Working to roll out GaN electronics applications

Mike Cooke looks at how some companies are preparing for increased commercialization in gallium nitride RF and power-switching markets.

Gallium nitride (GaN) electronic devices such as high-electron-mobility transistors (HEMTs) have been developing at a rapid pace in the past few years. However, the deployment in real-world applications has been slower than hoped by investors and engineers working to roll out GaN electronics. As always, a new technology has to compete with incremental developments of existing infrastructure (gallium arsenide, silicon, etc).

The properties of GaN combine a wide bandgap (~3.4eV) and high electron mobility (~900cm^2/V-s). The wide bandgap implies a high critical electric field for breakdown. The mobility allows higher switching frequencies and higher-speed operation for RF. These properties also allow for reduced amounts and sizes of auxiliary components (inductors, transformers, capacitors, heat-sinks, fans, cooling, etc) and casings.

Potential GaN electronics generally divides into two areas: radio frequency (RF) power amplification, and high-voltage power switching.

GaN RF power amplifiers (PAs) can be deployed in wireless network base-stations connected to the telecom network. Further applications can be found in general and tactical military communications, jamming, radar, and satellites.

The main focus for GaN power-switching has been for implementation in power supplies, motor drives, battery chargers, and DC–AC inverters deployed over many specific applications such as heating, ventilation & air conditioning (HVAC), solar panels, uninterruptible power supply (UPS) systems, battery management, power factor correction (PFC), electric vehicles, and ultra-small power supplies (AC adapters, PCs, servers, telecom). GaN could also be used to amplify audio signals by pulse-width modulation through high-speed switching rather than through linear gain. Such ‘class D’ amplifiers are more efficient than analog systems, creating less heat in the switching transistors.

The two target application areas lead to somewhat different approaches to implementation. For RF, it is hoped that superior performance will significantly increase power density and reduce auxiliary demands for cooling compared with alternative silicon and gallium arsenide (GaAs) systems. Also, some of the potential markets — one thinks of military customers here — are traditionally less cost-sensitive and more demanding of performance. Power-switching applications are more mass market, and cost looms larger in investment calculations.

The difference is often seen in the substrate used — silicon carbide (SiC) for RF power and silicon for power-switching. GaN grown on SiC is generally higher quality due to smaller lattice mismatch (~3%) compared with (111)Si (~17%). An additional advantage of SiC is a higher thermal conductivity of ~4W/cm-K, compared with ~1.3W/cm-K for Si.

The significant disadvantage of SiC is cost due to much more difficult production (75x that of silicon on one estimate, although this depends on the balance of power between supplier and customer). Also, silicon can be produced as larger-diameter wafers — presently up to 200mm (8 inches), with 300mm (12 inches) being worked on in research and development. GaN-on-SiC wafers are available up to 100mm (4 inches), with 150mm being rolled out (since 2012).

Some market researchers predict a market for GaN power conversion of the order of $1bn by 2024 — others are less sanguine. Meanwhile, Strategy Analytics suggests that the RF GaN market could reach $560m by 2019.

Here we look at how some companies are approaching these markets.

Cree and Wolfspeed

Cree Inc of Durham, NC, USA has been developing GaN RF devices alongside its SiC power electronics business for some time. In May it announced that this division would be spun off as a standalone company with the aim of “innovation and commercialization of next-generation power and wireless systems based on silicon carbide and gallium nitride”. The new company is called Wolfspeed and an initial public offering is expected by June 2016.

The new company’s main focus for GaN is RF devices on SiC substrates, while devices aimed at the power-switching market are pure SiC. This is not too surprising considering that Cree’s core and founding technology is growth and marketing of SiC substrates.

