

Bodo's Power Systems®

Unlocking the Full Potential of GaN with Vertical Devices

Substantially higher performing switching devices are required to deliver higher efficiency power conversion systems with increased power density and greater functional integration. Traditional silicon (Si) Super Junction MOSFETs (Si-SJ) have reached their performance limits while the newer silicon carbide (SiC) devices are constrained in their usefulness by their low switching frequencies.

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Introducing Vertical GaN™ Devices

This has led to an increased interest in Gallium Nitride (GaN) which, as a baseline material, provides superior properties to produce devices with high breakdown voltage and high switching frequencies, thus enabling the improvement of efficiency and power density needed by future power electronics applications. Current GaN power devices, however, are realized as lateral devices, with thin layers of GaN heteroepitaxially grown on a Si (GaN-on-Si) or SiC substrate. The current flows very close to the surface of the device surface in a 2-dimensional electron gas (2DEG). Although these devices enable high switching frequencies, they do not exploit the high breakdown voltage property of GaN – they do not scale to higher voltages. NexGen uses a fundamentally different approach, creating a 3D Vertical GaN™ device structure by homoepitaxially growing thick GaN layers on a bulk GaN substrate (GaN-on-GaN). Current flows through the bulk of the material, avoiding the intrinsic disadvantages of the close-to-surface current conduction inherent in lateral (hybrid) GaN-on-Si devices.

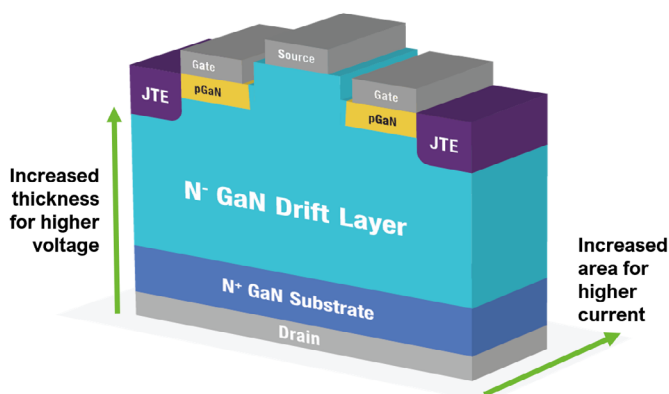


Figure 1: Conceptual View of NexGen's Vertical GaN™ FET

The NexGen Vertical GaN™ device is an enhancement-mode junction field effect transistor (eJFET) in which the vertical n-GaN channel is sandwiched between two p-n junctions. The gate-source voltage controls the extension of depletion regions into the channel and controls the drain current, showing the familiar FET I_{ds}/V_{ds} relationship.

The device cross-section bears some resemblance to FinFETs known from silicon logic devices. NexGen's Vertical GaN™ JFETs provide a unique combination of features enabling advanced devices.

Decoupling breakdown voltage from device area and $R_{DS(on)}$: The 3D device construction with the breakdown voltage mainly determined by drift layer thickness does not require large lateral dimensions to achieve a large breakdown voltage. Therefore, the Vertical GaN™ technology leads to small devices which combine low $R_{DS(on)}$ with large breakdown voltages $\geq 1200V$ and very high switching frequencies.

Very Small Turn-on-Losses: The smaller device area of the Vertical GaN™ technology leads to smaller device area and much smaller device capacitances compared to 1200V SiC devices at similar $R_{DS(on)}$ and drain currents. Vertical GaN™ based devices are smaller than comparable lateral GaN devices with have much lower breakdown voltage specification of 650V. In particular, C_{oss} (and consequently Q_{oss} and E_{oss}) is very small, greatly reducing turn-on losses

Robust Avalanche Properties: Being a GaN JFET with the gate forming a p-n junction, Vertical GaN™ FETs can robustly avalanche to protect themselves and surrounding application circuitry from transient spikes and other abnormal operating conditions. In contrast, lateral GaN-on-Si devices do not avalanche and may degrade if exposed repeatedly to voltages above their breakdown voltage.

Body Diode Function without Reverse Recovery Charge: Vertical GaN™ devices have no parasitic body diode and do not suffer switching losses caused by minority carrier/reverse recovery charge removal. The Vertical GaN™ eJFET device structure allows current conduction in reverse direction in case of a reversal of the drain-source voltage. In this way, the JFET effectively assumes the function of a freewheeling body diode without reverse recovery switching losses.

Insensitive to Device Surface Effects: The current conduction within the bulk of a Vertical GaN™ device is robust and insensitive to surface effects compared to lateral GaN-on-Si devices, avoiding by construction effects like dynamic $R_{DS(on)}$ variation. Insensitivity to

surface effects also simplifies cooling from both sides of the device leading to greatly improved thermal management options.

