GaN vs Silicon Smackdown

One way to tell when a new technology has passed the tipping point of adoption is by the voices advocating the status quo. The more conservative voices tend to cite older information that, given the fast change of trajectory that occurs at a tipping point, can lead to poor decisions for new designs.

By Alex Lidow, CEO and Co-founder, Efficient Power Conversion

In the world of GaN power devices the tipping point occurred in the past two years when the rate of new GaN-based designs started to double year-on-year, and the legacy MOSFET designs started to face critical supply shortages due to their finely tuned, but less flexible supply chains. GaN devices, on the other hand, have remained in stock at most major distributors due to their relatively new and flexible supply chains utilizing older silicon foundries, but affording these foundries a new and vibrant future.

In this article we will address some of the common misconceptions still showing up in articles and at conferences, usually presented by advocates of the status quo.

Prices and Cost

Lower voltage GaN device prices have been matching silicon MOSFETs for a few years. Figure 1 is a table of prices for 100 V GaN transistors from Efficient Power Conversion compared with the popular MOSFETs with similar on-resistance. This data was taken in February 2022 and used medium volume pricing data from distributors. GaN devices are not the cheapest, nor are they the most expensive. This comparison ignores the fact that the GaN transistors are 10 times faster and 10 times smaller than the silicon counterpart, thus delivering much more value for the price.

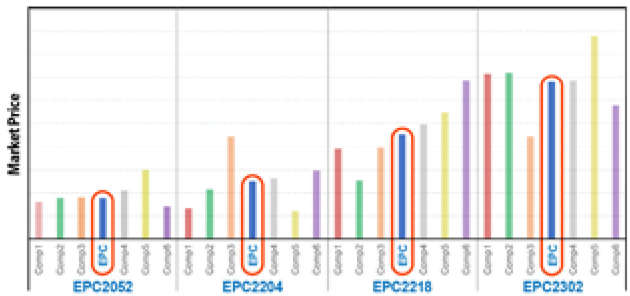
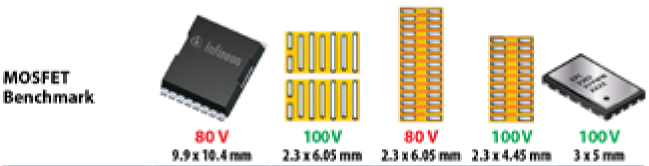


Figure 1: Comparison of market prices for 100 V GaN transistors and Si MOSFETs with similar on-resistance.

Thermal Efficiency

GaN transistors are much smaller than their silicon counterparts. This size difference is a major contributor to their lower manufacturing cost as well as their faster switching performance. One very common question that arises from the diminutive size is whether this makes it harder to extract the heat. The answer has two dimensions; (1) GaN devices tend to generate less heat due to lower conduction and switching losses, and (2) GaN devices have been designed to be extremely efficient thermally. As evidence of this second point, in figure 2 is a comparison between a popular MOSFET and several comparable eGaN® FETs from Efficient Power Conversion. Note that all the eGaN devices – even the one in a package on the far right – have much lower thermal resistance from the junction to the heatsink despite being six to 10 times smaller in size.



Parameter	IAUT200N08S5N023 (@ 10 V_{GS})	2 x EPC2218 (@ 5 V_{GS})	EPC2206 (@ 5 V_{GS})	EPC2071 (@ 5 V_{GS})	EPC2302 (@ 5 V_{GS})
$R_{DS(on)}$	2.3 Ω	1.6 Ω	2.2 Ω	2.2 Ω	1.8 Ω
Q_G typ (40 V_{DS})	36 nC	23.6 nC	15 nC	22 nC	18 nC
Q_{GD} typ (40 V_{DS})	28 nC	3.2 nC	3 nC	1.9 nC	3 nC
Q_{RR} typ	110 nC	0 nC	0 nC	0 nC	0 nC
Device size	103 mm²	14 mm²	13.9 mm²	10.3 mm²	10.3 mm²
R_{th} junction to heatsink	~0.7 °C/W	0.4 °C/W	0.4 °C/W	0.3 °C/W	0.2 °C/W

Figure 2: A comparison of 80 – 100 V GaN and MOSFET devices with similar on resistance. Note that, despite the smaller size of the eGaN FETs, they are significantly more thermally efficient.

Integration

One of the great advantages of GaN-on-Si technology is the ability to integrate multiple high voltage power devices onto one chip. This has enabled the development of monolithic power stages such as the one shown in figure 3. This device has essentially the same functionality as the Si-based lower voltage multi-chip "DrMOS" but with higher current and voltage capability, as well as better thermal properties. To illustrate the advantages of monolithic integrations, in figure 4 is a comparison between the efficiency in a 48 V – 12 V buck converter using the monolithic chip in figure 3 (green lines) and the equivalent discrete GaN transistors (blue lines). The additional efficiency is due to the virtual elimination of the common source, gate loop, and power loop parasitic inductances that are unavoidable when assembling multiple discrete elements on a PCB. The best MOSFET efficiency is also shown on this graph with a black "X".