Wolfspeed inherits two basic families in its GaN HEMT monolithic microwave integrated circuit (MMIC)

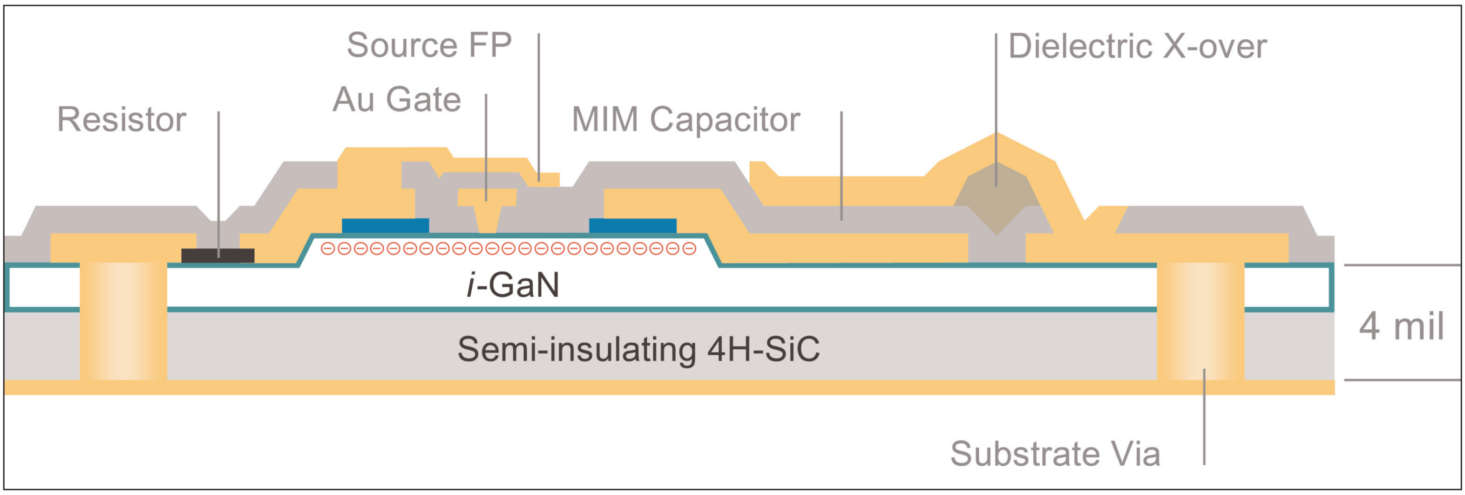

Figure 1. Cree's GaN MMIC process schematic.

foundry service for 0.4μm and 0.25μm gate lengths (Figure 1). The 0.4μm HEMT enables operation at up to 50V drain bias. The 0.25μm gate process allows biases up to 40V. Transistors built on these processes can handle power densities up to 8W/mm with high reliability up to 225ºC operating junction temperatures. The company also markets its own range of discrete and MMIC components.

Fabless and foundries

In 2013, Japan's Fujitsu and Transphorm Inc of Goleta, near Santa Barbara, CA, USA agreed to integrate their GaN power supply electronics businesses. At the beginning of 2015, the companies reported that mass production had begun at Fujitsu Semiconductor group's CMOS-compatible, 150mm silicon wafer fab in Aizu-Wakamatsu, Japan.

The companies commented: "The large-scale, automotive-qualified facility, which is providing exclusive GaN foundry services for Transphorm, will allow dramatic expansion of Transphorm's GaN power device business. This stepped up production can satisfy the increasing market demands for GaN devices, thereby enabling the next wave of compact, energy-efficient power conversion systems."

Transphorm claims that its ultra-efficient power solutions eliminate up to 90% of all electric conversion losses. Transphorm also claims the first and only JEDEC-qualified 600V GaN device platform and the world's first photovoltaic power conditioner products using GaN modules.

ON Semiconductor of Phoenix, AZ, USA is among the partners of Transphorm. Together, the two companies introduced co-branded JEDEC-qualified 600V GaN cascode transistors and a 240W reference design. The transistors in optimized TO-220 packages have typical on-resistances of 290mΩ and 150mΩ. The packaging of GaN HEMTs with silicon transistors in a cascode circuit gives normally-off rather than normally-on operation (Figure 2).

An evaluation board for the reference design targets a smaller footprint and better efficiency than power supplies using traditional devices. The boost stage delivers 98% efficiency with power factor correction. The DC–DC stage uses an inductor-inductor-capacitor (LLC) transformer topology and a resonant mode controller to achieve 97% full-load efficiency at more than 200kHz, while also meeting stringent EN55022 Class B EMC performance. GaN HEMTs are used as switches both in the boost and DC–DC stages.

