GaN – the New Frontier for Power Conversion

Due to its advantages GaN will probably become the dominant technology

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GaN fundamentals

In June 2009 Efficient Power Conversion Corporation (EPC) introduced the first enhancement-mode GaN on silicon power transistors designed specifically as power MOSFET replacements. These products were designed to be produced in high-volume at low cost using standard silicon manufacturing technology and facilities. The structure is relatively simple as shown in figures 1 and 2 (For a more detailed overview of this technology, go to www.epc-co.com/epc/ToolsandDesignSupport/ProductTraining.aspx

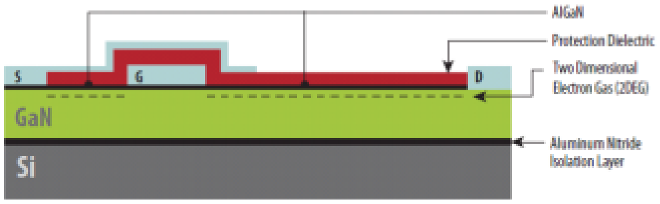

Figure 1: GaN on silicon devices have a very simple structure similar to a lateral DMOS device and can be built in a standard CMOS foundry

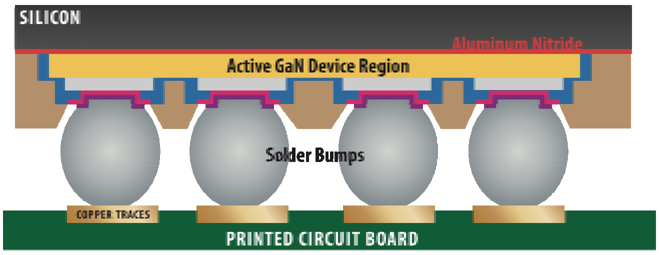

Figure 2: EPC's enhancement mode GaN transistors are sold as flip-chips. This gives the designer the ability to reduce system footprints, reduce parasitic inductances and resistances, and, due to the isolated silicon surface, attach the transistors directly to a heatsink without further isolation.

New capabilities compared with silicon

The most significant new capabilities enabled by enhancement mode GaN HEMT (High Electron Mobility Transistor) devices stem from the disruptive improvement in switching performance and overall device bandwidth. GaN also has a much higher critical electric field than silicon which enables this new class of devices to withstand much greater voltage from drain to source with much less penalty in on-resistance(see Figure 3).

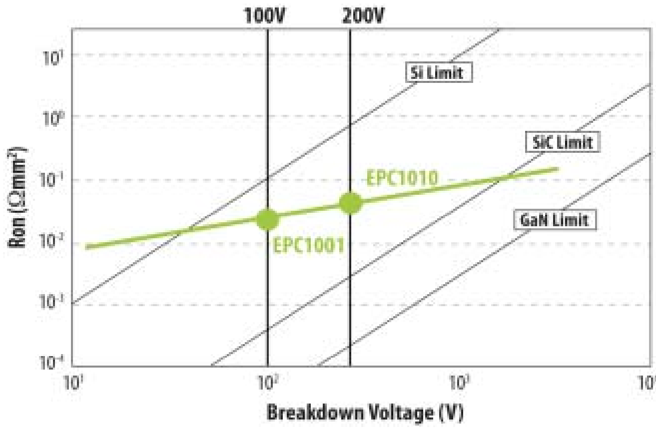

Figure 3: Theoretical resistance times die area vs breakdown voltage for silicon, silicon carbide, and GaN compared with EPC's first generation product

In power MOSFETs there is a basic tradeoff between the conductivity of a part and the amount of charge required to take the device from the ON to the OFF state (Or from the OFF to the ON state). From this tradeoff comes the figure of merit called RQ product. This is defined as a device's on-resistance multiplied by the total charge that must be supplied to the gate to switch the device at operating voltages and current. Improvements in this RQ product have been shown to translate into improved conversion efficiency in high frequency DC-DC converters. The absolute value of RQ is also indicative of the minimum pulse widths achievable in a practical circuit. Whereas there have been great improvements in RQ product over

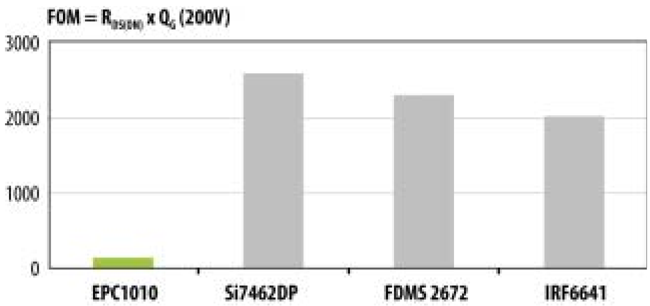

Figure 4: RQ product for 200V benchmark silicon compared with EPC's GaN

the last several years, silicon cannot come close to the figure of merit achieved in first-generation eHEMT (enhancement mode HEMT) devices already on the market. Figure 4 shows a comparison between benchmark silicon devices and GaN devices rated at 200V.

