities – particularly also for more complex monolithic integrated GaN power circuits, as used on our multi-level converter chip," says Fraunhofer IAF scientist Richard Reiner. "With a conventional design, we were hardly able to use and/or evaluate the powerful chip," he adds.

"Power electronics constitutes a major field of application and focus for the embedding technology from AT&S," says Dietmar Drofenik, CEO of AT&S' Advanced Packaging business unit. "Particularly for the use of wide-bandgap semiconductor materials such as GaN, the embedding technology makes innovative miniaturized power packages possible for higher efficiencies, enhanced thermal performance and higher power densities," he adds. "In collaboration with partners, AT&S has for example already implemented various GaN power circuits, which are characterized by excellent switching performance and high efficiency."

AT&S (in Hall 6, Stand 323) and Fraunhofer IAF (in Hall 7, Stand 237) are presenting their power solutions at the PCIM (Power Conversion Intelligent Motion) Europe 2017 exhibition in Nuremberg, Germany (16-18 May).
Read more

Is Avogy Inc. dead?

Source: PntPower

At PntPower we love to try, test, sneak and search. We acquired Avogy's laptop charger, named Zolt just to try and test. We also published about what we might find in there, and then re-published about what kind of power devices were really in there.

Recently, we went back to the website gozolt.com. It was down. It seems, according to social media, that the website has been down for a while. For all those (like us) who expected an update (like an EU plug version) or an additional plug to match latest laptops… I think you can try FinSix or Innergie's latest chargers, or even expect Cambridge Electronics or Appulse Power to release a product soon.

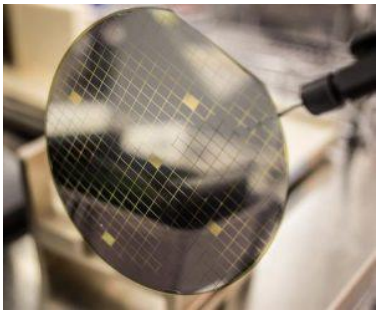
This down website led us to search more about Avogy Inc. The company is now renamed to NexGen Power Systems. A new name, an old website shut down, and probably a product line let down… what is happening at ex-Avogy ?

You can find traces of an auction from January 2017 where Avogy is selling a lot of equipment… Is Avogy preparing a rebirth from its own ashes ?
These signs are not very positive. But let's wait for further information.
Maybe Nexgen (ex-Avogy) is preparing something big, with next investments ! We will investigate further during PCIM in Nuremberg.
Read more

X-FAB and Exagan produce GaN-on-Si devices on 200mm wafers

Source: Semiconductor Today

X-FAB Silicon Foundries AG of Erfurt, Germany and Exagan of Grenoble, France, a gallium nitride (GaN) technology start-up enabling smaller and more efficient electrical converters, have demonstrated mass-production capability for manufacturing highly efficient high-voltage power devices on 200mm GaN-on-silicon wafers using X-FAB's standard CMOS production facility in Dresden, Germany. The achievement is the result of a joint development agreement launched in 2015, enabling cost/performance advantages that could not be achieved with smaller wafers.



Exagan and X-FAB say that they have resolved many of the challenges related to material stress, defectivity and process integration while using standard fabrication equipment and process recipes. Combined with the use of 200mm wafers, this can significantly lower the cost of mass producing GaN-on-Si devices. By enabling greater

power integration than silicon ICs, GaN devices can improve the efficiency and reduce the cost of electrical converters, which is expected to accelerate their adoption in applications including electrical vehicle charging stations, servers, automobiles and industrial systems.

The new GaN-on-Si devices have been built using substrates fabricated at Exagan's 200mm epitaxy manufacturing facility in Grenoble, France. These epiwafers meet the physical and electrical specifications to produce Exagan's 650V G-FET devices as well as the tight requirements for compatibility with CMOS manufacturing lines.

GaN industrial production has been limited to 100mm and 150mm wafers due to the challenges of layering GaN films on silicon substrates. Exagan says that its G-Stack technology enables GaN-on-Si devices to be manufactured more cost effectively on 200mm substrates by depositing a unique stack of GaN and strain-management layers that relieves the stress between GaN and silicon layers. The resulting devices have been shown to exhibit high breakdown voltage, low vertical leakage and high-temperature operation.

"This is a major milestone in our company's development as we accelerate product development and qualification," states Exagan's president & CEO Frédéric Dupont. "It demonstrates the combined strengths of our epi material, X-FAB's wafer fab process and our device design capabilities. It also confirms the success of our vertically integrated fab-lite model, with expertise from materials to devices and applications. It is perfect timing to establish GaN technology and products on the most competitive 200mm platform just as GaN power products are getting broad traction in IT server, consumer electronics and automotive markets," he adds.

"Through this productive partnership, X-FAB is leveraging its resources and expertise to bring Exagan's technology into manufacturing and provide the power conversion market with a reliable supply chain," says X-FAB's Rudi De Winter.
Read more

Step-Down dc-dc Converter Eliminates Ferrite Cores at 50kHz Enabling Power Supply on Chip with One-Cycle Transient

Source: Power Electronics

Virtually all present-day DC-DC converters store DC energy in magnetic devices with ferrite cores, such as inductors with DC bias. A new topology for non-isolated step-down dc-dc converters discards ferrite cores completely. The new Resonance Scaling Method results in use of 10nH resonant inductors even at 50kHz switching frequency and an effective factor of 1,000 times reduction of the magnetic size and weight of comparable buck converter at 50kHz.This opens a new power electronics era with the first true Power-Supply-on-a-Chip.

The groundbreaking PWM-Resonant Ćuk topology could revolutionize the design of non-isolated, step-down dc-dc converters. This new topology provides much higher-efficiency, fast-transient response settling in one cycle, with much smaller size and lower weight than its ferrite core cousins. This converter is ideal for 12V to 1V applications for supplying microprocessors, as it replaces four to eight modules of a multiphase buck converter with a single converter.

[…]

Power Electronics has been for the last 60 years focused exclusively on the development of ever faster switching devices from 20kHz bipolar transistor through 200kHz MOSFET devices to present 2MHz GaN devices. In fact, it is precisely the availability of the high frequency switching devices which was, all along, hiding the fundamental flaws of the buck converter and delayed the inevitable conclusion: the buck converter should now be retired.

In engineering designs we are accustomed to hail 40% improvement in size as a milestone achievement. The PWM-Resonant Ćuk converter has already resulted in 40 times size reduction over buck converter (Fig. 8). The new Scaling Method generated another factor of 100 reduction in size of magnetic components for a total factor of 4,000 times reduction in magnetic size (Fig. 10). The simultaneous high efficiency of over 99% and ultra-small size of magnetics makes for the first time possible both Power Supply on the Chip (PwrC) with ultra-high power density and at the same time extremely compact size with minimal or no heat-sink depending on power level.

The novel PWM-Resonant Ćuk converter proves that the new switching methods along with the corresponding novel topologies and the breakthrough Resonance Scaling Method are by far the most important for size reduction, efficiency improvement, simultaneous cost reduction and ultimately the best use of switching devices, both classical MOSFET and new GaN and SiC MOSFET devices. Switching device requirements are then dictated by the new switching methods and their sister topologies and not the other way around as is the case now.

