# How to get GaN power devices into mainstream, high volume power management applications?

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## Abstract

**GaN power devices have been demonstrated in multiple end applications including battery chargers, motor drives, DC/DC converters for servers or class-D audio amplifiers. GaN devices delivers clear benefits in system performance. However, it is also obvious that GaN has been primarily successful at the premium segment of these applications, where cost is less critical. This paper will highlight the massive opportunities for GaN power devices in low voltage segments of power supply and power management in data servers, and computing and mobile applications, including direct battery-connected functions. Several examples will be given to illustrate the value proposition and performance required to successfully replace the incumbent Si power MOSFETs. It will be shown that contrary to a common belief, the superior switching performance of GaN is not always required. On the other hand, reducing GaN device leakage current to levels comparable to silicon is mandatory. We will show how the latest innovations by Innoscience in technology and devices in the 30-40V range address these challenges. Combining our technological innovation with our leadership in a high-yield, cost efficient, internal manufacturing on 8-inch GaN-on-Si wafers enables us to successfully serve high volume markets with superior device performance at the right price point.**

## INTRODUCTION

The industry has seen an incredible progress in development and market adoption of GaN power devices for switching applications in the past 15 years. The device technology has evolved from depletion-mode HEMT in cascode configuration to enhancement-mode HEMT devices. The commercial e-mode devices utilize gate technology consisting of p-doped GaN capped with Schottky [1] or Ohmic [2] metal. Diverse companies are offering commercial GaN products today, from GaN focused startups to more traditional incumbent IDMs. Accordingly. different business models have been adopted from fabless design houses using foundry-based GaN technology to small-scale IDMs with (partial) internal manufacturing to fully-fledged IDMs with high-volume GaN manufacturing capability. This diversity of business models also impacts innovation, production cost, and choice of targeted applications or markets.

In the absence of own technology and given the lateral nature of the GaN devices (as opposed to mostly vertical Si-Power MOSFETs), there is an inherent trend to innovate and differentiate by adding more functionality on GaN-chip, thus creating effectively GaN ICs even though with limited complexity. The desire to suppress parasitic inductances to support high-frequency operation with low switching losses, further feeds the on-chip integration efforts. At the same time, the power applications are vastly dominated by Silicon discrete power MOSFETs switching at relatively low frequencies. It seems appropriate to challenge the integration approach as the primary way forward. The question “how to accelerate the adoption of GaN and bring it into mainstream power management functions” is highly appropriate.

## LOW VOLTAGE APPLICATIONS FOR GAN

The market forecast for GaN power devices [3] is shown in Fig. 1. It is very clear that the power supply business and to some extent (H)EV automotive segment will drive the volume production of GaN power devices until 2030. The other market segments bring a relative niche business. Since a high-volume production is required to bring down manufacturing cost, it is mandatory to further understand the sub-segments of the power supply markets and the requirements for GaN devices to replace incumbent Si power technologies in-there.

The discussion in this paper will be focused on servers / data centers and computing/mobile as end-applications. The 650V GaN device use in primary stage of power conversion chain in data centers and fast chargers is well established, and it has driven the GaN sales so far. We want to draw the readers’ attention to the vast opportunities for low voltage GaN devices in the secondary side and on-board power (see Fig. 2). Similarly, overvoltage protection (OVP) load switches, buck-boost converters in chargers or Vcore functions for all mobile devices are great examples of high-

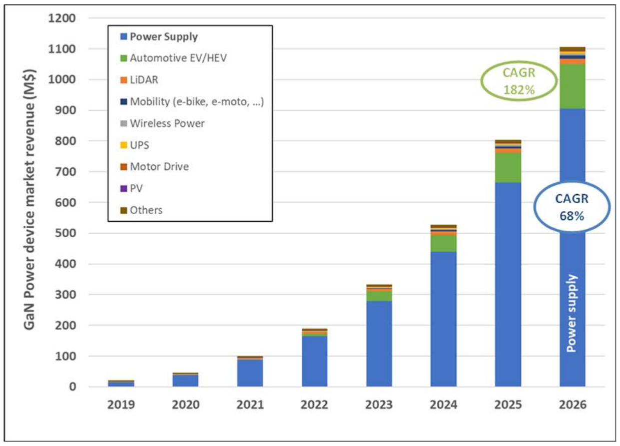

Fig. 1. GaN Power device market revenue forecast for different segments. The forecast was published by Yole in 2021 [3]. CAGR is highlighted for the most interesting segments.

volume use cases for GaN devices. All these applications require 30V to 40V rated components with Ron of 1-4mOhm. Fig. 3 summarizes the key aspects of these applications and value proposition using Innoscience GaN products.

