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# Where are the High-Voltage GaN Products?

Where are the high voltage gallium nitride (GaN) power switching devices? After all, GaN is reputed to be a high voltage technology by leading technologists in that field.

I was discussing the compound semiconductor landscape with fellow attendees at APEC 2010. Our discussion was probably one of many prompted by IRís further introduction of devices and the presence of Cree, TranSiC, and others at APEC. I posed the question, "Where are the high voltage gallium nitride (GaN) power switching devices? After all, GaN is reputed to be a high voltage technology by leading technologists in that field."

In the past few years, compound semiconductors have become the focus of development as semiconductor engineers have strived to get to the next better device. The bulk of the development has been for applications such as radio frequency (RF) power transistors and light emitting diodes (LEDs). Now, as of this writing, two suppliers have introduced low voltage GaN power switching devices.

However, we saw that GaN might well be the technology to provide 600 volt and 1200 volt semiconductor devices for every type of high voltage power conversion, including variable-speed motion control, solid-state lighting, electric vehicle drives, wind and solar converters, uninterruptible power supplies, and, yes, eventually the higher power distribution, transmission, and traction markets.

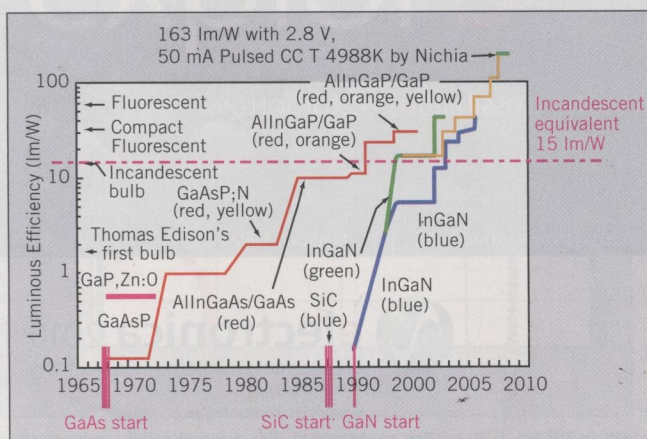
## WHY GALLIUM NITRIDE?

GaN is the most practical, lowest loss, power semiconductor material available today. SiC can achieve reasonable performance as a low-loss device, but experts have assured me the performance of fully developed GaN will be two times (2X) better than SiC.

GaN provides the fastest path to market. As one expert told me, "GaN has always had a high natural speed of device development and market accessibility." Technologists will develop GaN materials and products faster than either gallium

arsenide or silicon carbide devices. The reason: material problems plague GaN far less than other compound semiconductors. For instance, if a non-GaN LED had as many imperfections as a GaN LED, it would not emit any light. It would be absolutely dead! Yet the GaN LED operates extremely well, even with imperfections.

Let's use previous compound semiconductor LED development history as a guide. The figure illustrates GaAs development taking 26 years to obtain 15 lumens per watt (lm/W) which is the equivalent of the incandescent lamp. SiC never got onto the roadmap before GaN development took off. In only six years, GaN LEDs reached 15 lumens per watt. GaN material development was considerably shorter than either GaAs or SiC so therefore product development could commence sooner. In the development of both GaAs and SiC devices, it was first necessary to create a near-perfect material. For instance, perfect SiC mate-



1. This timeline traces the development of Light Emitting Diodes (LEDs). Source: University of California at Santa Barbara, Solid State Lighting and Energy Center.



rial has taken over a decade to develop! According to Yole's market analysis, it is still plagued with micro-pipe and basal plane dislocations. GaN material development was much faster! Thus, GaN engineers could start on product creation a lot sooner in the development process than their SiC or GaAs counterparts could. Experts tell me that we can expect the same fast GaN development time line for high voltage power switching devices. A leading GaN technologist recently shared with me, "If we needed to develop GaN power device material to the extent that they had to develop GaAs material, we would not have seen the devices that are already introduced. We would have to spend a billion dollars before the material became clean. That would make the whole industry not only late in device development but also make the devices expensive. Fortunately, that will not be the case!"

