# Gallium Nitride Targets EV Powertrain Applications With New Module Innovation

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The lucrative electric vehicle (EV) inverter market, currently the domain of efficient but expensive silicon carbide technology or cheaper but less efficient IGBTs, is the next target for a gallium nitride (GaN) solution. GaN combines the efficiency of wide bandgap switching with ease of manufacture which promises to reduce cost to silicon-like levels very shortly. However, until recently, GaN could not attain the power levels required. A new approach addresses this conundrum.

Gallium nitride (GaN) has more than proven its value at low power levels. Today, GaN is routinely found in smart mobile device chargers, and over the past 18 months, has been moving into higher power applications, addressing industrial power supplies and appliance motor drives. Solutions for datacentres, too, are being developed. The reason for the incredible market growth that GaN power devices are experiencing is that engineers have understood that by employing GaN ICs in their power conversion circuits they are able to increase the available power while reducing size. The high efficiency of GaN means that heatsinks can be eliminated, saving space, weight and cost. GaN switches have a Figure of Merit (FoM – arrived by multiplying the on resistance by the gate charge) which is 10 times better than best-in-class silicon. This enables systems to switch at a higher frequency without paying any efficiency penalty. Therefore, the passives can be miniaturised, making the whole system smaller and often cheaper. Also, because GaN does not have a body diode, reverse recovery current is literally zero, enabling the use of a simple, elegant totem pole bridgeless PFC topology in many applications.

But even by using more complex multi-level configurations, GaN has struggled to hit the power levels required for EVs. The first modern electric vehicles used IGBTs which are cheap, but suffer from low efficiency at low load conditions. This is a significant drawback, since an EV inverter operates at low loads during cruising, idling, or regenerative braking. Some estimates say that the load on the traction inverter of an EV will be less than 30% for 95% of the time. In 2017, Tesla launched its game-changing and influential Model 3, which replaced IGBTs with silicon

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carbide (SiC) inverter technology. The efficiency of the wide bandgap technology was well-known, and it enabled smaller, lighter batteries and/or extended range. However, SiC is expensive to produce, with huge energy processing costs, therefore, although it is a mature technology, significant future price drops can not be expected.

**GaN plus IGBT in one module**

A new combinational approach that promises to deliver the low cost benefits of IGBTs plus the efficiency of GaN has been proposed. A recent IEDM paper details Combo ICeGaN™ (Figure 1), a module that is based on a parallel configuration between a lateral smart GaN HEMT – ICeGaN® from CGD - and a discrete vertical IGBT. At low loads, the low switching losses of GaN enable increased range and smaller battery size. IGBTs become more efficient at higher loads, so when the energy demand is greatest, they will take over the heavy lifting. Although not as efficient as a full SiC solution, Combo ICeGaN will deliver performance increases of 3-4%, resulting in an excellent balance between cost and performance.

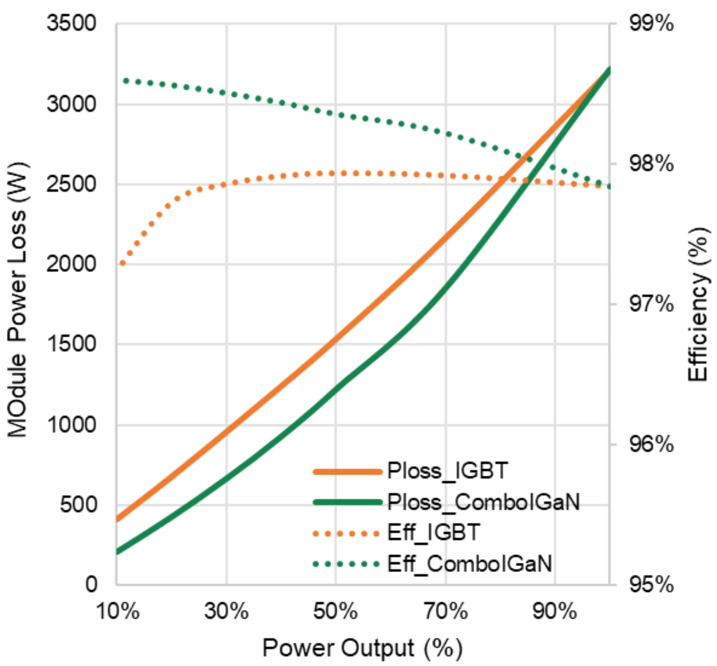


*Figure 1 Comparing power loss and efficiency across the load for IGBTs and Combo ICeGaN*

Figure 2 shows the basic operation of Combo ICeGaN. A feedback signal is provided to the driver/controller to adjust the waveforms on G1 and G2, to optimize the operation of the switch. For example at light load conditions the ICeGaN® can be switched independently, before being switched off or switched together with IGBTs when higher load conditions need to be met. Other modulation schemes to optimize the efficiency and reliability of the switch can be applied depending on the specific application.

