# Proving the Ruggedness of GaN technology in Automotive and Demanding Applications

To achieve the most efficient power conversion circuit requires the best semiconductor switch as the fundamental building block. Many people now consider gallium nitride to be a better switch than silicon. This is because GaN transistors feature a very low on-resistance and very high switching speeds; they are also rugged as they do not suffer avalanche breakdown of traditional MOSFETs. GaN is commonly used in RF and LED applications, yet employing GaN as a power technology brings new challenges. This article discusses product robustness, quality and reliability issues at high voltage and high temperatures, for Nexperia's latest 650 V power GaN FET technology which is now qualified in accordance with AEC-Q101 automotive standard. **Dr. Dilder Chowdhury, Dr. Jim Honea, Nexperia, Nijmegen, Netherlands**

**Wide bandgap (WBG) materials offer a** combination of higher critical electric field performance and greater electron mobility which together result in devices with lowest RDS(on) (source drain on state resistance) at higher voltages and significantly better switching FOM (Figure of Merit). Unlike the various different Silicon transistor implementations – vertical, lateral, super-junction etc –, GaN technology reduces both switching and conduction losses, resulting in a very significant improvement in switching efficiency. Therefore, for most designers the argument as to which technology results in the best power switch is over – it's GaN. However, proving the robustness of GaN switches in operation, plus the quality and reliability of the technology and its scalability raises different questions.

GaN devices are beginning to become generally available on the market. Many show significant promise and do not suffer from the limitations of Silicon IGBT and super-junction (SJ) devices. For example, some of the hard-switched topologies where Silicon SJ FETs cannot be used due to the reverse recovery diode losses can easily use GaN FETs, thereby benefiting from reduced component count and higher efficiency with simpler control schemes.

Currently GaN FETs are produced in two main types: Enhancement (E)-mode normally-off single die products; and Depletion (D)-mode normally-off two die, often termed cascode styles. While a single die solution would seem to offer obvious size and cost advantages, driving E-mode devices is complex, especially for high-voltage high-power applications. The stability and leakage current of E-mode devices can also be a concern. To avoid gate-bounce and harmful shoot-through, a high gate threshold voltage and stable gate drive is necessary. Currently existing E-mode technologies have a gate threshold of only around 1 V. In contrast, Nexperia's new H2 cascode GaN HEMTs achieve a gate threshold equal to 4 V, and the gate drive is relatively simple. To achieve a normally-off operation, Nexperia packages a small Silicon MOSFET on top of the HEMT source. Dynamic matching of the