#### SCALABILITY

GaN has much better device size scalability. We can also conclude from the figure that technologists were able to scale GaN four times (4X) beyond either SiC or GaAs materials, reaching a benchmark of 168 lm/W. We can

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expect this to be the case for GaN power switching device scalability. GaN will happen sooner, and then will scale to a much higher device size. Presently, the low voltage GaN designers are proving that very point.

GaN is low cost. It is higher cost than silicon, but GaN will always cost less than SiC because GaN is compatible with silicon substrates affording a large-area foundation substrate - and SiC is not compatible. At APEC 2010, low voltage

GaN speakers very accurately emphasized this point. However, if there ever is a fundamental breakthrough to make SiC compatible with silicon, then that will seriously reduce its cost. If we look ahead, diamond is the only material better than GaN, but that is most probably more than 20 years away from becoming a reality. Even if developed, experts cannot even get a glimpse of a roadmap to cost-competitive devices yet.

#### POWER DENSITY

GaN offers high efficiency concurrent with high power density. GaN offers almost zero switching losses and lower conduction losses per mm<sup>2</sup>. We see time and time again

### INDUSTRY LOOKS TO GAN

**ALDERMAN IS NOT ALONE** in his enthusiasm for GaN devices, as several individuals from industry and academia here express their thoughts on the technology.

From **Alex Lidow**, *Chief Executive, EPC*:

*"Arnold has it right; there is a big opportunity for someone to launch higher voltage GaN devices!*

*There are two key criteria for a successful 600V GaN product as a MOSFET/IGBT displacement technology:*

*Is it VERY cost effective?*

*Is it VERY easy to use?*

High voltage GaN devices will have a much lower  $R_{DS(ON)}$  per unit area than IGBTs or MOSFETs. I would estimate that first-generation 600V product will be 1/5 the size of an IGBT for the same current handling capability. These products will also have very high frequency capability and an extraordinary switching figure of merit (RQ product).

The technology needed to produce these devices economically is already here. GaN can be grown with device-grade quality on silicon and can be produced in a standard CMOS foundry.

Cost effectiveness will be realized quickly.

The issue will be ease-of-use. Using a high-voltage device at very high frequencies poses many new challenges in drive

electronics. There are no commercial drive ICs with the ability to switch at the high frequencies needed to fully exploit the remarkable new capabilities of GaN.

In June 2009, EPC introduced the first enhancement mode GaN devices with voltage ratings up to 200V. The reception has been extraordinary! In a few months, we will be launching 600V product as well and are now developing solutions that will make the product as easy to use as the MOSFETs and IGBTs that have been so successful in efficient power conversion applications."

From Professor **Umesh Mishra**, *University of California, Santa Barbara*:

*"Thank you for your continued interest in the emergence of GaN and in your role in educating the community about its potential.*

*It is also gratifying that the industry is seriously considering GaN and is open to its insertion into applications.*

*Though difficult (as Mr. Alderman correctly said), high voltage GaN-based devices are inevitable and I imagine will be here within a year or less."*



the present highly efficient converter designs achieved at the expense of power density. Designers, utilizing either silicon superjunction or standard silicon technologies, are intentionally reducing the switching frequency to achieve ultra-high efficiency. Of course, lower-frequency converters require larger power-passive components - especially magnetic elements. So, designers choosing that route are doing so at the expense of power density. I cited in a previous editorial that high-voltage standard silicon transistors were preferred over superjunction devices in ultra-high

efficiency design. GaN offers the opportunity to increase efficiency while raising the switching frequency and thus increasing power density.