GaN Systems Inc of Ottawa, Ontario, Canada is a fabless company that designs and supplies a range of GaN high-power transistors for power conversion. The company made a GaN-on-silicon foundry agreement with RF Micro Devices Inc of Greensboro, NC, USA in 2013.

RFMD has since combined with Triquint Semiconductor Inc of Hillsboro, OR, USA to become Qorvo Inc. Qorvo's

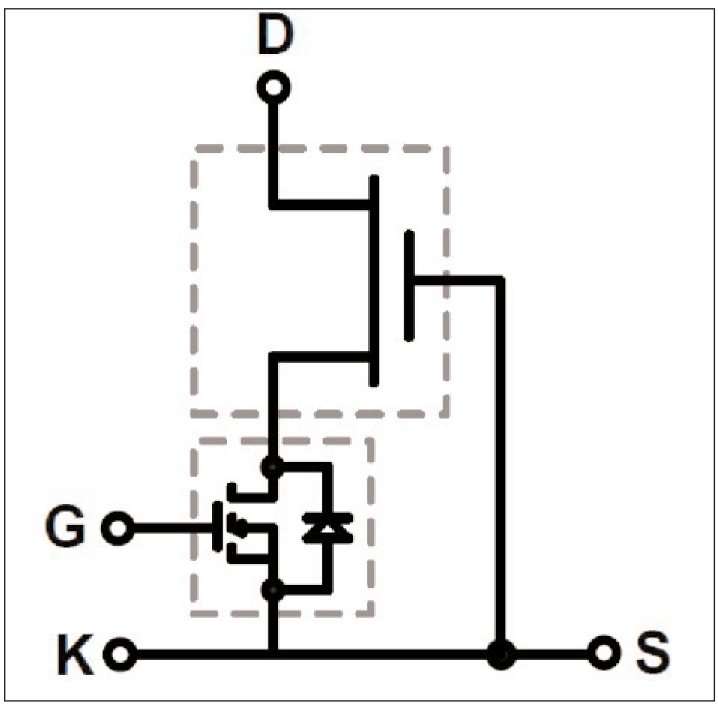

Figure 2. Cascode circuit to give normally-off operation of GaN HEMT.