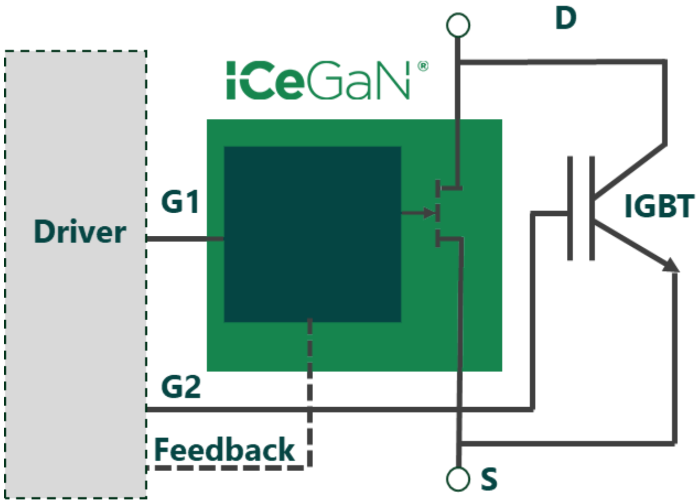


*Figure 2: Schematic representation of Combo ICeGaN*

The proprietary Combo ICeGaN approach uses the fact that ICeGaN and IGBT devices can be operated in a parallel architecture having similar drive voltage ranges (e.g. 0-20V), as well as excellent gate robustness.

**Why ICeGaN?**

ICeGaN (see Figure 3) is industry's first enhancement-mode GaN transistor that can be operated like a silicon MOSFET without the need for special gate drivers, driving circuitry, or unique gate voltage clamping mechanisms. ICeGaN ICs can be operated with standard, off the shelf gate drivers, up to 20-V. With a built-in Miller clamp and a threshold voltage set at around 3 V, there is no requirement to provide negative gate voltages to ensure that the device remains OFF when it is supposed to be OFF. Delivered in a low profile/low inductance package, ICeGaN integrates several additional integrated functions such as current sensing on the same GaN chip as the HEMT, enabling users to save on external components such as sense resistors.