So getting back to the low-voltage GaN power switching devices we saw at APEC 2010, I asked, "What have the low-voltage developers achieved?" The response I got from those knowledgeable in that field was that GaN products with ratings of 28 V and 48 V have been available for several years. High volume RF applications use them. However, those working in the low-voltage GaN arena

## WHERE ARE THE HIGH VOLTAGE GAN PRODUCTS? IT'S ALL ABOUT PERFORMANCE PER COST (P/C)

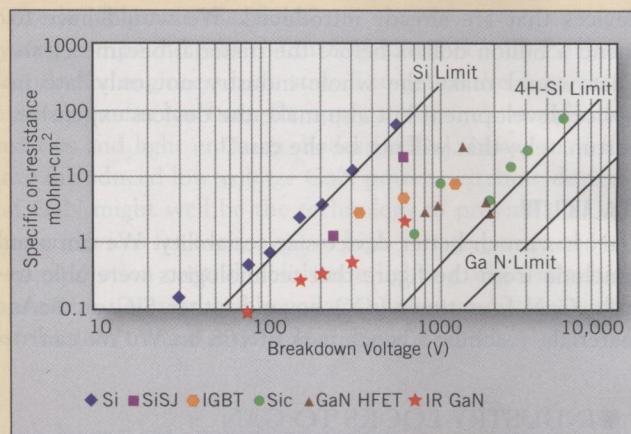
By TIM MCDONALD, VP Emerging Technologies, International Rectifier

**THERE IS A TREMENDOUS INTEREST** in the market today for GaN based power conversion technology. Over the last decade or so, the international research community and corporate researchers have published performance results that clearly demonstrate device figure of merit superiority of GaN based power transistors over conventional silicon based power MOSFETs<sup>1</sup>. Several companies have demonstrated in circuit application performance benefits of GaN based power transistors<sup>2,3</sup> across the voltage range from 12V to 600V and beyond. And most recently, during APEC 2010, International Rectifier became the first company to publicly announce production release of a GaN based power transistor device: the iP20104. The future is bright for this new technology.

Why is GaN performance superior to Silicon? GaN HEMT (high electron mobility transistor) devices, with a wider band-gap than silicon have much higher critical field. Together with high carrier concentration and high mobility, GaN devices offer a superior trade off of specific RDS(ON) (think conduction losses) vs. breakdown voltage rating. With very high mobility, fewer carriers are required to achieve these low conduction losses which translates into low charge and low switching losses as well. Overall, there is a virtuous combination of material properties adding to superior efficiency, density and (with commercialization hurdles conquered) cost for power conversion solutions.

### LOW VS HIGH VOLTAGE GAN

Note from Figure 1 that GaN FOM (Figure of Merit) has been demonstrated superior to silicon across a wide range of voltage. When faced with such a large opportunity for commercialization, development resources must be prioritized. There is an urgent mandate in the low voltage point of load application space for high efficiency and high density which is best met by GaN power devices. As this represents a large market opportunity with rapid adoption rates, IR has chosen to focus in this area first.



1. FOM (Figure of Merit) superiority of GaN based power transistors have been demonstrated across a wide range of voltages.

In addition, IR has already demonstrated excellent 600V device switching performance based on the cost effective GaNpowIR manufacturing platform (Figure 2)<sup>5</sup>. Further, IR has announced a planned 600V product release before the end of calendar year 2011<sup>6</sup>.

Ultimately, as industry further develops the technology, GaN based power FETs should widely displace their silicon counterparts from the range 20 to 1200V.

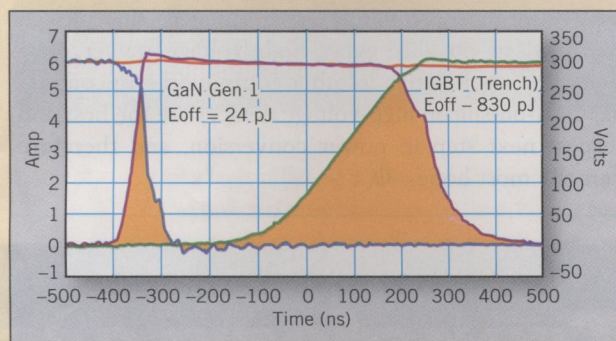
Moving from mere technology demonstration to commercialization and market adoption requires application performance per cost ratio (P/C) competitive with silicon MOSFETs. This makes mandatory a manufacturing platform that is capable of delivering consistent output, high quality and reliability at cost low enough to reach the required P/C.