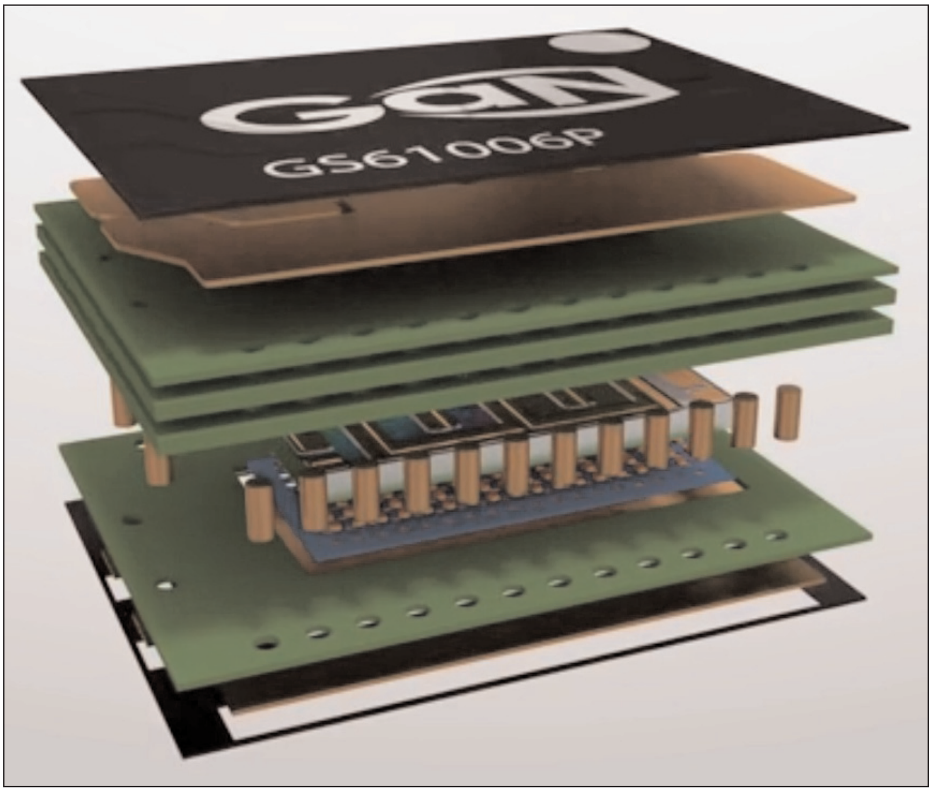

Figure 3. Exploded view of GaN Systems' GaN*PX* packaging.

process is 0.5µm AlGaN/GaN. The foundry promotes GaN/SiC for RF power amplifiers with operation up to 48V continuous wave and 65V pulsed. Power density can reach 8W/mm. The company also has extensions with greater linearity and higher breakdown voltages.

GaN Systems has two particular pieces of packaging intellectual property. First, an island structure that aims to reduce the size and cost of GaN devices, while transferring substantial current from on-chip metals to a separate carrier. Second, GaN*PX* packaging targets extreme speed and current (Figure 3). GaN*PX* is a near-chip-scale embedded package with no wire bonds. The company claims high current density, low profile and low inductance with optimal thermal performance. The last factor allows the elimination or reduction of thermal management measures such as heat-sinks or fans, creating more compact, low-cost equipment.

GaN Systems estimates that a typical silicon-based converter for electric vehicles will be optimally 95% efficient with a loss of about 5kW. The firm says that its GaN converters can achieve up to 99% efficiency, allowing a shift from water-cooling to air-cooling. Further, silicon efficiency of 95% at low load drops to around 70%, while GaN Systems claims that it can maintain efficiencies higher than 90%.