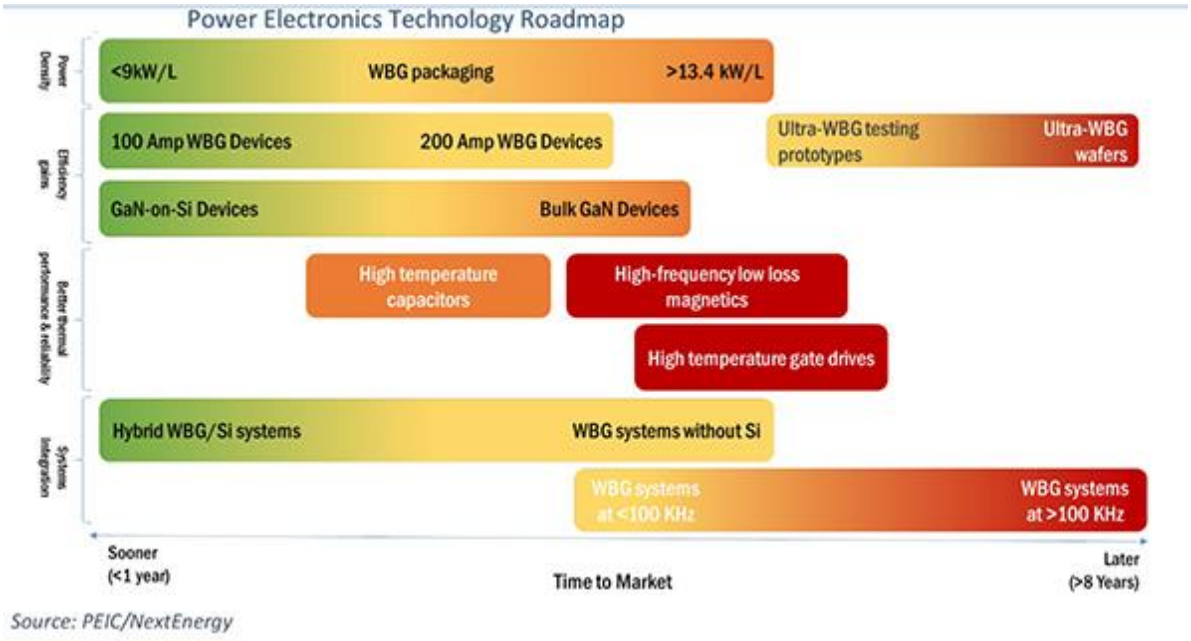
This is an exciting time in power electronics as a new era begins, opening a wealth of innovations and possibilities.
Read more

Semiconductors, Power Electronic Systems Roadmaps Point to the Future

Source: Power Electronics

Portrayed in roadmaps, future trends for power electronic systems will include semiconductors as well as other components and manufacturing impacts.

Roadmaps have been a staple of the semiconductor industry, in particular the International Technology Roadmap for Semiconductors (ITRS). The final ITRS roadmap was issued in 2016. In May 2016 the IEEE announced the launch of the International Roadmap for Devices and Systems (IRDS), a new IEEE Standards Association (IEEE-SA) Industry Connections (IC) program to be sponsored by the IEEE Rebooting Computing (IEEE RC) Initiative in consultation with the IEEE Computer Society. Together, this group will ensure alignment and consensus across a range of stakeholders to identify trends and develop the roadmap for all of the related technologies in the computer industry.



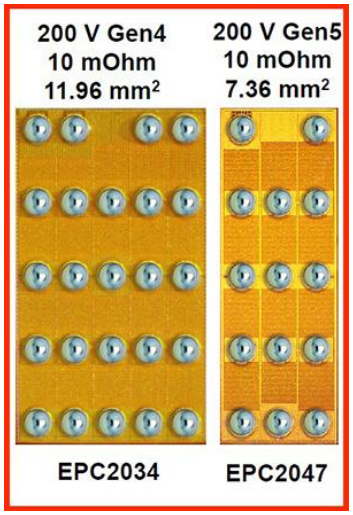
Source: PEIC/NextEnergy

[…]
Development of wide bandgap (WBG) semiconductor devices is a major component of the global innovation race in power electronics. WBG semiconductor devices, especially SiC and GaN-on-Si devices, are beginning to penetrate the market, although Si devices continue to dominate the industry.

The U.S. WBG semiconductor device manufacturing supply chain is more developed in SiC device technology, while GaN-on-Si devices tend to be manufactured in Asian foundries, leveraging the massive silicon device foundry infrastructure there.

In addition, next-generation WBG semiconductors like bulk GaN and so-called ultra-wide bandgap (UWBG) semiconductors like gallium oxide (Ga2O3), aluminum gallium nitride (AlGaN) and diamond are in aggressive development as they promise additional performance advantages over SiC and GaN-on-Si.

[…]
EPC
Efficient Power Conversion (EPC) is working its way toward improved GaN-on-Si devices that appear on the PEIC roadmap. The company's recently introduced Generation 5 devices are physically smaller and have significantly lower capacitance than Generation 4. This translates into lower gate-drive losses and lower device-switching losses at higher frequencies for the same on-resistance and voltage rating. In the case of the EPC2045, a 30% reduction in power loss with 2.5 percentage points better efficiency than the best comparable MOSFET was achieved in a 48 V to 5 V circuit operating at 500 kHz switching frequency. Figure 2 compares Gen 4 and Gen 5.



Comparison of Generation 4 and Generation 5 eGaN transistors.

Widening the performance/cost gap with equivalent silicon power transistors, the 100 V, 7 mΩ EPC2045, cuts the die size in half compared to the prior-generation 10 EPC2001C eGaN FET. The 200 V, 10 mΩ EPC2047 eGaN FET also cuts the size in half so that it is now about 15 times smaller than equivalently rated silicon MOSFETs.

The performance, size, and cost improvement evidenced in Gen 5 products were made possible by an innovative method of both reducing the electric fields in the drain region during breakdown, and significantly reducing the number of traps that could cause electrons to become inactive.

Alex Lidow, CEO of EPC, said he felt the PEIC roadmap was good. In particular, he said that he thought it was a good idea to include other components in addition to semiconductors. The one area that he felt was keeping pace with GaN products were core materials. He has run into applications where the core material prevented GaN devices from working up to their full potential.

Navitas

GaN-on-Si is in mass production now at 650V and below, and Navitas would welcome the option of US-based manufacturing capability.

AllGaN monolithic GaN Power ICs (with lateral integration of FET, logic and drive) deliver higher switching frequencies and higher efficiencies simultaneously, so enable higher power densities and alleviate thermal management concerns. Operation is already well above the 100 kHz mentioned, and has been demonstrated in commercial-ready designs up to 1 MHz and in development up to 40 MHz.

Today, 650V single and half-bridge GaN Power ICs may be applied to all ac-dc, 380V dc-dc and dc-ac topologies. Initial applications are consumer and mobile, with near-term design in also possible in industrial, automotive, and new energy applications. True "digital-in, power-out," easy-to-use converter building blocks, with features such as level-shifting, high-side bootstrap charging and UVLO, ESD protection, etc., maximize design productivity and reduce design-time and costs. Two to three times smaller converters can be achieved at powers from 25W to 3kW+. Low-voltage silicon is used for advanced control and logic functions but AllGaN technology can integrate everything high current, high voltage, and high power today. High-frequency control IC platforms exist today, with new ASIC designs being introduced throughout 2017 and 2018 to enable mass adoption of GaN in soft-switching PFC, LLC, and Active Clamp Flyback circuits.

Monolithic gate-drive and power-device integration dramatically lowers the switching losses, enables the high frequency loss-less operation, and is the key to driving system power density to 30 kW/L and higher in the medium term. Navitas is collaborating with industry and academic partners and the DoE ARPAe Circuits program to demonstrate this. Integration of the gate drive also addresses the high-temperature gate-drive concern, since the gate driver is made with the same WBG material as the power switch.

Power density is a system consideration, though the chart refers to WBG packaging. The main drivers of system size are the passives and heatsinking. High frequency and soft switching enable both of these to be dramatically reduced. Cost-effective wafer production and industry-standard QFN packaging, plus the reduced system costs due to smaller magnetics, PCBs, heatsinks, and cases enable BOM costs to remain flat or even reduce as performance increases and sizes shrink. Magnetics are available and cost-effective for applications up to and above 1 MHz from Hitachi Metals, TDK, and Ferroxcube. With system efficiencies of 95-99% now possible, the amount of thermal management in packaging and at the system level is substantially reduced. (Note: Magnetics should be highlighted in green and shifted to left on the chart.)

The combination of fast-switching resonant topologies, fast GaN transistors, and GaN lateral integration enables a shift in power conversion performance not seen since the late 1970s/early 1980ss brought the MOSFET and PWM ICs.

Infineon Technologies

Tim McDonald, senior director, GaN applications and marketing at Infineon, agrees with the GaN on silicon technology on several key points made in the U.S. Power Electronics Technology and Manufacturing Roadmap. In particular, GaN on silicon devices is ready for use in applications where highest efficiency is a key performance parameter.

It is important to note that the full PEIC roadmap (and many of our customers) all list "reliability" as one of the main barriers to wide market adoption of GaN on silicon power conversion devices. Infineon has studied this issue and determined to establish new application-specific qualification criteria for GaN devices. Basically they match the intended use (stress conditions, targeted lifetime hours of operation in each key stress mode, quality level, etc.) with failure models for their devices in each key stress mode. These models are based on highly accelerated testing to failure that allows determination of useful life and quality level at normal operating conditions. In this manner, Infineon has established an application-specific GaN qualification process.