Efficiency and Power Density

Thermal and electrical efficiency can be combined into a superior system power density. GaN power devices have consistently been

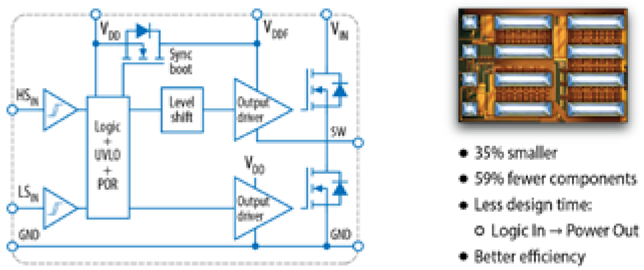


Figure 3: The EPC2152 is a monolithic power stage. The block diagram is on the left, and the 10 mm2 GaN chip is shown on the right.

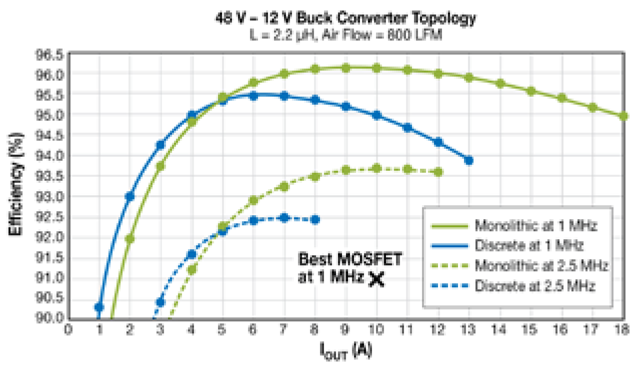


Figure 4: A comparison of efficiency in a 48 V – 12 V buck converter between a monolithic EPC2152 and comparable GaN discrete devices with a silicon driver IC. The IC is 35% smaller in size and is significantly more efficient. Note the maximum efficiency of a MOSFET-based buck converter is significantly worse.

the devices of choice at the power density benchmarks in 48 V converters. In figure 5 is shown the evolution of power density in 48 V – 12 V unregulated converters over the past 7 years. The latest benchmark has a power density of over 5,000 W/in3 compared with the benchmark MOSFET-based converters prior to GaN adoption at about 350 W/in3.

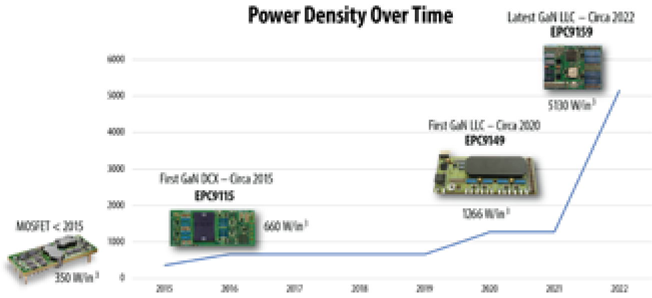


Figure 5: Since 2015 the benchmark power density for a 48 V – 12 V DC-DC converter has increased by a factor of eight.

Setup	Inverter 20 kHz, 500 ns dead time 400 RPM, 5 A_{RMS}	GaN inverter 100 kHz, 14 ns dead time 400 RPM, 5 A_{RMS}
Input Inductance	2.7 µH	None
Input capacitor	660 µF electrolytic	44 µF ceramic
Pin	121.3 W	113.3 W
Pout	119.6 W	111.3 W
$\eta_{inverter}$	98.50%	98.20%
Speed	42.25 rad/s	41.94 rad/s
Torque	1.876 Nm	1.940 Nm
Pmech	79.3 W	**81.36 W**
η_{motor}	66.30%	73.10%
η total efficiency	65.30%	**71.80%**

Figure 6: Using three EPC2152 GaN power stage ICs to create a BLDC motor drive operating at 100 kHz instead of the traditional MOSFET-based inverter at 20 kHz improves overall system efficiency by 10% while shrinking the size by a factor of two.

Brushless DC (BLDC) motor drives also benefit from improved power density due to the superior properties of GaN. In this case, the absence of reverse recovery charge (QRR) in an enhancement mode GaN transistor allows for a significant reduction in deadtime and a significant increase in the optimal operating frequency on the motor drive. Figure 6 is a comparison between a 20 kHz BLDC drive with 500 ns deadtime (needed to accommodate MOSFET Q_{RR}) and a 100 kHz drive with 14 ns deadtime. Both motor drives are running at 5 A_{RMS} and 400 RPM, and the GaN-based drive uses just three of the ICs in figure 3 coupled with a simple microcontroller to create a very low component count motor drive. Surprisingly, the 100 kHz drive has about the same inverter efficiency but can deliver 10% more torque to the motor shaft, and therefore 10% more range for an e-bike. This is a result of the elimination of a sixth harmonic signal that is derived from the long deadtime needed to accommodate the MOSFET diode recovery. This harmonic causes a significant acoustic noise as well as a counterforce to the motor. By going to the higher frequency there is also a reduction in EMI, and the designer can go to ceramic instead of electrolytic capacitors. The reduced size makes it easier to incorporate the entire drive inside the motor housing thus reducing costs and EMI even further.

Future Generations

GaN power devices have been around in volume for more than 12 years, yet the technology is far from achieving its theoretical capability. The latest generation GaN transistor technology is still 300 times larger than prescribed by the physical limits of the crystal. This means that GaN technology will continue to improve in performance and cost while the aging silicon MOSFET stagnates at the silicon crystal limits reached several years ago. GaN integrated circuits are just coming on the scene in volume applications such as fast chargers for cell phones, ebike motor drives, and lidar systems for cars and robots. Designers can look forward to many years of upgrade possibilities once they take the plunge into GaN-based power conversion.

www.epc-co.com