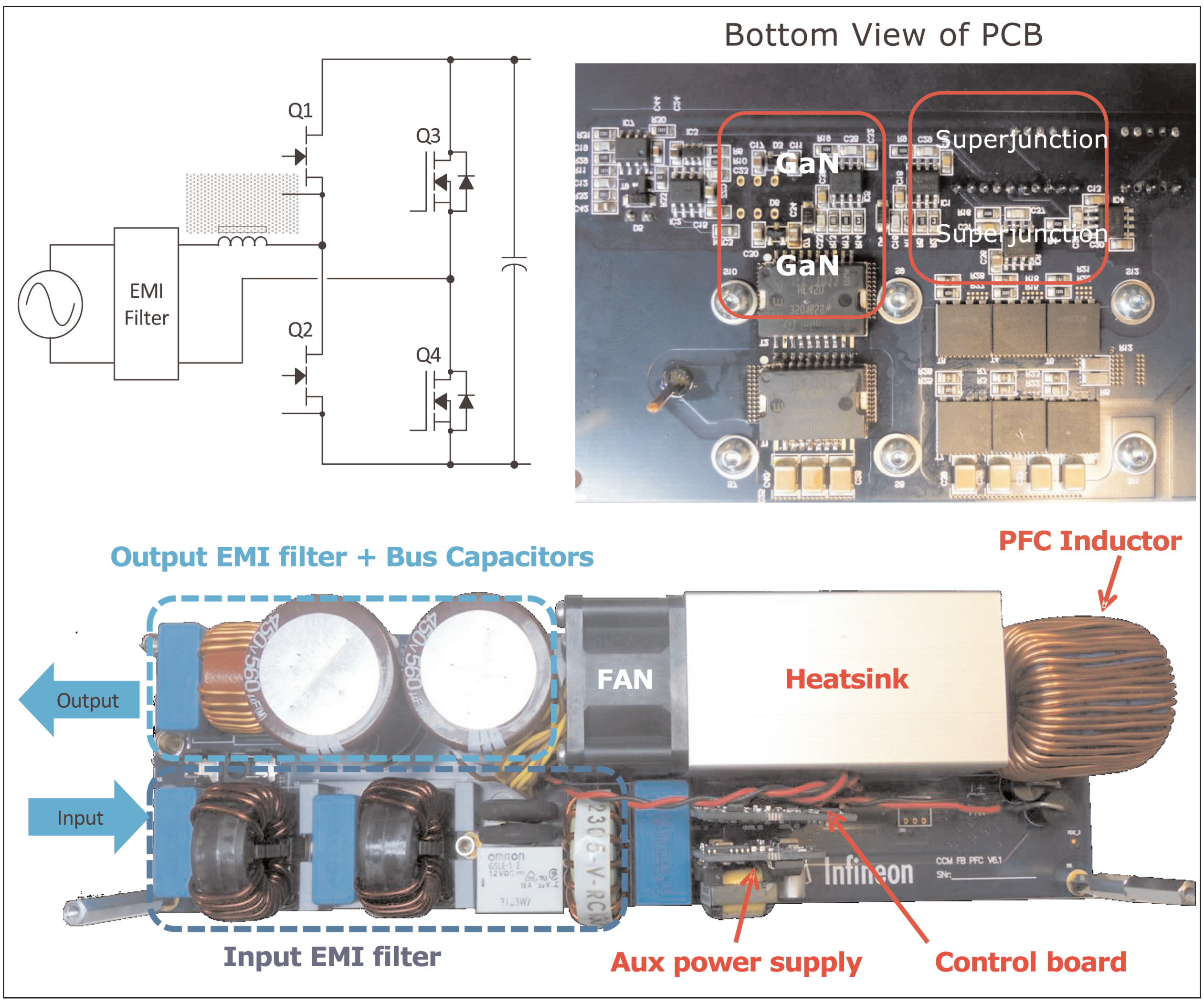

Figure 4. Infineon's totem-pole PFC full-bridge proof-of-concept circuit and photos.