Infineon recently completed successful qualification of 600V GaN on silicon emode devices for use in 1 to 3+ kW ac:dc datacenter applications that demand the highest efficiency and/or density. The company has started shipping of these devices to select customers.

Infineon further concurs with PEIC that in the medium-term GaN ecosystem, items such as magnetics, drivers, and controllers are limiting near-term adoption of solutions at high (>1 MHz) frequency /density. Here, there is a body of promising commercial development and university work available and underway that points the way.
Read more

GaN Systems releases first E-HEMT bridgeless-totem-pole PFC reference design

Source: Semiconductor Today

To provide design engineers with a platform to demonstrate the performance of gallium nitride high-electron-mobility transistors (HEMTs), GaN Systems Inc of Ottawa, Ontario, Canada – a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications – has released the GS665BTP-REF, the first 3kW continuous current mode (CCM) E-HEMT-based BTPPFC reference design.

To achieve efficiencies greater than 98% in conventional power factor correction (PFC) circuits, the major hurdle is fixed diode bridge losses. An option for overcoming this is to use silicon MOSFETs in place of the diodes to achieve efficiencies of 99% or more. However, this bridgeless-totem-pole power factor correction (BTPPFC) approach suffers from poor reverse recovery performance, is suitable only for low power, and requires complicated control parameters. GaN Systems mitigates these drawbacks by replacing silicon MOSFETs with GaN E-HEMTs that eliminate the body diode (zero Qrr) and exhibit very fast switching.

The new 3kW GS665BTP-REF reference design compares the switch-on losses of a silicon-based CoolMOS CFD2 with losses exhibited by a GaN Systems 650V E-HEMT. The results show that GaN has superior reverse recovery, says firm. Operating the CCM BTPPFC at 50kHz, GaN dissipates only 0.75W switching loss due to the Qoss loss at turn-on, while the CoolMOS CFD2 exhibits a loss of 20W, solely due to Qrr. The result is excellent hard-switching performance in a CCM BTPPFC with maximized efficiency, says GaN Systems.

Comprehensive documentation for the GS665BTP-REF reference design ('High-Efficiency CCM Bridgeless Totem Pole PFC Design using GaN E-HEMT') – including includes the motivation, operating principles, and design considerations for the BTPPFC using 650V GaN E-HEMTs – is available for download from GaN Systems' website. Also included are discussions pertaining to test setup, test results (i.e. efficiency, power factor, waveforms, thermal measurements), and applications.

"Now, power design engineers have a tool to help them leverage the increased efficiencies and reductions of space, weight and BOM costs provided by GaN transistors," says Paul Wiener, GaN Systems' VP of strategic marketing. "Today we are seeing these benefits show up in products as diverse as battery chargers, energy storage systems and power supplies in enterprise applications," he adds. "As design engineers explore ways to improve power system performance, we expect that this reference design will play an instrumental role in the development of many more commercial products."
Read more

GaN Systems' transistors used in SolPad's FlexGrid solar power inverter

Source: Semiconductor Today

GaN Systems Inc of Ottawa, Ontario, Canada – a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications – says that its transistors are being used by power inverter design engineers to increase power efficiency and to reduce inverter size and weight. In particular, SolPad (which designs sustainable personalized energy systems that integrate solar power conversion with battery storage) is using GaN Systems' 650V GaN transistors in its FlexGrid inverter.

Using an intelligent design capable of compensating for diverse power environments, the FlexGrid inverter is integrated into two devices, SolPad Home and SolPad Mobile, creating a new range of 'smart energy' products.

SolPad Home is a built-in 'solar micro-storage' system that can power an entire home or business with electrically optimized power efficiency. SolPad devices have the built-in intelligence to automatically charge from converted solar energy or the local utility grid, depending on changes in sun intensity. When daytime utility rates are high, SolPad switches to battery power, and then switches back to grid power when rates are low.

The FlexGrid inverter is also integrated within SolPad Mobile, in a unibody enclosure that houses solar power generation, energy storage and communication. The device delivers enough power to operate heavy-duty power tools such as leaf blowers and skill saws. SolPad Mobile provides two universal outlets that output grid-quality, pure sine-wave AC. When in direct sunlight, the device's three fast-charging USB ports provide unlimited power to smartphones. For additional power requirements, multiple SolPad Mobile units can be linked via a standard IEC power outlet. Using PLC and wireless technology, SolPad Mobile communicates, monitors and controls power via a mobile application.

SolPad Mobile's features are built into a compact, lightweight design. Since neither silicon nor silicon carbide (SiC) solutions would provide the required inverter performance, SolPad selected GaN Systems' 650V GaN transistors to obtain the desired inverter operating characteristics (by delivering performance five times better than the best silicon or SiC products, and by shrinking the inverter into a much more compact package). GaN transistors also help to provide system stability across a wide range of power levels, as well as aiding inverter integration and facilitating stable device expandability.

"GaN Systems transistors were easy to use and their economics are suitable for consumer products. They were instrumental in reducing the size, weight and number of FlexGrid inverter parts and increasing the inverter's efficiency," comments SolPad's CEO Chris Estes. "GaN transistors allowed SolPad to develop the world's thinnest, lightest and most efficient portable AC micro-grid solar product. Now, whether customers need 60W or 6000W, SolPad Mobile can be linked easily to safely provide mobile, grid-quality power wherever needed," he adds.
Read more

GaN Systems sponsors China Power Supply Society competition to design high-efficiency, high-power-density GaN-based inverters

Source: Semiconductor Today

To inspire power design engineers at Chinese universities to advance electronic power technology, GaN Systems Inc of Ottawa, Ontario, Canada – a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications – is again sponsoring the annual CPSS competition to design high-efficiency, high-power-density GaN-based inverters, which is conducted by the China Power Supply Society (CPSS), the China Power Society Science Popularization Committee, and Nanjing University of Aeronautics and Astronautics.

Choosing GaN instead of legacy silicon transistors allows power systems designers to increase both system efficiency and power density while reducing system size, weight and cost, says GaN Systems. Nowhere is this trend more apparent than in the energy market, where GaN transistors are replacing MOSFETs in applications such as energy storage systems, inverters and AC solar panels, the firm adds.

The theme of the 3rd annual competition is the application of power electronics technology for innovation, energy saving and new energy use. Inverter design entries will be evaluated based on performance criteria, including inverter efficiency, power density and output stability across various load conditions.

The CPSS will announce the finalist teams on 15 September, and the competition winners will be announced and presented with their awards at the 22 November annual meeting. Cash awards of 20,000 yuan, 10,000 yuan, and 5000 yuan will be given to the first, second and third place winners, respectively.

"Design contests like the CPSS competition serve to motivate and excite power system designers to design and build systems with efficiencies and power densities never achieved before," believes GaN Systems' CEO Jim Witham. "The industry saw this firsthand with the Google Little Box Challenge, where GaN-based inverter power densities dramatically exceeded the challenge goals," he adds. "We are proud to provide opportunities for engineers to explore and expand the performance limits of power inverters by leveraging the benefits of GaN transistors in novel inverter designs."
Read more

GaN Systems' investors receive venture capital awards

Semiconductor Today

GaN Systems Inc of Ottawa, Ontario, Canada – a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications – says that its funding partners have been recognized for their investment success.

After releasing its 8th annual Global Cleantech 100 list, Cleantech Group (CTG) has honored GaN Systems' investor Crysalix Venture Capital with the 2017 Financial Investor of the Year Award. The Global Cleantech 100 is a peer-reviewed list of the top private companies involved in innovative clean technology, and that have the greatest potential to impact the future of a wide range of industries within a 5-10 year timeframe.

In a parallel development, in its 2016 'Year in Review' report, the CVCA (Canadian Venture Capital and Private Equity Association) reported that GaN Systems' funding partner Cycle Capital Management was recognized for being the most active cleantech venture capital firm in Canada in 2016. Additionally, Cycle Capital was Canada's 2nd most active independent private venture capital firm, consummating 29 deals and investing at total investment of $132m. According to the CVCA report, Canadian cleantech investments for 2016 experienced a 200% increase over the previous year.