The buck-boost converter for chargers is essentially a half-bridge DC/DC converting USB bus voltage 20V to 12V. The Vcore is DC/DC converter from 12V to 1.8V or any other CPU voltage. In both applications, the system level benefits are directly derived from the superior switching performance of GaN devices (output charge Qoss, gate charge Qgg and reverse-recovery charge Qrr).

On the other hand, the OVP load switch application purely benefits from a superior Ron*A scaling of a bi-directional GaN in a single package replacing 2 MOSFETs in individual packages in back-to-back configuration. Overall, our unique BiGaN solution has almost 7x smaller footprint for the same Ron vs. state-of-the-art silicon solution. The significant reduction of conduction losses translates into 40% lower case temperature. This is a fantastic example of a value proposition entirely independent of any switching performance improvements but benefiting solely from device architecture innovation and Ron*A scaling.

## LV GAN DEVICES WITH A LOW LEAKAGE CURRENT

Innoscience runs R&D and production of GaN devices in state-of-the-art 8-inch production fabs using high-throughput modern manufacturing tools. Uniquely among GaN manufacturers, we are producing on 8-inch GaN-on-Si epiwafers with a good uniformity and yield including wafer edges. The superior wafer die productivity (1.8x) on 8-inch wafers vs. 6-inch wafers used by our competitors combined with high-volume capable fab enables a very cost-effective production.

We have been optimizing our E-mode GaN technology towards

(1) zero dynamic-Ron performance including at hard-switching conditions, and
(2) low gate Igss and drain Idss leakage currents.

Our superior dynamic-Ron performance, see Fig. 4) has been achieved by a proprietary strain passivation layer combined with an epitaxy optimization. Similarly, through gate module process and pGaN epitaxy cross-optimization, we have been able to reduce gate and drain leakage currents to values comparable to Si power MOSFET devices. For example, a 4mOhm switch has a total gate forward leakage current at full bias of less than 3µA at 85C. These technology breakthroughs have been essential enablers of adoption of GaN switches in direct battery connected power management functions (e.g. inside a smartphone), where standby currents are critical. Fig. 5 summarizes the overall performance of Innoscience 40V Gen2 devices that has been released to market in 2023.

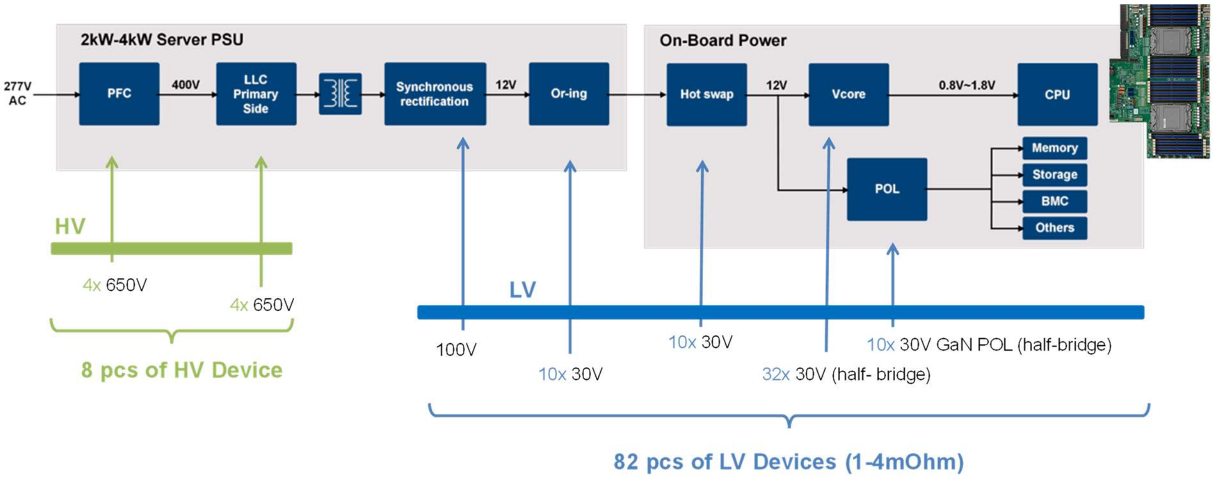

Fig. 2. Schematic of a typical total power conversion chain in data centers with an indication of the used switching devices, their quantities and voltage / on-resistance rating.