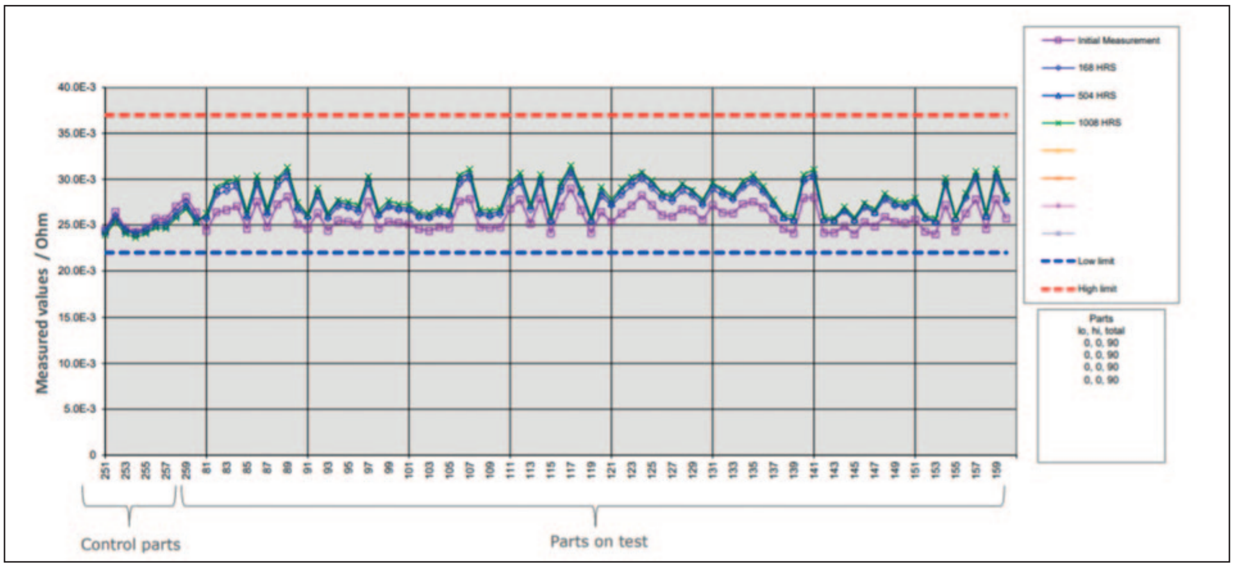

Figure 1: **Dynamic RDS(on) measurement during 650 V 175°C HTRB tests**

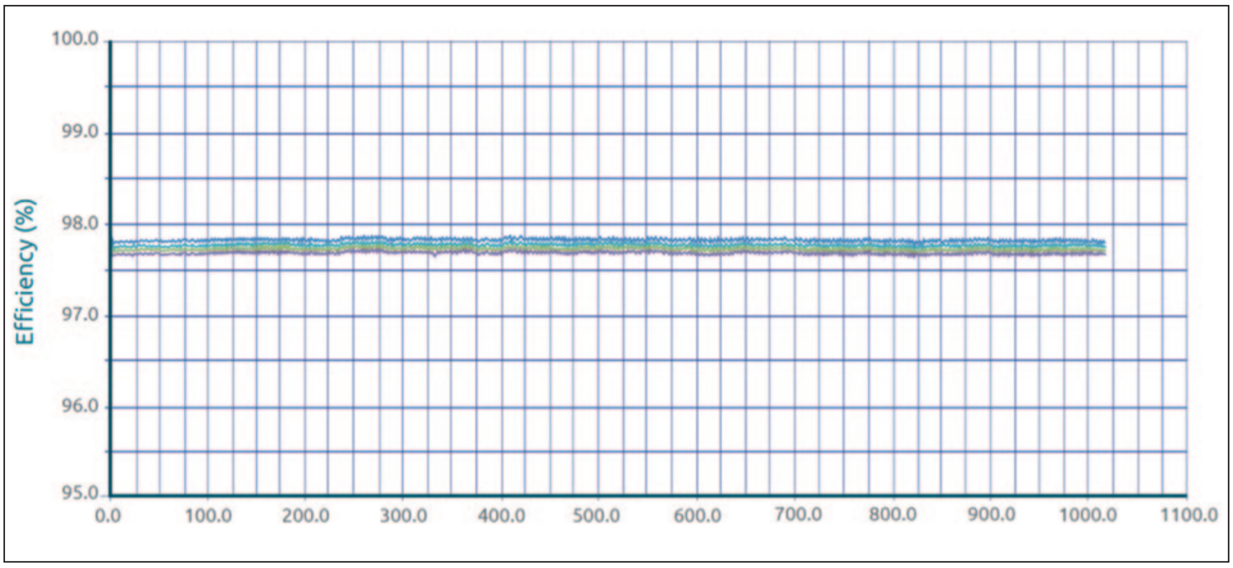

**Figure 2:** Efficiency of boost converters (HTOL) over 1000 hours

pair is ensured because Nexperia makes both the GaN transistor and the Silicon MOSFET in-house. This structure means that the switch is simply a Silicon MOSFET gate, which engineers have been used to driving for two decades.

Nexperia buys in GaN-on-Silicon wafers and is able to scale up production at its existing fabs by bringing on more lines and utilizing increased wafer sizes from 150 mm to 200 mm as part of a planned expansion program that is already in progress.