Chrysalix Venture Capital was selected from a field of over 11,000 peer-reviewed nominees. They were chosen for having the highest percentage - in excess of 60% - of their qualifying portfolio companies on the 2017 Global Cleantech 100 list. Founded in Vancouver, Canada in 2001, Chrysalix is a technology-focused investment firm that invests in companies that bring disruptive innovation to the world's largest industries. GaN Systems is one of seven such companies in its portfolio that are also included in the Global Cleantech 100 list.

"This award is a great endorsement of our portfolio and validation of Chrysalix's strategy of targeting breakthrough industrial innovations leveraging intelligent systems and components, which we pioneered in our last fund and have made the central focus of our new Chrysalix RoboValley Fund," says Chrysalix's president & CEO Wal van Lierop.

Cycle Capital invests in cleantech entrepreneurial companies that are dedicated to fostering a sustainable future. “It’s by investing in globally competitive companies led by great entrepreneurial teams like GaN Systems that we become the leader of the cleantech investment in Canada,” comments founder & managing partner Andrée-Lise Méthot.
Read more

Transphorm showcasing GaN FETs at PCIM Europe

Source: Semiconductor Today

At the 2017 Power Conversion and Intelligent Motion (PCIM) Europe expo in Nuremberg, Germany (16-18 May), Transphorm Inc of Goleta, near Santa Barbara, CA, USA - which designs and manufactures JEDEC-qualified 650V gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications – is demonstrating its high-voltage GaN FETs for power electronics systems (including power supplies, servo motors and photovoltaic inverters) as well as showcasing its AEC-Q101 qualified GaN FET (launched in late March, and claimed to be the industry’s first automotive-qualified 650V GaN FETs):

- 3.5kW integrated half-bridge module preview: Transphorm’s easy-to-use surface-mount half-bridge module is designed to simplify PCB layout and shorten design time. The firm will soon offer this module as a building block for bridgeless totem-pole, half-bridge, full-bridge and LLC topologies.
- First GaN servo motor: Targeting 100-400W applications, the Yaskawa integrated servo motor uses Transphorm’s GaN FETs to increase system power density and efficiency, to simplify system architecture, and to deliver a dramatic reduction in system size.
- First GaN redundant power supply: Targeting 500W applications, the Telcodium redundant AC power supply uses Transphorm’s TPH3206PS and TPH3202PS GaN FETs to increase efficiency and power density while reducing standby power (to less than 1W) and internal temperature yields.
- First GaN AC-DC power supply with bridgeless totem-pole PFC: Targeting 3kW applications, the Bel Power TET3000 uses Transphorm’s TPH3205WS to achieve 80 Plus Titanium efficiency while reducing system size to meet a 1U design.
- High-voltage GaN reference design previews: Transphorm’s 4.2kW PV inverter (DC-to-DC, DC-to-AC) and 3.3kW totem-pole power factor correction (PFC) reference designs, scheduled for release later this year, exemplify one type of customer design resource provided by Transphorm’s Silicon Valley Center of Excellence (formally opened in March).

Transphorm’s PCIM showcase is being hosted in the HY-LINE Power Components booth (9-525). Additional demonstrations are being displayed in the GLYN GmbH & Co booth (9-3010.

Transphorm is also leading an educational session on high-voltage GaN design methods. Specifically, on 17 May (at 14:30 in hall 6, booth 143) senior director of technical marketing Philip Zuk will speak in the session ‘GaN – Design, EMC and Measurement’.
Read more

PowerAmerica funding speeds Transphorm’s development of 900V GaN HEMT product

Source: Semiconductor Today

Due to funding assistance from PowerAmerica – a private-public partnership between the US Department of Energy, industry and academia – Transphorm Inc of Goleta, near Santa Barbara, CA, USA, which designs and manufactures what it claims are the industry’s only JEDEC-qualified 650V gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications, has developed what it says may be the first offerings of their kind on the market.

The first is a bilateral switch that will enable a reduction in 2-4x part count as well as a reduction in losses. The second is a 900V GaN HEMT, which will enable increased energy efficiency. The products are used to convert power in applications such as power supplies, solar inverters, AC-AC converters, industrial converters and electric vehicles.

Transphorm already has several GaN products on the market in the 650V range (its second-generation 650V GaN FET recently became the first GaN solution to earn automotive qualification). These have helped to dispel doubts about the reliability and manufacturability of GaN, says Transphorm. Previously, though, 900V GaN was not thought possible, the firm adds. While Transphorm had set a roadmap target to develop the higher node, its partnership with Power America enabled it to focus specifically on the higher-node 900V GaN devices.

"The fact that PowerAmerica provided 50% of the funding for this project allowed us to focus on it as a roadmap item and develop streamlined technology – and offer first engineering samples with a datasheet – within a year," says Transphorm co-founder & chief operating officer, Primit Parikh. "PowerAmerica helped to get us to the next level with our product," he adds.

"Working with PowerAmerica, we were able to leverage our strong baseline of industry's highest-reliability, highest-quality GaN to improve existing technologies and get them closer to product commercialization," Primit continues. "PowerAmerica helped accelerate and risk reduce our roadmaps of these advanced devices."

Transphorm has preliminary samples released to select customers, and is continuing to focus on broader product release.
Read more

EPC issues ninth reliability report

Source: Semiconductor Today

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 its Phase Nine Reliability Report, which documents a combined total of over 9 million GaN stress device-hours with zero failures after rigorous thermo-mechanical board-level reliability testing.

The report adds to the growing knowledge base previously published in EPC's first eight reports and represents an ongoing commitment to study, learn and share information on the reliability of GaN technology, says the firm. "Demonstration of the reliability of new technology is a major undertaking," comments CEO & co-founder Dr Alex Lidow. "The test results described in this ninth reliability report show that EPC gallium nitride products in wafer-level chip-scale packages have the superior reliability, cost and performance to displace silicon as the technology of choice for semiconductors," he adds. "The time has come to finally ditch the package."

EPC FETs and ICs are made in wafer-level chip-scale packages (WLCSP), which improves performance, lowers cost, and minimizes board real-estate, while improving reliability, says the firm. WLCSP offer excellent thermal dissipation, which is critical when the devices are soldered to printed circuit boards for end-use applications, EPC adds. The main section of the report covers thermo-mechanical board-level reliability.

Devices for this study were chosen that span package size and solder layout configurations and a predictive model for solder joint integrity was developed. Customers can apply the thermo-mechanical stress model given in the report to predict reliability in their specific end-use applications. Using the correlation between strain at the solder joint together with fatigue lifetime, the model can be used to predict thermal cycles to failure for arbitrary stress conditions related to specific end-use applications.

The cumulative reliability information compiled over EPC's nine reliability reports shows that eGaN FETs and ICs have solid reliability and can operate with very low probability of failures within expected lifetimes of end-products, says EPC. Given the superior performance, cost and reliability reported of GaN products over silicon devices, the time has come to move away from the less reliable packaged silicon devices and move to chip-scale GaN technology FETs and ICs, the firm asserts.
Read more

Custom MMIC boosts passive mixer linearity by using GaN rather than GaAs

Source: Semiconductor Today

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has announced a new technical brief detailing its progress in boosting linearity by using passive MMIC mixers based on gallium nitride (GaN) technology.

For decades, gallium arsenide (GaAs) has been the process of choice for passive mixers fabricated on MMIC technologies. However, in terms of linearity, GaAs mixers tend to have input third-order intercept points (IP3) that reach +20-24dBm, which is typically only 3-8dB above the applied LO drive. This level of 'linear efficiency', which is newly defined as the difference between IP3 and LO drive level, is one reason why higher IP3 levels have generally been unachievable in GaAs.

Over the past year, mixer experts at Custom MMIC have been exploring the use of GaN processes as the basis for extremely linear RF mixers. Deducing that the high linearity performance of GaN power amplifiers may cross-over to other critical microwave components, the firm has gone through several iterations of GaN mixer technologies and topologies with several of its key foundry partners.