Intrinsic Reliability: Crystal Lattice and Coefficient of Thermal Expansion mismatch do not exist in the homoepitaxial layer buildup of GaN-on-GaN devices. Increased defect densities at layer interfaces, reliability weaknesses, manufacturing challenges, yield and performance compromises are avoided by construction.

For the first time NexGen's Vertical GaN™ technology combines device properties previously believed to be incompatible and therefore impossible to achieve:

- Devices with superior switching frequency and very high breakdown voltage
- Avalanche robustness better than silicon SJ-MOSFETs and SiC devices with switching frequencies of GaN devices
- Mass production cost scalability with advanced device and material properties

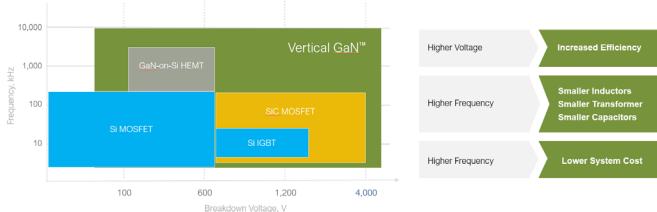


Figure 2: Vertical GaN™: A Superset of existing Power Semiconductor Technologies

Vertical GaN™ delivers the promise of GaN materials without being subjected to the reliability and cost compromises inherent in the construction of lateral GaN-on-Si devices. The unique combination of properties of the Vertical GaN™ power device allows a single technology to address the full range of power conversion application that currently can only be served by a multitude of technologies.

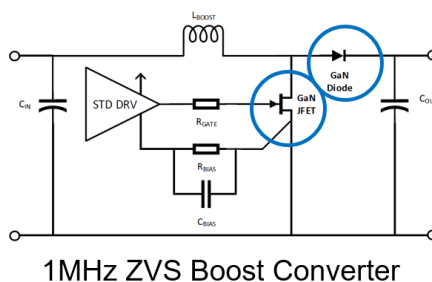
Application Benefits

NexGen has developed a range of application demonstrators to showcase the superior performance of Vertical GaN™ devices in high voltage, high switching frequency applications. Details of 1MHz, 100W, 800V Buck and Boost converters as well as a 1 MHz, 20W T8 LED driver are described in Application Notes on NexGen's website (<https://NexGenpowersystems.com/>)

NexGen's Vertical GaN™ eJFET devices are compatible with existing superjunction MOSFET drivers, only two resistors and one small capacitor are needed to match a standard MOSFET driver to NexGen's eJFET. Complicated and costly technology-tailored drivers are not needed, thus making the integration of Vertical GaN™ devices into existing designs extremely easy, allowing customers to benefit from superior device performance almost immediately without undergoing elaborate redesigns.



Figure 3: 1MHz Boost Converter



Currently a range of power supplies with output power above 100W are in development. The performance of Vertical GaN™ devices allow operation at switching frequencies of higher than 1MHz and employ novel control features in PFCs and LLCs.

Particularly in soft-switching topologies, the extremely small and almost linear output capacitance of Vertical GaN™ devices dramatically reduces the requirements on circulating current (a source of power dissipation) and dead-time (a fundamental switching frequency limitation) necessary for ZVS operation. This enables high frequency operation with high efficiency, allowing to reduce the size of passive components and leads to an estimated volume reduction of 50% for passively cooled power supplies.



Figure 4: NexGen's GaN Fab in Syracuse/NY

NexGen Introduction and Vertical GaN™ Product Schedule

Founded in 2017, NexGen operates a state-of-the-art GaN device fabrication facility (fab) in Syracuse, New York. NexGen is the First Mover in this space, with an IP portfolio of 100+ fundamental patents in device architectures, process technology and circuits for Vertical GaN™ products. NexGen's 66,000 sq. ft. fab is dedicated to GaN and combines device development with production. It has the necessary metrology and failure analysis capabilities to achieve fast cycles of learning. By operating its own fab, NexGen is afforded the critical independence necessary to reduce development time and accelerate the commercialization of Vertical GaN™ devices.

Beginning in Q3 2020, NexGen will sample 1200V and 700V devices with R(DSON) of 85mΩ, 170mΩ and 290mΩ in standard 8x8 DFN and TO247-4 packages. Customers participating in NexGen's early adopter program receive early engineering samples in mid-Q2 2020, including design support.

The comparatively small die size of Vertical GaN™ eJFETs together with volume-based cost reductions of 4" GaN wafers allows NexGen to compete very effectively with Si-SJ pricing. NexGen enables designers to overcome the limits of existing devices and employ robust Vertical GaN™ devices with high switching frequencies and high breakdown voltages in cost sensitive applications.

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