## Robustness

H2 650 V GaN FETs have an operating temperature of -55°C to +175°C with $T_{jmax}$ of 175°C. As mentioned, devices have a high 4 V threshold voltage which provides a wide safety margin against gate-source transients. Gate structure is also very reliable (± 20 V), and the 650 V rated parts handle switching transients of up to 800 V reliably. Body diode characteristics include a very low $V_f$ of 1.3 V, enabling a Silicon-like freewheeling current capability without complex dead time adjustments (parameters from the 50 mΩ GaN FET @ 25°C).

## Quality qualification

Nexperia's latest generation GaN FETs are qualified in accordance with AEC-Q101 Rev D. High Temperature Reverse Bias (HTRB) tests (1000 hrs) and dynamic $R_{DS(on)}$ shift tests were performed on 50 mΩ (typ @ 25°C) 650V device. 'Dynamic' $R_{DS(on)}$ is used to emphasize that $R_{DS(on)}$ measurements are taken from a dynamic, switch-mode test - this is important for GaN FETs to detect any short-term change due to charge trapping. Temperature cycling tests (1000 cycles) were performed over the range of -55°C to 150°C. High temperature (175°C) Gate positive (+20 V) and negative (-20 V) bias tests plus high temperature biased and unbiased humidity tests and operating life tests were also performed.

The condition for passing AEC-Q101 HTRB testing is that $R_{DS(on)}$ must not shift by more than 20 %. Figure 1 shows that the maximum shift in dynamic RDS(on) is less than 15 %. An additional HTRB test was performed and passed at 800 V for 10 hours. This voltage is well above the DC rating, but does correspond to the repetitive transient voltage rating.

High Temperature Operating Life (HTOL) tests are not part of the AEC-Q101 standard, but are useful in validating reliability of the parts under actual operating conditions. This is particularly important for new materials, like GaN, to ensure that any new or unfamiliar failure modes are uncovered. A basic half-bridge operating in continuous conduction mode provides the most fundamental exercise of switching behavior. For this test, a number of identical half-bridge circuits were prepared using two each of the GaN063-650WSA. These were operated continuously as synchronous-boost converters with the following conditions:

- Vin = 200 V
- Vout = 480 V
- Pout = 800 W
- Tj = 175°C
- Frequency = 300 kHz

Figure 2 shows the efficiency of all samples during the 1,000 hour test. As may be seen, there is no indication of degradation in any of the sample circuits. Following the tests, all devices were tested for shifts in dynamic RDS(on), leakage current, and threshold voltage. All parameters were found to be stable, with

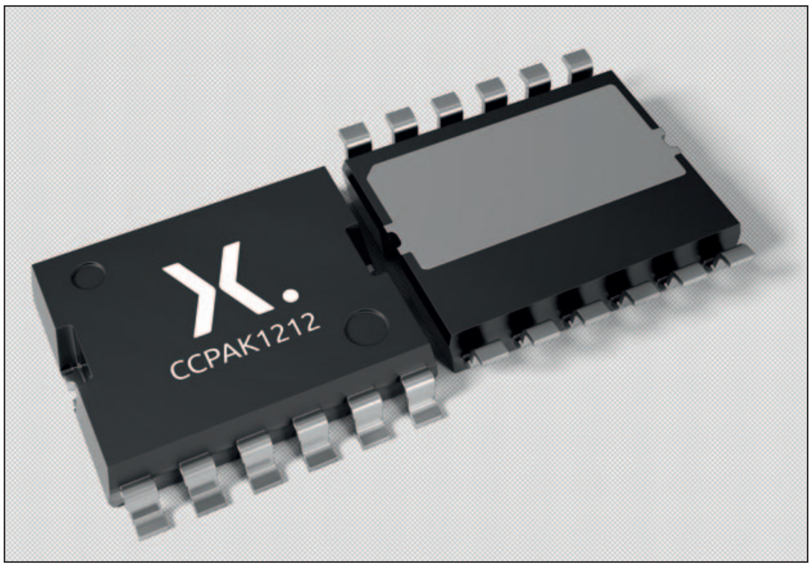

**Figure 3:** CCPAK copper-clip surface-mount packaging also for power GaN

any parametric shift within allowed levels. The HTOL test results also indicate excellent product quality.