Ultimately, this has led to passive GaN mixer designs that surpass all gallium arsenide (GaAs) passive mixer designs in terms of the ratio of input third-order intercept point (IIP3) to local oscillator (LO) drive - a figure-of-merit that Custom MMIC is coining linear efficiency. From S-band to K-band (2GHz to 19GHz) the new passive GaN mixers are demonstrating IIP3 figures well above 30dBm, LO drive levels around 20dBm, and linear efficiencies above 10dB.
Read more

Ampleon Showcases LDMOS, GaN RF PA Portfolio and High-Power RF Solutions at IMS2017

Source: Microwave Journal

Ampleon announced its participation at the forthcoming International Microwave Symposium (IMS) 2017.
At booth #914, Ampleon will showcase its latest RF power devices and modules suitable for use in mobile broadband, broadcast, industrial, radar and avionics and RF energy applications.

Product demonstrations for mobile broadband include several power amplifiers for base station, small-cell and massive MIMO applications using Ampleon's latest 32 and 50 V LDMOS and GaN processes, as well as a multiband power amplifier covering simultaneously 2.3 to 2.7 GHz (bands 40 and 41) linearized with a Xilinx DPD solution on Xilinx 16 nm Zynq® UltraScale+™ MPSoC devices.
Read more

OTHER

Ammono enters insolvency as court-appointed liquidator invites auction bids

Source: Semiconductor Today

Ammono S.A. in Warsaw, Poland, which produces bulk gallium nitride (GaN) using ammonothermal technology, has entered into insolvency proceedings. The court-appointed liquidator has invited interested parties to submit written proposals to purchase the firm via an auction process.

The minimum selling price is PLN20m (zlotys). All documents for an auction tender should be submitted in Polish, together with a security deposit of PLN1m (zlotys).

Proposals should be submitted on or before 22 May, either personally at the registry office of the District Court for the capital city of Warsaw, 10th Commercial Division (Sąd Rejonowy dla m. st. Warszawy, X Wydział Gospodarczy), ul. Czerniakowska 100A, 00-454 Warszawa, or via a registered letter to the court's address. Proposals will be reviewed at the courthouse (room 120) at 1pm on 24 May.

The assessment of the business, tender rules and financial statements are available from the liquidator's office (at ul. Kotsisa 2/4 lokal 14, 03-307 Warszawa; Tel: +48 22 8141020 or +48 22 6145288) upon prior appointment and execution of a non-disclosure agreement.
Read more

Nitride Solutions closes $2.75m funding round

Source: Semiconductor Today

Nitride Solutions Inc of Wichita, KS, USA, which manufactures nitride substrates for LEDs, lasers and power electronics) has closed $2.75m in a new round of funding, led by Nelnet Inc of Lincoln, NE, USA (one of Nitride Solutions' earliest investors) and joined by new investors Leawood Capital Venture Fund of Leawood, KS, and DK Group of Omaha, NE.

"The combination of Nitride Solutions' expertise in the manufacturing space, as well as its advanced technology, made them a great addition to our portfolio," comments Chuck Norris, director at Nelnet, which is involved in loan servicing, payment systems and fiber internet deployment (focusing on new businesses, businesses with strong regional impact, and businesses that provide innovative solutions across a variety of industries).

"When evaluating potential investments, we look for disruptive technologies," says Karl Gemperli, managing director of Leawood Ventures, which manages Leawood Capital Venture Fund (which spans a diverse portfolio of private technology companies). "The aluminum nitride process could be transformative to the electronics industry," he believes. "With massive global export potential, Nitride Solutions has built a production line that can manufacture at scale."

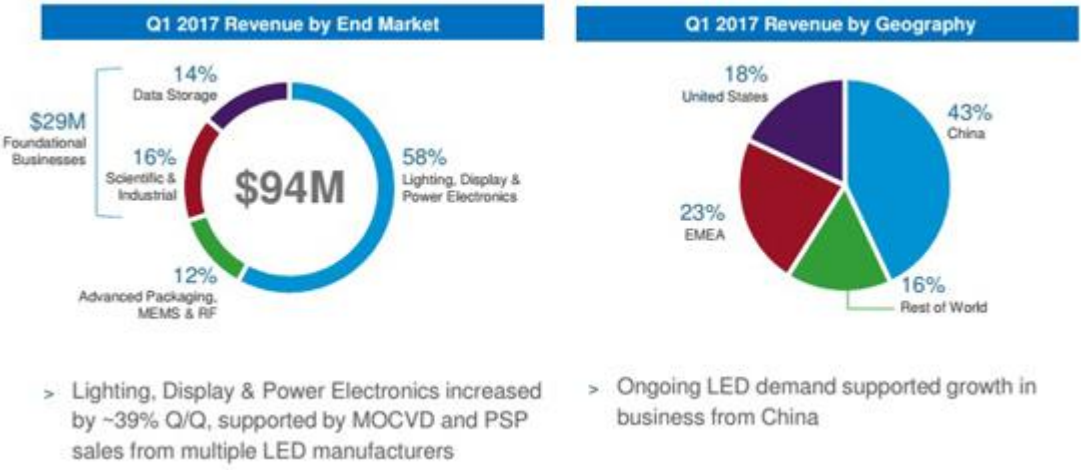
Leawood Ventures and DK Group join Nitride Solutions' existing national investment group including angel investors from Kansas, Nebraska, Oklahoma, Washington DC, Wisconsin, California, Alaska, and South Korea.

The new funds will be used to ramp up production capacity and staffing to meet rapidly growing demand from the USA and Asia for aluminum nitride (AlN) products. "These customers have clearly indicated that our unique products are enhancing performance in various electronic applications," says CEO Jeremy Jones. "We are investing to be able to continue to meet and exceed their quality and delivery expectations," he adds.
Read more

Veeco's Q1 revenue up 21% year-on-year to $94.4m, driven by LED demand

Source: Semiconductor Today

For first-quarter 2017, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of $94.4m, rebounding further from $93.6m last quarter and up 21% on $78m a year ago. This is above the seasonal average, reflecting the ongoing recovery in LED industry conditions (as evidence by customer utilization rates rising in recent months).



The Lighting, Display & Power Electronics segment – primarily metal-organic chemical vapor deposition (MOCVD) systems – grew by 39% from last quarter (rebounding from 42% to 58% of total revenue, compared with just 29% a year ago). This was driven mostly by sales of EPIK MOCVD reactors to support ongoing demand for blue LED applications. In addition, demand for red, orange and yellow (R-O-Y) LEDs drove an increase in K475i product sales. Also, sales of Precision Surface Processing (PSP) systems to LED makers represented a record.
Read more

Qorvo's quarterly revenue hit by delayed smartphone launches in China and Korea

Source: Semiconductor Today

For fiscal fourth-quarter 2017 (to 1 April), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of $642m, up 5.7% on $607.1m a year ago but down 22% on $825.4m last quarter.

Revenue for Mobile Products (MP) was $474m, down 28% on $656.8m last quarter and up just 2% on a year ago, as two leading customers in China and a tier-1 customer in Korea delayed flagship smartphone launches. With Samsung and Huawei comprising just over 10% of Mobile Product revenue each and open-market China lower than normal at about 24%, China fell from 41% of Mobile Product revenue to 35%.

Revenue for Infrastructure & Defense Products (IDP) was $168m, roughly equal to last quarter's record and up 18% on $142m a year ago, due to continued growth in defense, Wi-Fi and Internet of Things (IoT), reflecting the repositioning of the firm's product portfolio to target high-growth segments. In particular, Wi-Fi grew more than 40% year-on-year, with notable strength in 5GHz power amplifiers (PAs) and 802.11ac front-end modules (FEMs). Defense & Aerospace grew more than 20% year-on-year, with strength in gallium nitride (GaN)-based power amplifiers.