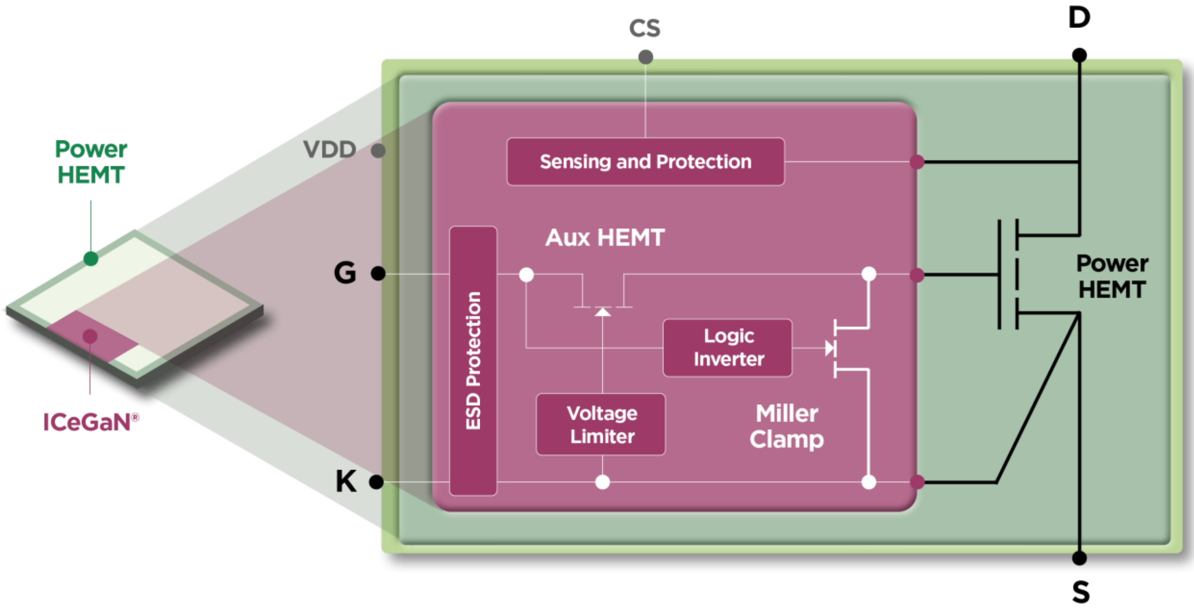


*Figure 3: A diagrammatic representation of the ICeGaN IC*

CGD's ICeGaN technology addresses the challenges that have previously prevented the automotive industry from adopting GaN. As discussed earlier, the monolithic integration of the GaN HEMT switch and interface circuity makes using GaN very simple. ICeGaN has also been proven to have excellent gate robustness. Evidence detailed in an APEC 2023 paper entitled '*A GaN HEMT with Exceptional Gate Over-Voltage Robustness*', presented by researchers from Virginia Tech and CGD, shows that ICeGaN HEMTs, enabled by smart protection circuitry, has an exceptionally high over-voltage margin of over 70 V, which is comparable to state-of-the-art traditional silicon devices, and possibly even higher. In addition to this hugely elevated dynamic gate breakdown capability, ICeGaN technology has a higher voltage threshold of 3 V, higher voltage range (0 – 20 V), and a stronger gate voltage clamping action at lower temperatures than other GaN implementations. More, the integrated Miller-clamp ensures immunity against high dV/dt and dI/dt events and obviates the need for negative gate voltages for turning-off (and keeping-off) the HEMT, which in turn reduces exposure to dynamic $R_{on}$ stress.

GaN - and ICeGaN in particular - has another major technical advantage. Unlike SiC, GaN is a lateral technology so other functions such as sensing can be more easily integrated monolithically onto a single chip.

Combo ICeGaN also benefits from the high saturation currents and the avalanche clamping capability of IGBTs. At higher temperatures, the bipolar component of the IGBT will start to conduct at lower ON-state voltages, supplementing the loss of current in the ICeGaN. Conversely, at lower temperatures, ICeGaN will take more current. Sensing and protection functions are intelligently managed to optimally drive the Combo ICeGaN and enhance the Safe Operating Area (SOA) of both ICeGaN and IGBT devices.

**The cost of GaN v SiC**

Some readers may be puzzled – GaN HEMTs are priced higher than IGBTs or, indeed, SiC. How then, is any saving possible? The answer lies in the fact that GaN ICs are lateral devices that can be made on standard silicon processing lines with the same equipment as standard silicon semiconductors. Therefore, they are inherently low cost. By contrast, SiC use vertical technology, which is a lengthy process that requires a huge amount of energy. SiC is a relatively mature technology, therefore the cost of devices is unlikely to drop. However, GaN is a comparatively new technology, and as the market grows – which it is doing, exponentially – and there are moves to 8in wafer production, then the price will fall. Industry commentators expect GaN devices to cost the same as SiC by 2028, then fall even lower, potentially to the same levels as IGBTs whose price has also plateaued.

**Conclusion**

As discussed earlier, in the Combo ICeGaN module – samples of which are expected this year - the ICeGaN switch is very efficient with low switching losses at relatively low currents (light load), while the IGBT is dominant at relatively high currents (towards full load or during surge conditions). The combination is expected to deliver excellent price/performance benefits. Figure 4 shows a schematic representation of a 3 phase inverter used in motor control (traction inverter) applications, employing Combo ICeGaN.

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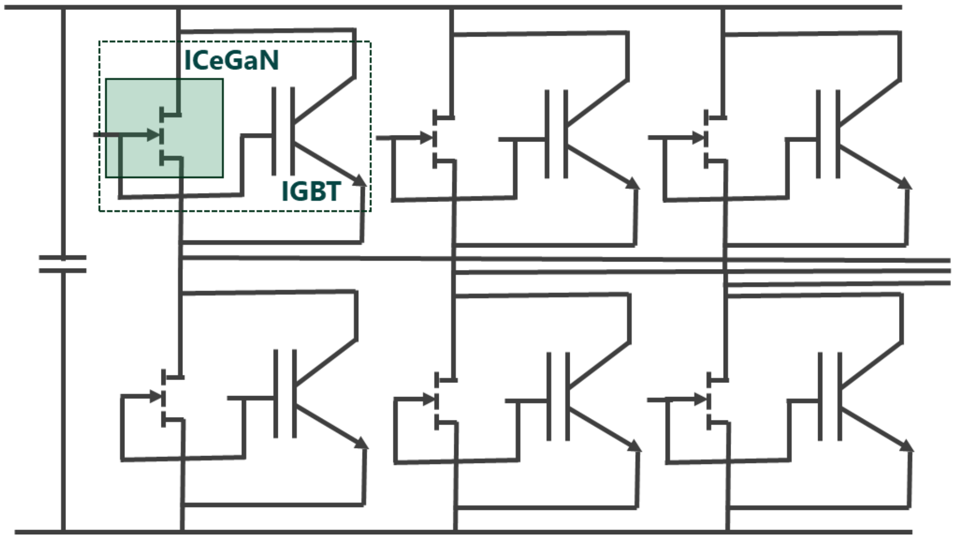


*Figure 4: 3 phase inverter employing Combo ICeGaN*

The efficiency gains are predicted to be 3-4%, similar to combinational solutions featuring SiC, but, of course, with the potential to be cost effective. CGD's roadmap also stretches out to full GaN-powered EV inverters which should deliver efficiency savings of 7-8%.