Efficient Power GaN Technology and Packaging Innovations Delivers a Winning Combination

Gallium nitride for power applications has moved out of the development phase and into the mainstream. No longer is it a niche 'exotic' technology to be discussed in esoteric papers at academic conferences, it is being used in many power applications and being designed in widely for volume growth.

By Dr. Dilder Chowdhury, Director, Strategic Marketing, Power GaN Technology at Nexperia

Of course, the technology – like all others – is being, and will continue to be, constantly refined, leading to significant performance enhancements. It is also important to consider the chip packaging as this can greatly enhance – or compromise – device performance.

The time is right for Wide Band Gap technology

The world is changing. A greater awareness of our environmental responsibilities has led to EU Eco-design Directive and Energy Labelling Regulation and societal demand for less polluting technologies. Therefore, there is a move by all industries – especially power-hungry sectors such as automotive, communications and servers where 24/7 operation is required to move to electrification and even higher efficiency power conversion.

Traditional silicon technologies have performed beyond the wildest dreams of their inventors for 70 years and will continue to be a mainstay of many systems way into the predictable future. But in power applications, both silicon FETs and IGBTs are limited in switching speed, and it is harder and harder to make any significant steps in increasing efficiency.

This is why wide bandgap (WBG) semiconductors have emerged into the mainstream. Power GaN technology and specifically power GaN-on-silicon (GaN-on-Si) High Electron Mobility Transistor (HEMT) technology is today delivering on its long-discussed promise to provide the high-power performance and high frequency switching that many applications clearly require and can take the benefit to move to next level.

Commercial availability of GaN

In 2020, Nexperia launched its first-generation of commercially available power GaN products. Cascode mode devices were offered in leaded TO-247 packages. Just ahead of the PCIM show in 2021, the company announced volume availability of its second-generation 650 V power GaN FET device family, offering significant performance advantages over previous technologies and competitive devices. With RDS(on) down to 35 mΩ (typical), the new power GaN FETs target single phase AC/DC and DC/DC industrial switched mode power supplies (SMPS), ranging from 2 kW to 10 kW, especially server and telecom power supplies that must meet 80 PLUS® Titanium efficiency regulations. The devices are also an excellent fit for solar inverters and servo drives in the same power range.

Nexperia is making significant performance improvements that not only lowered the RDS(on), but also result in better switching Figure Of Merit (FOM) and lower capacitances, leading to improved efficiency and power density. The company is also investigating ways to achieve further optimization going forward with efficient designs to enable more efficient use of die space and higher breakdown voltages, as well as other improvements to drive yields up and costs down.

Cascode provides stability and ease of use

Nexperia's cascode power GaN FET structure has an effective gate rating of ± 20 V (as good as existing silicon super-junction technology) and can be driven by standard cost-effective gate drivers with a simple 0-10 or 12 V drive voltage with lower current compared to SiC while offering high gate threshold voltage of 4V for immunity against false turn on.

Packaging plays a crucial role

As systems move to higher switching frequencies to improve efficiency, the limitations of traditional power packages (TO-220 / TO-247 and D2PAK-7) have become increasingly obvious. To maximize