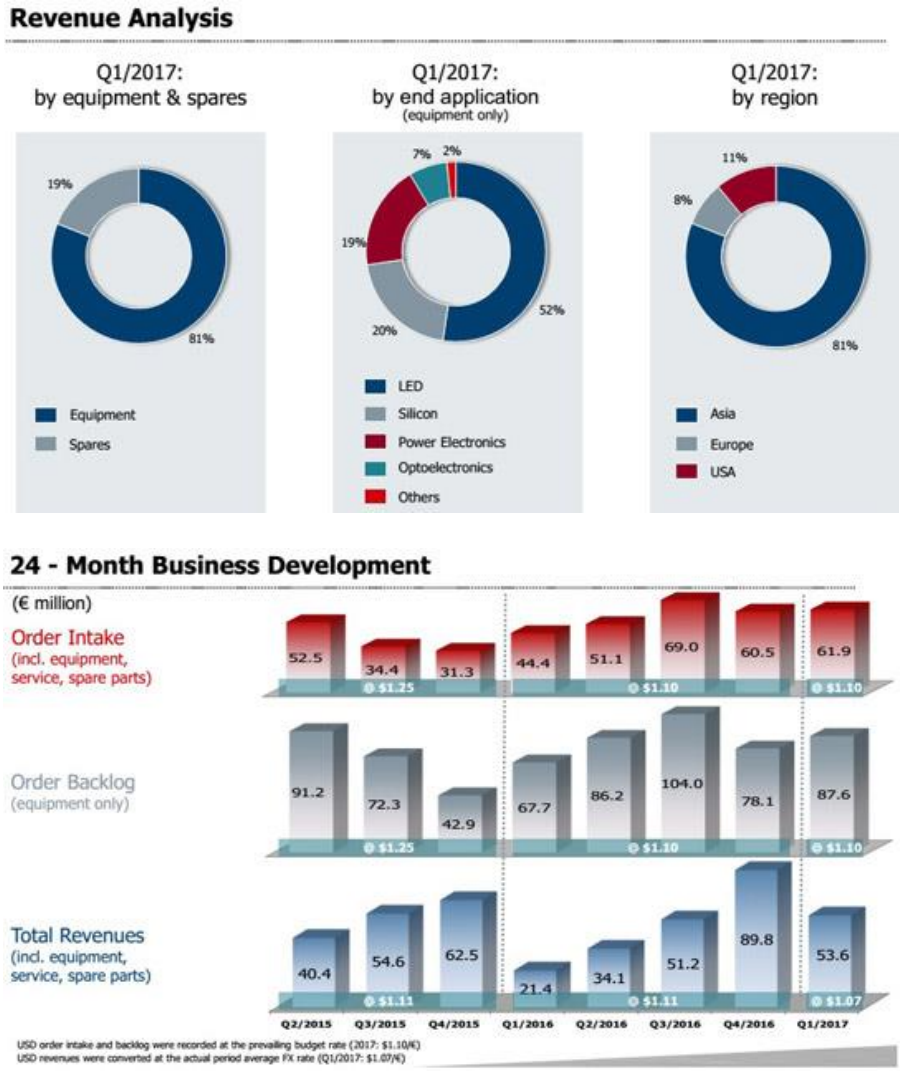
“In the March quarter, we collaborated with all major infrastructure OEMs on next-generation 4G and pre-5G macro base-station GaN PAs, we supported 1Gbps throughput in the ZTE Gigabit smartphone, we supplied the industry's first 5G RF front-end in collaboration with Intel, and we achieved full certification of the first single-placement integrated module [spanning all major RF functions required in the main path, including amplifiers, switches and filters] covering low, mid and high bands on a MediaTek baseband,” says president & CEO Bob Bruggeworth.

Also during the March quarter, Qorvo shipped its first BAW 5-based bulk acoustic wave filters (launched in the December quarter) in its RF Fusion WiFi integrated front-end modules (iFEMs), in support of Xiaomi, Oppo and Vivo;
Read more

Aixtron’s Q1 revenue and order intake rise strongly year-on-year

Source: Semiconductor Today

For first-quarter 2017, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €53.6m, down 40% on last quarter’s exceptionally high €89.8m (which comprised about half of full-year 2016 revenue) but up on €21.4m on a year ago (and the highest Q1 revenue since 2011). Based on solid order backlog at the end of 2016, growth was driven mainly by demand for production systems for Optoelectronics, Power Electronics, and LEDs, as well as for Memory applications.



Specifically, equipment revenue was €43.5m (81% of total revenue), up on just €11.9m (56% of total revenue) a year ago. Meanwhile, revenue from spare parts & services has grown by 6% from €9.5m a year ago to €10.1m.

On a regional basis, 81% of revenue came from Asia (continuing to rebound, after dipping from 70% a year ago to just 44% in Q2/2016), 8% came from Europe (down from 15% last quarter), and 11% came from the USA (down from 17%).
Read more

Riber's revenue booms in Q1/2017, driven by Cells & Sources for PV and screen applications

Source: Semiconductor Today

For first-quarter 2017, 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 €9.2m, up dramatically from €1.4m a year ago.

This is due mainly to revenue for Cells & Sources booming 18-fold from €0.4m to €7.3m, primarily for the photovoltaic and screen industries. In addition, one MBE research system (worth €0.9m) was delivered, compared with none a year ago. Sales of Services & Accessories are steady year-on-year at €1m.

By geographic region, 75% revenue came from Asia, 21% from Europe and just 3% from the USA.

The total order book has risen by 37% from €12.4m at end-March 2016 to €17m at the end of Q1/2017. This has been driven mainly by Cells & Sources orders quadrupling from €0.5m to €2m, supplemented by orders for Services & Accessories rising by 88% from €2.4m to €4.5m.

The systems order book has risen by 11% from €9.5m to €10.5m, comprising four production machines (up from two in 2016) and three research systems (down from five in 2016), all for delivery in 2017. This does not include an order from University of California Santa Barbara (UCSB) in the USA (announced on 18 April) for a model C21T MBE system, to be used for research on chalcogenide materials.

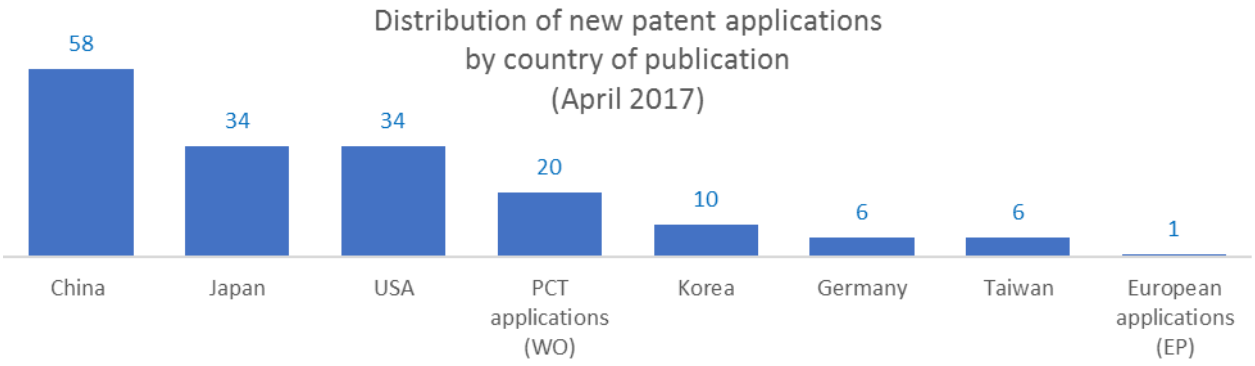
Considering its good visibility, Riber is targeting revenue growth of at least 30% for full-year 2017.

The firm's executive board has also implemented the share buyback program that was authorized by the combined general meeting of 22 June 2016.
Read more

PATENT APPLICATION

More than **136 new patent applications** were published in **April 2017**.