Much work has been done to circumvent the poor switching capabilities of the silicon MOSFET. Gate charge, reverse recovery charge, output charge, and common source inductance all limit a MOSFET's ability to be efficient at high frequency. For example, resonant DC-DC converters have become standard in bus converters where both size and efficiency are important. As with all resonant topologies, the tradeoff for improved switching losses is increased circulating energy with higher peak currents and increased RMS conduction losses. This migration to resonant topologies also comes at the cost of dynamic performance as the control bandwidth is orders of magnitude less than other hard switching topologies such as fixed frequency or constant on/off time PWMs. This limits the use of these "MOSFET saving" topologies to applications where an additional low-frequency hard-switching converter (placed either before or after the bus converter) will be there to handle dynamic transients. With improved hard switching performance, and the reduced input and output capacitances (Ciss and Coss) that EPC's enhancement mode GaN transistors offer, this tradeoff will have to be reevaluated. All these characteristics allow the increase of switching frequency (both for hard and soft switching).The question then becomes how can the use of hard switching be traded for an improvement in bandwidth and a reduction in circulating energy? Are there two isolated islands of hard and soft switching, or is there some bridge that can exploit the best of both worlds?

In Table 1 are listed some of the early applications for EPC's enhancement mode GaN transistors.

Application	Key Benefit	Other Benefits	Key GaN Attributes
Buck Converters	Higher Vin/Vout ratio	Lower system cost, improved efficiency, less board space	Fast switching, high frequency capability, narrow and repeatable pulse width, zero diode reverse recovery
LED Drivers	Higher dimming ratio	Improves contrast ratio, reduces space, saves energy	Fast switching, high frequency capability, narrow and repeatable pulse width, zero diode reverse recovery
Power Over Ethernet (POE)	Higher power density	Smaller system volume, higher efficiency	Very low RQ product, zero diode reverse recovery
Bus Converters/ Bus Transformers	Higher power density	Smaller system volume, higher efficiency	Very low RQ product, zero diode reverse recovery
Synchronous Rectification	Higher efficiency	Smaller system volume, higher efficiency	Very low RQ product, zero diode reverse recovery
Class D Audio	Very low distortion (thd)	Higher sound quality, higher efficiency, smaller system volume	Fast switching, high frequency capability, narrow and repeatable pulse width, zero diode reverse recovery
Cell Phone	Longer battery Life	Lower system cost, fewer components, smaller form factors	High frequency capability with high voltage capability. Complete circuitry easily integrated.
Base Station	Lower System Cost	Fewer components, less energy consumption	High frequency capability with high voltage capability. Complete circuitry easily integrated.

Table 1: Early applications for EPC's enhancement mode GaN transistors

GaN readiness

The cumulative reliability information available on silicon power MOSFETs is staggering. Many years of work have gone into understanding failure mechanisms, controlling and refining processes, and designing products that have distinguished themselves as the highly-reliable backbone of any power conversion system.

GaN on silicon transistors are just beginning this journey. Preliminary results, however, are encouraging. As of the date of this writing, EPC has established the basic capability of enhancement mode GaN on silicon transistors. Tested devices are stable after 1000 hour stresses of the gate, the drain-source, and when exposed to high humidity with bias. EPC also put devices into 48 V - 1 V DC-DC converters and operated them at maximum stress for 1000 hours without failure. To see the entire EPC GaN readiness report, go to www.epc-co.com/epc/documents/product-training/EPC_relreport_030510_finalfinal.pdf

There is still much to be done to understand the various failure mechanisms associated with this new technology. Nevertheless, the data we have so far suggests this technology is today capable of performing at acceptable levels of reliability in commercial applications.

The future

The GaN journey is just beginning. There are many large improvements that can be made in basic device performance as measured by the RQ figure of merit. As we learn more about the material and the process, a factor of two improvement can be reasonably expected over the next three years and a factor of ten over the next 10 years.

We can also expect devices to emerge with much higher breakdown voltages as EPC plans to introduce 600 V devices in the second half of 2010 and other companies have discussed openly their intentions in this area. Higher voltage GaN transistors will eventually displace silicon IGBTs and even SiC-based transistors due to the lower manufacturing costs and lower conduction losses.

Perhaps the greatest opportunity for GaN to impact the performance of power conversion systems comes from the intrinsic ability to integrate both power-level and signal-level devices on the same substrate. GaN on silicon, much like SOI (silicon on insulator), has no significant parasitic interaction between components. This capability opens the door to power system-on-chip products where the entire power section is integrated with full control and drive circuitry.

Summary

The traditional power MOSFET is not dead, but is nearing the end of major improvements in performance and cost. GaN will probably become the dominant technology over the next decade due to its large advantages in both performance and cost; advantage gaps that promise to widen as we quickly climb the learning curve.

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