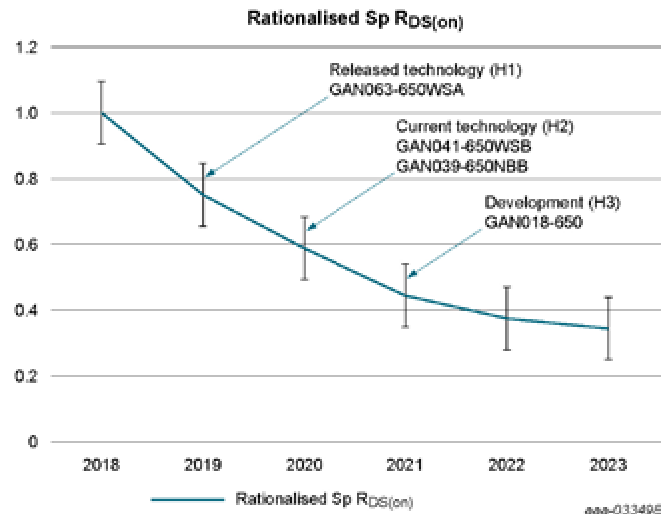

Figure 1: Rationalised Sp $R_{DS(on)}$

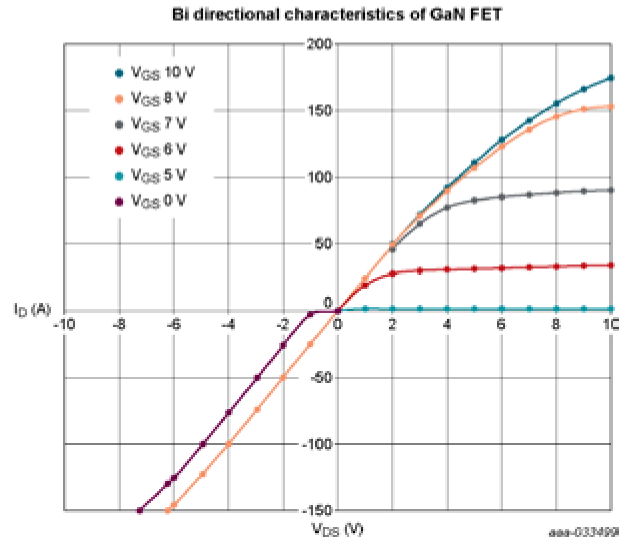

Figure 2: Bi-directional characteristics of GaN FET

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the benefits of high-voltage WBG semiconductors, new packages are required. As the innovators of copper-clip package (CCPAK) technology, Nexperia brings almost 20 years' experience of producing high-quality, high-robustness SMD packaging to its high voltage power GaN FET portfolio.

The new CCPAK package is completely free of wires and has been designed to optimize both electrical and thermal performance.

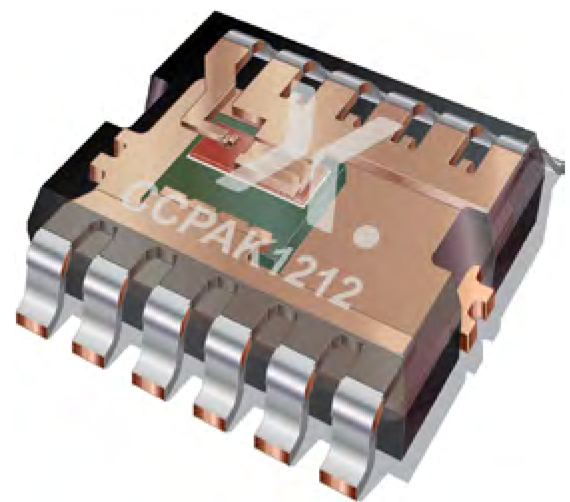


Figure 3: Internal arrangement of CCPAK1212

CCPAK delivers many benefits, firstly size. The CCPAK1212 is compact measuring 144 mm^2 (Solder pad design 168 mm^2) with a low 2.5 mm profile. This is less than a quarter (21.4 %) the body size of a TO-247 and 10 % smaller than the D2PAK-7. This enables significantly higher power density systems to be developed. Also, the CCPAK1212's exposed gull-wing leads facilitate easy optical inspection and enhance board-level reliability.

Electrically, the internal copper clip delivers many benefits. With no internal wire-bonds, the CCPAK enables significantly lower inductances than leaded packages. The table below highlights the comparison of CCPAK1212 and TO-247 operating at 100 MHz, which results in a total loop inductance of 2.37 nH compared to almost 14 nH. The copper-clip package also helps deliver ultra-low package resistance and a thermal resistance of < 0.5 K/W.

Inductance	CCPAK1212 (nH)	TO-247 (nH)
G_MOS_L	1.92	8.19
G_GAN_L	0.53	1.18
S_MOS_L	0.38	0.74
Common_L	0.55	5.92
D_GaN_L	1.44	5.13

Figure 4: Self-inductance @ frequency 100 MHz

Thermal challenge

Thermal management is a constant headache for power applications, becoming ever more difficult to address as power levels and circuit density both increase.

Combining power GaN-on-silicon technology with CCPAK packaging addresses this challenge. Nexperia's 650 V high-power FETs in CCPAK are rated for use at 175 °C, and offers a low typical $R_{th(j-mb)}$ (<0.3 K/W) for optimal cooling. This is shown in thermal simulations (Figure 5) when dissipating 37 W, where in comparison to a TO-247 (Rth = 0.7 °C/W) the CCPAK has a Rth of just 0.173 °C/W. The result is that the CCPAK1212 can comfortably manage over 300 W of power dissipation.