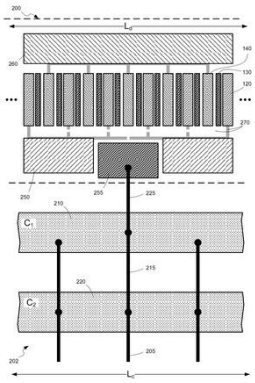
Main patent applicants	Number of new patent applications
Beijing University (China)	6
Shenzhen Founder Microelectronics – FMIC (China)	5
Ushio Electric (Japan)	5
Zing Semiconductor (China)	5
Sanken Electric (Japan)	4
South China University of Technology (China)	4
Other patent applicants: Agileswitch, Air Water, Asahi Kasei, BYD, Carnegie Mellon University, Chengdu Changdao Technology, Chigo, China Electronics Technology, Chongqing University, Toyota Central R&D Labs, Coorstek, Datang Mobile Communications Equipment, Denso, Electronics & Telecommunications Research Institute (ETRI), Enraytek Optoelectronics, Epileds Technologies, Ericsson, Florida State University Research Foundation, Foshan Guoxing Semiconductor Technology, Fuji Electric, Fujitsu, Genesis Photonics, Gigalane, Hangzhou Dianzi University, HRL Laboratories, IBM, IHI Corporation, Infineon Technologies, Institute of Applied Electronics - China Academy of Engineering Physics, Institute of Microelectronics - Chinese Academy of Sciences, Institute of Semiconductors - Chinese Academy of Sciences, Jiangsu Broadwave Electronics Technology, Jinan Optoelectronics, King Abdulaziz City for Science & Technology, King Abdullah University of Science & Technology, Korea Advanced Nano Fab Center, Led Pack, LG Electronics, LG Innotek, Lite, MACOM Technology Solutions Holdings, Mitsubishi Chemical, Mitsubishi Electric, Nanchang University, Nanjing University, National Institute of Advanced Industrial Science & Technology (AIST), NGK Insulators, Nichia, Ningbo Branch of Ordnance Science Institute of China, Northeastern University, Osram Opto Semiconductors, Ostendo, Philips, Quora Technology, Rohm, Samsung Electronics, Sanan Optoelectronics, Sensor Electronic Technology, Seoul Viosys, Shanghai Junwan Microelectronics Technology, Shinetsu Handotai, South China Normal University, Sumitomo Electric Industries, Sun-Yat Sen University, Sunmoon University Industry - Academic Cooperation Foundation, Suzhou Epi Photoelectric Material, Suzhou Institute of Nano Technology & Nano Bionics - Chinese Academy of Sciences, Suzhou Jiexinwei Semiconductor, Taiwan Semiconductor Manufacturing (TSMC), Toshiba, Toyoda Gosei, Toyota Motor, University of Illinois, Win Semiconductors, Xiamen Changelight, Xiamen San An Integrated Circuit, Xidian University, Zhangjiagang Ever Power Semiconductor …	



Tuned semiconductor amplifier

Publication Number: EP3154193, JP2017073769, US2017104073, US2017104075, KR20170042253
Patent Applicant: MACOM Technology Solutions Holdings (USA)

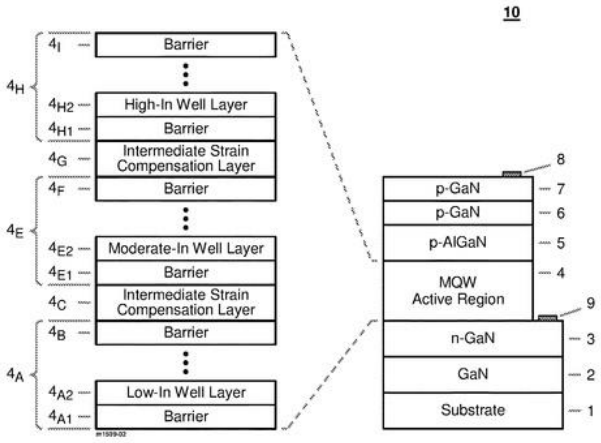
Methods and structures for improving the performance of integrated semiconductor transistors operating at high frequency and/or high power are described. Two capacitors may be connected to an input of a semiconductor transistor and tuned to suppress second-harmonic generation and to transform and match the input impedance of the device. A two-stage tuning procedure is described. The transistor may comprise gallium nitride and may be configured as a power transistor capable of handling up to 1000 W of power. A tuned transistor may operate at frequencies up to 6 GHz with a peak drain efficiency greater than 60%.
Read more



III-nitride semiconductor light emitting device having amber-to-red light emission (>600 nm) and a method for making same

Publication Number: US2017104128, WO2017062889
Patent Applicant: Ostendo Technologies (USA)

A III-nitride semiconductor light emitting device incorporating n-type III-nitride cladding layers, indium containing III-nitride light emitting region, and p-type III-nitride cladding layers. The light emitting region is sandwiched between n- and p-type III-nitride cladding layers and includes multiple sets of multi-quantum-wells (MQWs). The first MQW set formed on the n-type cladding layer comprises relatively lower indium concentration. The second MQW set comprising relatively moderate indium concentration. The third MQW set adjacent to the p-type cladding layer incorporating relatively highest indium concentration of the three MQW sets and is capable of emitting amber-to-red light. The first two MQW sets are utilized as pre-strain layers. Between the MQW sets, intermediate strain compensation layers (ISCLs) are added. The combination of the first two MQW sets and ISCLs prevent phase separation and enhance indium uptake in the third MQW set. The third MQW set, as a result, retains sufficiently high indium concentration to emit amber-to-red light of high output power without any phase separation associated problems.
Read more



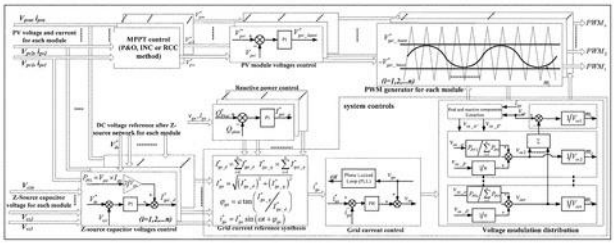
1MHz scalable cascaded Z-source inverter using gallium nitride (GaN) device

Publication Number: US9621073

Patent Applicant: The Florida State University Research Foundation (USA)

The scalable cascaded Z-source inverter is able to interface flexibly different distributed renewable energy sources or storages in wide voltage change range, such as wind power, solar power, battery, fuel cell, Ultra-capacitor and so on. The invention facilitates the AC 1 MHz frequency output; therefore high power density can be reached. Z-source network is integrated in each inverter module to wide system operation range, improve high system efficiency, and enhance high system reliability. The invention is applied for PV system to verify the performance.

Read more



An apparatus comprising a waveguide-modulator and laser-diode and a method of manufacture thereof

Publication Number: WO2017060836

Patent Applicant: King Abdullah University of Science & Technology (Saudi Arabia), King Abdulaziz City for Science & Technology (Saudi Arabia)

Example apparatuses are provided for simultaneous generation of high intensity light and modulated light signals at low modulation bias operating characteristics. An example apparatus includes a semipolar or nonpolar GaN-based substrate, a reverse- biased waveguide modulator section, and a forward-biased gain section based on InGaN/GaN quantum-well active regions, wherein the forward-biased gain section is grown on the semipolar or nonpolar GaN-based substrate. Methods of manufacturing the apparatuses described herein are also contemplated and described herein.

Read more

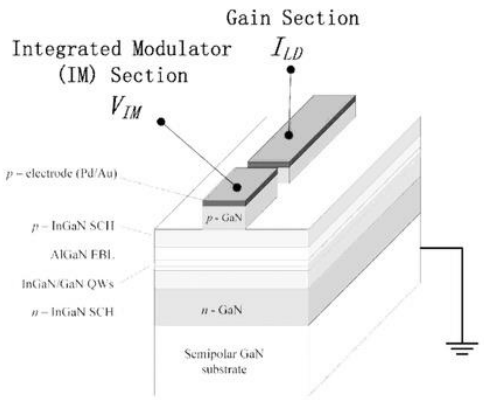


FIG. 1

GaN-on-sapphire monolithically integrated power converter

Publication Number: WO2017062056

Patent Applicant: HRL Laboratories (USA)

A half bridge circuit includes a sapphire substrate, a GaN upper switch on the sapphire substrate, a GaN lower switch on the sapphire substrate and coupled to the GaN upper switch, a first conductor coupled to the upper switch, a second conductor coupled to the lower switch, and a capacitor. A portion of the first conductor and a portion of the second conductor are on a plane vertically separated from the upper switch and the lower switch by a height, and the capacitor is coupled between the portion of the first conductor and the portion of the second conductor. Read more

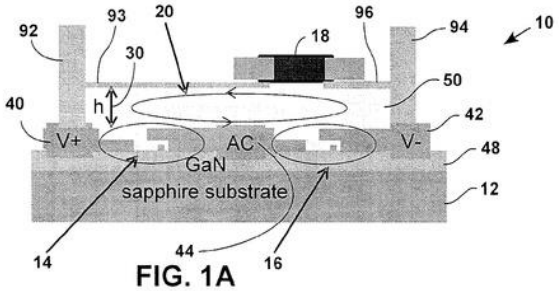
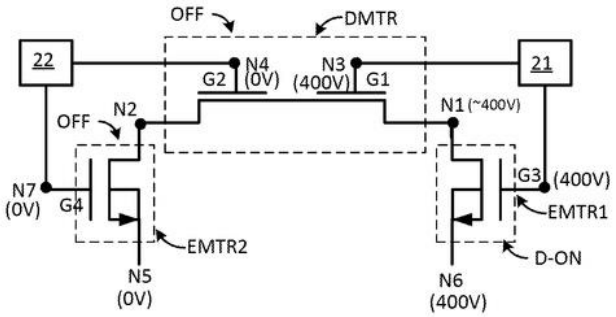


FIG. 1A

Bidirectional normally-off devices and circuits

Publication Number: US2017110448, DE102016119563, CN106603052
Patent Applicant: nfineon Technologies Austria AG (Austria)

Circuits and devices for bidirectional normally-off switches are described. A circuit for a bidirectional normally-off switch includes a depletion mode transistor and an enhancement mode transistor. The depletion mode transistor includes a first source/drain node, a second source/drain node, a first gate, and a second gate. The enhancement mode transistor includes a third source/drain node and a fourth source/drain node, and a third gate. The third source/drain node is coupled to the first source/drain node.