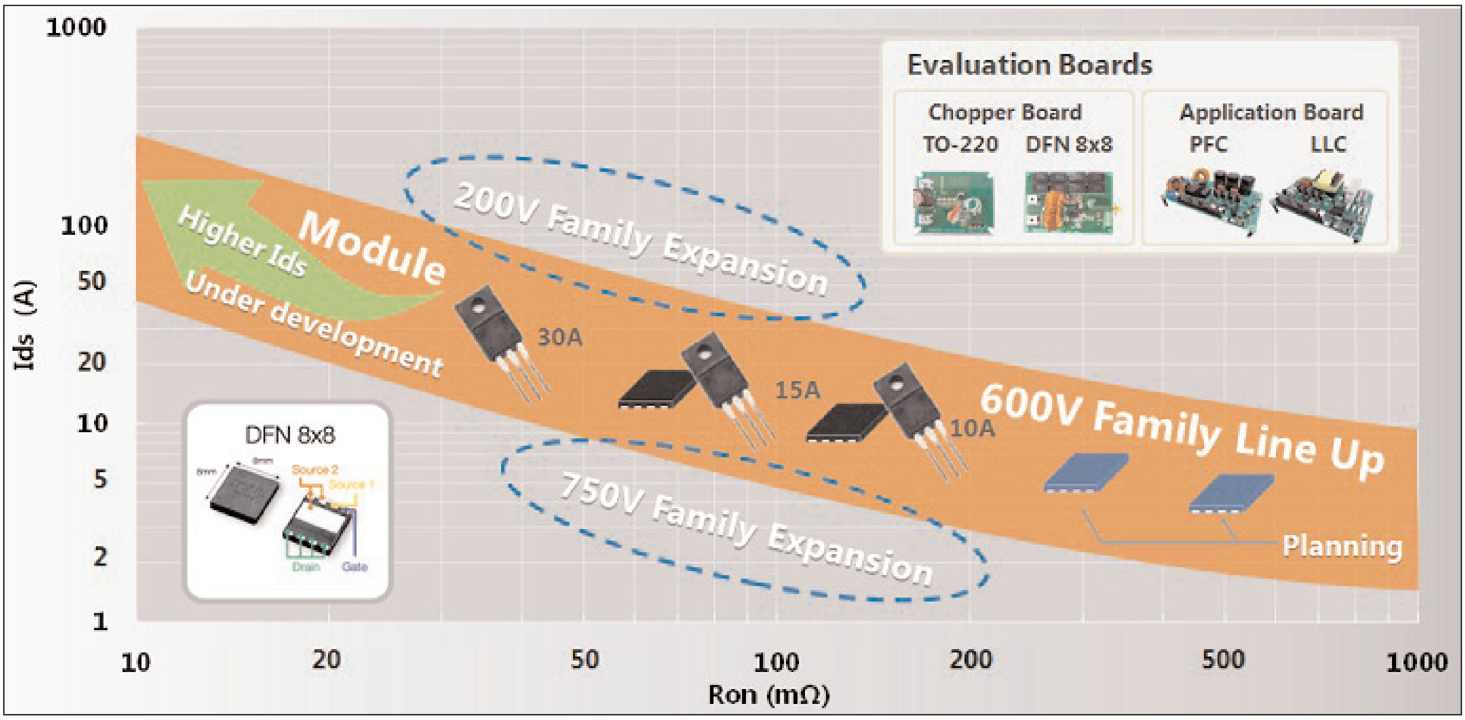

Figure 5. Panasonic's GaN roadmap.

Combining RF and power-switching

Germany's Infineon Technologies AG introduced its first devices in a family of GaN-on-SiC RF power transistors in September. Infineon claims that the new RF power transistors achieve 10% higher efficiency, five times the power density, and twice the RF bandwidth of silicon LDMOS transistors. The greater bandwidth should allow one power amplifier to support multiple operating frequencies. Increased instantaneous bandwidth offers higher data rates via data aggregation techniques specified for 4.5G cellular networks. Engineering samples and reference designs are available for the Infineon devices.

Infineon has also been broadening its patent portfolio related to GaN, expanding GaN-on-silicon (GaN/Si) with an epitaxy process and 100–600V technologies resulting from the acquisition of International Rectifier. Also, in March the company announced a strategic partnership with Japan's Panasonic aimed at integrating enhancement-mode GaN-on-silicon transistor structure into Infineon's surface-mount device (SMD) packages.

Infineon offers both enhancement-mode and cascode configuration energy-efficient GaN-based power-supply platforms. Andreas Urschitz, president of Infineon's Power Management & Multimarket Division, comments: "Using our GaN technology, a laptop charger found on the market today could be replaced by one that is up to four times smaller and lighter."

A recent application example from Infineon is a 2.5kW totem-pole PFC full-bridge circuit that combines GaN HEMTs with silicon superjunction field-effect transistors (Figure 4). GaN devices are used for the boost stage, allowing 70mΩ maximum resistance in enhancement-mode. The circuit handles 230V AC input and outputs 6.25A at 400V DC.

The Infineon/Panasonic partnership will use Panasonic's normally-off (enhancement-mode) GaN-on-silicon transistor structure integrated into Infineon's SMD packages, resulting in 600V GaN power devices from dual sources.

Meanwhile, in May Panasonic claimed the industry's smallest enhancement-mode GaN power transistors in its own specially designed X-GaN 8mm x 8mm x 1.25mm dual-flat no-lead (DFN) surface-mount package. The transistor breakdown rating is 600V and the switching speed is 200V/ns. The on-resistance ranges from 54mΩ to 154mΩ (Figure 5). The company was to ship samples in July of 10A and 15A devices. One advantage of SMD packaging is reduced parasitic inductance. Also, the footprint is decreased by 43% compared with Panasonic's conventional TO-220 package.

Finally, a company that has some GaN products is NXP Semiconductors N.V. of Eindhoven, The Netherlands, which has a focus on GaN RF power devices for base-station, industrial scientific & medical (ISM) and aerospace & defense applications. On its website, the company claims best-in-class linearity, but this may be a historical statement. A back-end assembly facility packages the high power density of GaN into smaller and more broadband circuitry, according to NXP. ■

Author:
Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.