## Packaging

Packaging affects both device performance and reliability. Nexperia offers two package options for its H2 GaN FETs: the conventional TO-247 which has a thermal resistance ($R_{th(j-mb)}$) of 0.8 K/W and an operating temperature of up to 150°C at the junction; and a surface mount copper clip CCPAK version with an $R_{th(j-bm)}$ of <0.5 K/W which will operate up to 175°C. The CCPAK surface-mount packaging, shown in Figure 3, adopts the company's copper-clip package technology to replace internal bond wires. This reduces parasitic losses, optimizes electrical and thermal performance, and improves reliability. CCPAK GaN FETs are available in top- or bottom-cooled configurations making them very versatile and help further improving heat dissipation. As gull-wing devices, the CCPAK allows some flex to reduce the stress from thermal cycling and eases automatic optical inspection – important for automotive use.

## Conclusion

Power GaN technology is being used in applications such as on-board chargers, DC/DC converters and traction inverters in electric vehicles, and industrial power supplies in the 1.5- to 5-kW range for titanium-grade rack mounted telecoms, 5G and data centres. Nexperia's latest devices have the proven product and technology robustness, quality, reliability and volume manufacturability necessary for these applications. Current devices offer industry-leading $R_{DS(on)}$ performance down to 39 mΩ. In the near future this will reduce to <20 mΩ and even <10 mΩ, enabling the parts to address higher power applications up to 150 kW with the sub-10 mΩ transistors.

# Demonstrator for GaN EV Inverter

Nexperia partners with renowned automotive engineering consulting company, Ricardo, to produce a technology demonstrator for an EV inverter based on GaN technology.

With every gram of CO2 exhaust being vital in today's cars, it is driving the move to vehicle electrification. From hybrids through to full electric vehicles, electrification of the powertrain is expected to dominate power semiconductor market growth in the next two decades. The power density and efficiency of GaN-on-Si will play a leading role in this space, specifically for on-board-chargers (EV charging), DC/DC converters and motor drive traction inverters (xEV traction inverters).

GaN is the preferred switch for these applications as GaN FETs lead to systems with greater efficiencies at lower costs with improved thermal performance and simpler switching topologies. In automotive terms this means that the vehicle has a greater range – the major concern for anyone looking to buy an electric vehicle. GaN is now on the brink of replacing Silicon based IGBTs as the preferred technology for the traction inverters used in plug-in hybrids or full battery electric cars.

Nexperia announced a range of AEC-Q101-approved GaN devices as shown above, providing automotive designers with a widening portfolio of reliable devices in this high-efficiency technology, providing the power density required for electrification of the powertrain. Ricardo is very well regarded in the automotive industry, the Global engineering innovation company designs and consults on concepts within the automotive industry, including the manufacture of prototypes and demos, and boast collaborations with high-profile leading brands such as McLaren and Bugatti. Thus Ricardo was the perfect partner for Nexperia for this project.

Michael LeGoff, General Manager GaN, Nexperia: "By designing our GaN devices into an inverter and trialing them through Ricardo, we will be able to better understand how a vehicle can be driven safely and reliably. We are developing a real solution that I think a lot of automotive designers will be interested in having a look at and will find extremely advantageous." Adrian Greaney, Director Technology & Products, Ricardo: "Semiconductor technology is key to the efficiency of the inverter system and the role that it plays in the performance and efficiency of an electrified vehicle. By delivering significant benefits in terms of the switching speed and efficiency, gallium nitride is a real enabling technology. As well as leading to increased range, it allows us to reduce the package size and weight of the inverter, which provides greater powertrain design flexibility as well as contributing to vehicle mass reduction. There are also many associated benefits that when we look at the design from a system level, and Ricardo is therefore pleased to be collaborating with Nexperia on GaN devices."

**www.ricardo.com**

**"Gallium Nitride is a real enabling technology for increased range in electric vehicles," said Ricardo's Adrian Greaney**