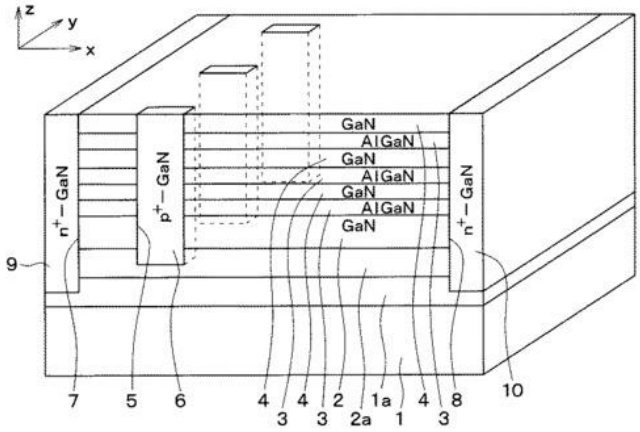


[Read more]

Nitride semiconductor device

Publication Number: JP2017073526
Patent Applicant: Denso (Japan)

PROBLEM TO BE SOLVED: Guaranteeing high obstruction resisting pressure while, from, low it offers the nitride semiconductor device whose it is possible to assure on resistance conversion. SOLUTION: Electric charge fixed bed 2a is had on the lower stratum of GaN layer 2. For example, it can occur negative fixed electric charge due to the fixed electric charge layer 2a which is formed by the GaN layer of p type. Because of this, can the depletion layer width of 2DEG layer of the lowest layer which most is formed to baseplate 1 side to the case of obstruction state operation, bring close to the depletion layer width of the 2DEG layer which that compared to is formed to higher stratum of society. This way, by the fact that depletion layer width that tries extends concerning the 2DEG layer of the lowest layer, the fact that electric current concentrates on the channel of the lowest layer at the time of switching transition of the switching element can be controlled. Therefore, be able to control the fact that heat generation occurs in the nitride semiconductor device, becoming possible to prevent the damage of the switching element, making the nitride semiconductor device where the operation whose reliability is high at low gate voltage JG is possible it is possible.

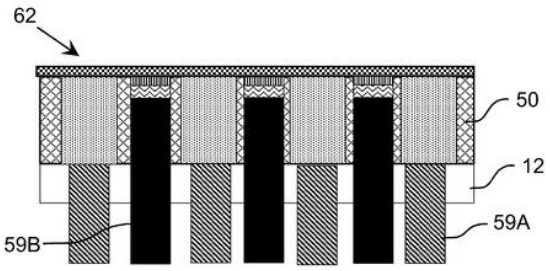


[Read more]

Optoelectronic device with a nanowire semiconductor layer

Publication Number: US2017117437, US2017117438
Patent Applicant: Sensor Electronic Technology (USA)

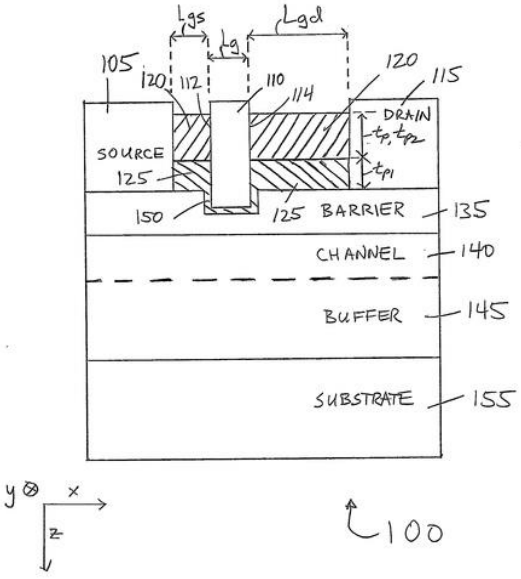
The disclosure relates generally to optoelectronic group III nitride semiconductor devices containing nanostructures, such as AlGaN nanowires.
Aspects of the invention provide a heterostructure for use in an electronic or optoelectronic device is provided. The heterostructure includes one or more semiconductor layers containing columnar nanostructures (e.g., nanowires). The nanowire semiconductor layer can include sub-layers of varying composition, at least one of which is an active layer that can include quantum wells and barriers. A heterostructure can include n-type and p-type semiconductor contact layers adjacent to the nanowire semiconductor layer containing the active layer. Read more



MISHFET having a comparatively high and selectable or customizable breakdown voltage

Publication Number: US2017117401
Patent Applicant: University of Illinois (USA)

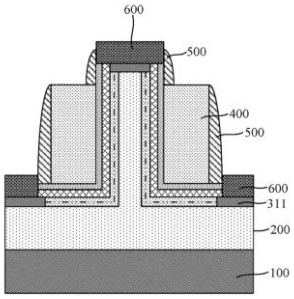
Representative embodiments provide an InAlN/GaN MISHFET having a predetermined breakdown voltage, calibrated to a permittivity-thickness parameter and selectable before or during transistor fabrication, which can be greater than 700 V for a normally-off InAlN/GaN MISHFET. Representative embodiments include a first dielectric layer coupled to a gate and to an InAlN barrier layer, a second dielectric layer, and an optional third dielectric layer. The first dielectric layer comprises a first dielectric material having a first predetermined thickness and a first relative permittivity. The second dielectric layer comprises a second dielectric material having a second predetermined thickness and a second relative permittivity, with the second relative permittivity greater than or equal to twenty (20), such as HfO2, HfAlOx, HfSiOx, SrTiO2 (STO), HMO2, HfYOx, Er2O3, Y2O3, TiO2, ErTiOx, ErxTi1-xOy; AlTiOx, SrTiO3, tantalum oxide, zirconium oxide, barium strontium titanate, barium strontium oxide, strontium oxide, and combinations thereof.
Read more



Method for formation of vertical cylindrical GaN quantum well transistor

Publication Number: US2017117398
Patent Applicant: Zing Semiconductor Corporation (China)

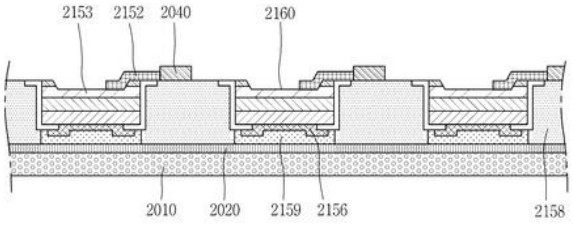
The present invention provides a method for forming a quantum well device having high mobility and high breakdown voltage with enhanced performance and reliability. A method for fabrication of a Vertical Cylindrical GaN Quantum Well Power Transistor for high power application is disclosed. Compared with the prior art, the method of forming a quantum well device disclosed in the present invention has the beneficial effects of high mobility and high breakdown voltage with better performance and reliability.
Read more



Display device using semiconductor light emitting device and method for manufacturing the same

Publication Number: US2017117257, WO2017/073865
Patent Applicant: LG Electronics (Korea)

A display device including a substrate; a first electrode on the substrate; and a plurality of semiconductor light emitting devices disposed on the first electrode; and a second electrode. Further, at least one of the semiconductor light emitting devices includes a first conductive semiconductor layer; a second conductive semiconductor layer overlapping with the first conductive semiconductor layer; and an active layer between the first conductive semiconductor layer and the second conductive semiconductor layer. In addition, an upper surface of the second conductive layer includes a recess groove having a bottom portion and a lateral wall portion formed along an edge of the second conductive semiconductor layer, and the second electrode extends partially on the bottom portion of the groove and on the lateral wall portion.
Read more



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