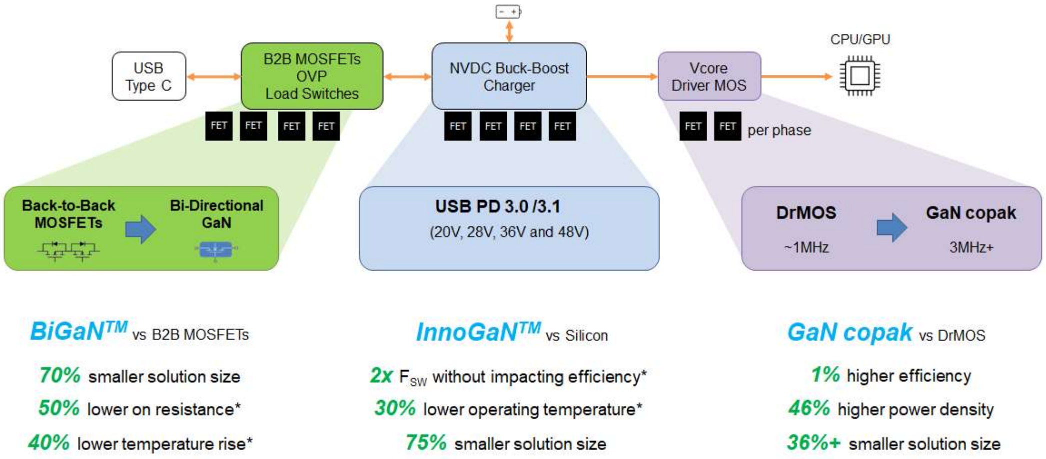

Fig. 3. Next Generation Compute Platform powered by Innoscience low voltage GaN technology. The indicated system level benefits are based on actual board level measurements.

## Bi-directional 40V GaN switch

Bi-directional voltage blocking and current conduction is an important capability in some circuits. Traditionally, designers have been limited to using two N type MOSFETs connected back-to-back in a common source configuration. Such a solution requires two components and suffers from inefficient space utilization related to on-resistance.

The lateral character of GaN devices and the absence of body diode allows straightforward design of bidirectional functionality. We have developed a symmetrical device design with a single gate and dual drain, so-called BiGaN$^{TM}$, see Fig. 6. This is a very compact structure with a total pitch and Ron*A only slightly larger than that of a unilateral device with the same drain voltage rating. The key innovation in such a bi-directional device is ensuring that the body (channel) is always connected to the lowest potential. This is done through on-GaN die integrated circuit element.

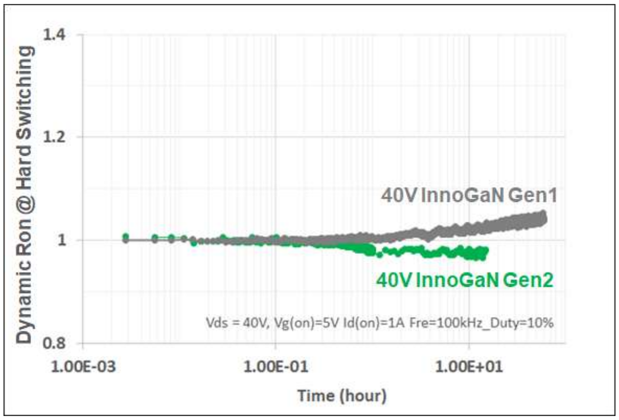

Fig. 4. Typical dynamic-Ron performance of Gen1 and Gen2 GaN devices measured under 40V hard-switching conditions. Both components are in volume production at Innoscience.

Our 40V Bi-directional GaN device with a low gate leakage module was released in 2022 [4]. The device shows excellent lifetime performance with a very low failure rate, for example:

- over 20 years lifetime with 10ppm failure rate at full $V_{GD}$ = 5V and 125°C, and
- over 10,000 years lifetime with 10ppm failure rate at $V_{DD}$=32V and 125°C.

When used as OVP load switch in mobile phone, the device saves 70% of board space and reduces case temperature rise by 40% (see details in Fig. 3). Since its market introduction, our bi-directional switch has been successfully adopted to smartphone handsets, the first-time direct use of GaN inside a mobile phone [5].