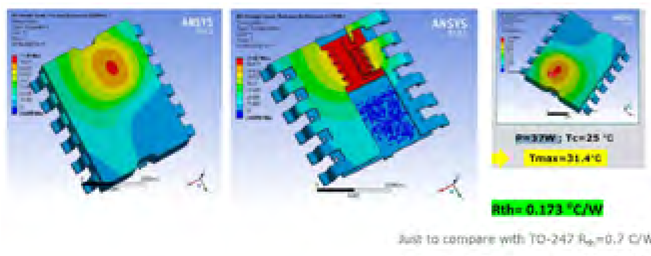
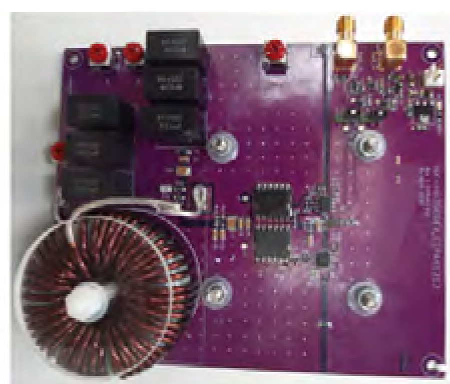


Figure 5: Thermal simulation power GaN FET

For even greater thermal performance, CCPAK1212i "flips" the internal connections, permitting top side cooling and providing a system solution for hard switching topologies or where high ambient temperatures are a concern.

Half-bridge demonstrates GaN FET advantage

The basic building block for most topologies - AC/DC PFC stage, DC/DC converter, or traction inverter - is a half-bridge. If we compare gallium nitride FETs to silicon FETs in a simple boost converter, the superior performance of the power GaN device is clearly shown.



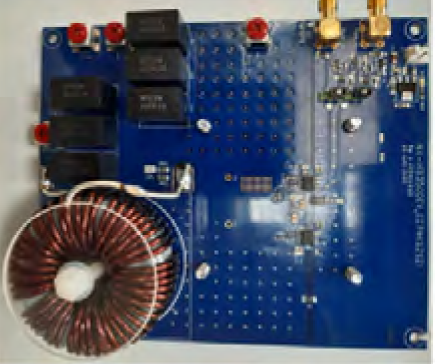


Figure 6: Half bridge demo board top and block diagram

The half-bridge demo in Figure 6 uses Nexperia's top-side cooled GAN039-650NTB delivering 400 VIN and 230 VOUT at 100 kHz with 57.4 % duty configuration operating at an ambient temperature of 23.1 °C. The resulting efficiency results are impressive. At 2 to 3 kW, or the typical operating range for current industrial PSUs, efficiencies are in excess of 99%. To put this in perspective, Titanium is the most demanding of the 80 PLUS® specifications, requiring greater than 91 % efficiency under full load conditions (>96% at 50% load). Therefore, the Nexperia 650 V power GaN FETs provide the efficiency and power density boost that server, storage and telecom PSUs designs require. In fact, the power GaN FETs continue to deliver high efficiencies of 98 % and above even beyond 6 kW.

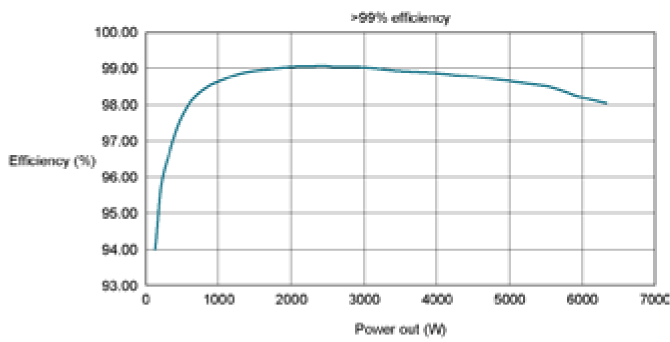


Figure 7: Half bridge demo efficiency

For servo drives, lower motor loss and lower noise are the result of improved current waveforms and the bottom-cooled GAN039-650NBB showcases the fast soft switching offered by these devices. In a 400 V_{DC} buck-mode set-up with a low-side V_{DS} for I_D of 20 A, the spike, overshoot, negative undershoot and ringing are almost negligible during both the turn-on and turn-off. This provides a significant advantage in terms of noise and any silicon related Qrr issues.

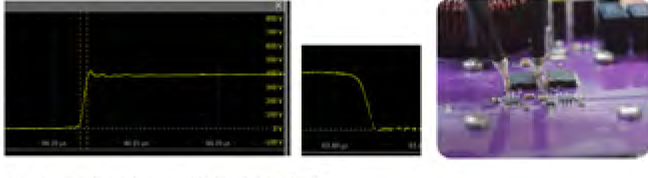


Figure 8: CCPAK1212 switching waveform

Conclusion

As designers increasingly look to wide bandgap (WBG) technology they need also to consider the availability of efficient packaging solutions such as Nexperia's all copper-clip CCPAK in order to take full advantage of the new power GaN semiconductor FETs. By delivering increased power conversion efficiency and fast, hard and soft switching Nexperia's power GaN technology in CCPAK is enabling automotive, telecoms and server companies to address growing requirements for a more sustainable future.

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