## Conclusions

This paper has outlined low voltage (<40V) application opportunities for GaN power devices in mainstream power management functions, potentially enabling a true high volume production. The differentiation comes from superior Ron*A scaling in combination with a very compact bi-directional design for protection functions, while buck-boost converters in chargers and Vcore applications benefits also from zero reverse recovery and 2x smaller total output charge and gate charge. A low gate and drain leakage currents approaching those of Si power MOSFETs is a prerequisite.

## Acknowledgements

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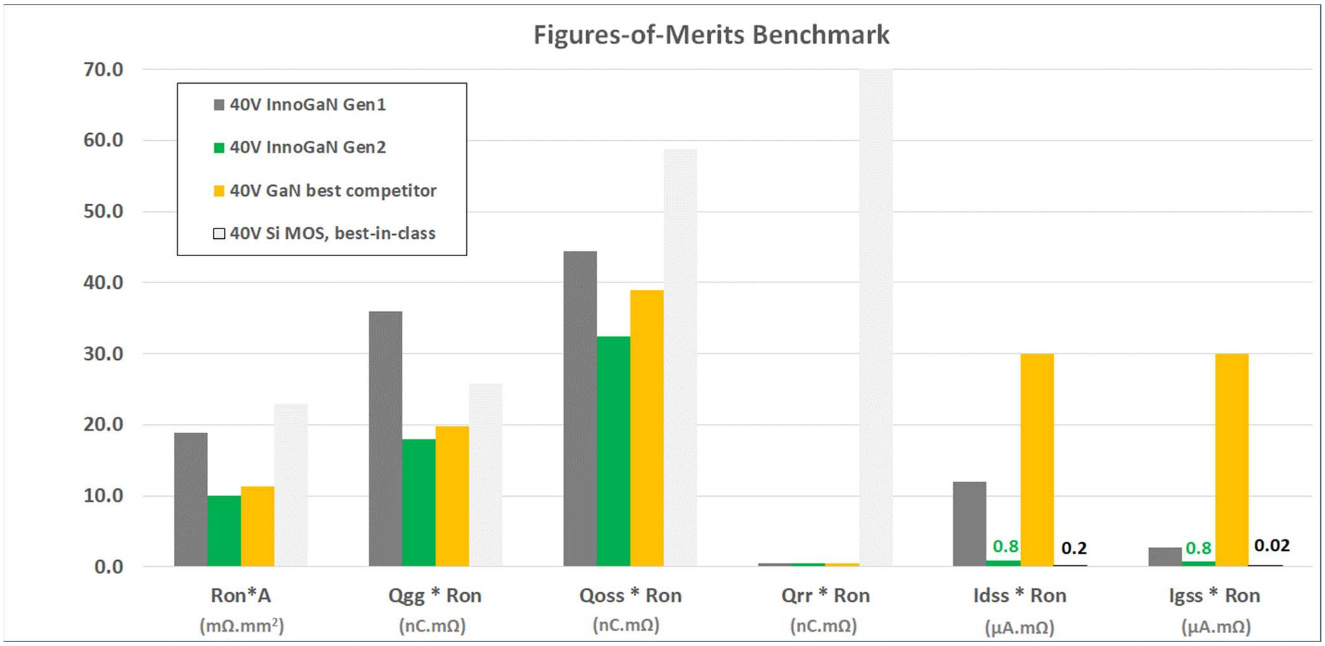

Fig. 5. Key figures of merits of 40V GaN devices by Innoscience compared with best-in-class Si TrenchMOS and GaN competitor. All data comes from the respective products datasheet.

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## ACRONYMS

HEMT: High Electron Mobility Transistor
IDM: Integrated Device Manufacturer
CAGR: Cumulative Average Growth Rate
OVP: Over Voltage Protection
BiGaN: Bi-directional GaN switch

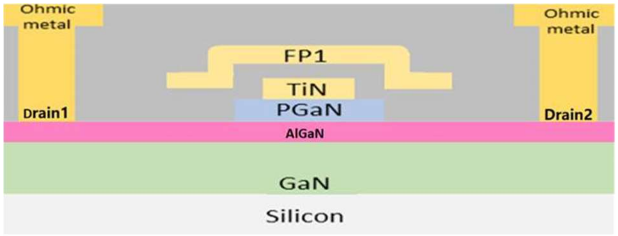

Fig. 6. Sketch of our bi-directional GaN transistor.