The iP2010 provides cost effective point of load power conversion where space is a premium and efficiency is a must. Likewise, adoption of 600V GaN based solutions will occur when P/C is compelling and ease of use issues such as assembly and product robustness is demonstrated.



have recently strived very successfully to scale the technology to higher current reaching 40 A or greater. They have achieved large-scale devices as one might expect from the GaN LED scalability exhibited so dramatically in the figure. That is a significant accomplishment! They have proven that GaN is no longer a university technology.

Yet, their path to product success may not be that easy. Unfortunately, low voltage GaN is uncomfortably close to silicon in performance and cost expectations. This will make their road to success difficult.



2. A comparison of switch off energy (EOFF) of IR's 600V prototype GaN based switch (left side) compared to a typical high speed IGBT (right side). Integration of ID and VDS shows a 34X reduction in EOFF for the 600V GaN prototype compared to the IGBT.

## GaN VS SiC

As Figure 1 shows, GaN has almost an order of magnitude better material limited performance potential compared to SiC. But, as stated above, it is P/C that drives market adoption and so the cost factor plays an equal role to performance. GaN on silicon based power conversion benefits from more than 10x lower substrate costs compared with SiC. Additionally, Si substrates are easily available in larger wafer diameters which can be used to drive down wafer fabrication costs. Putting together both performance and cost, P/C of GaN is much, much more than 2x that of SiC.

## REFERENCES

1. N. Ikeda et.al. ISPSD 2008 p.289
2. "GaN Based Power Conversion," Dr. Michael A. Briere, Power Electronics Europe, 2009 Issue 5, pp 23-27 :<http://www.power-mag.com/pdf/issuearchive/30.pdf>
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4. <http://www.irf.com/whats-new/nr100223.html> , and also APEC 2010 Proceedings, Professional Education Seminar: Current State and Future Improvements of GaN Based Power Conversion
5. APEC 2010 Proceedings, Professional Education Seminar: "Current State and Future Improvements of GaN Based Power Conversion"
6. <http://www.irf.com/product-info/ganpowir/GaNAPEC.pdf>

Further, their attempt to scale voltage appears to be somewhat elusive. I have received comments from those who have tested presently available GaN transistors. They advised me that they have experienced a considerable decrease in efficiency when the devices operated at voltages approaching 80% of product voltage rating.

Upon learning of this, I asked how one might minimize this increased power loss. An expert in the field of GaN device development informed me that operating the devices at voltages considerably lower than rated voltage would minimize this increase in power loss.

Considering this to be a waste of device capability, I inquired whether this was an insurmountable problem. He assured me that GaN devices could be made that did not exhibit this phenomenon. I was shown device performance data that proved a GaN transistor, rated for several hundred volts, did not have this significant power loss increase when operated close to its rated voltage. Therefore, we can rest assured that future GaN devices will have excellent voltage scalability.

## HV SEMICONDUCTORS

If we look at the high-voltage compound semiconductor power switching devices, we see a struggling landscape. SiC devices have tried for a decade to get traction with a high-voltage Schottky diode. It performed well, but cost has remained high and it lacked the partner transistor. The high-voltage SiC transistor is finally making its debut - but at what price? It may get some traction in boutique markets, but may still be plagued with yield problems - which will further affect cost.

There is one high-voltage GaN supplier with a diode product purported to be available this year. History has shown that the various previous attempts to introduce a solo diode product are far from stellar ventures - in any technology! For that reason, even if they produce an excellent diode, they may not get enough successful traction in the market unless they also develop the transistor.

As one expert advised me, even though GaN is a high-voltage material, developing GaN product with ratings of 600, 1200, and 1700 V is not a trivial matter. Another shared that GaN is not an easy material to master for high-voltage devices. Although GaN does not require a "perfect material", there are other challenges for designers. Technology papers presented over the past few years cite some of those challenges. Further, if it were easy, power conversion designers would already have devices and would be designing them into their circuits. He concluded by remarking that potentially, designing high voltage GaN into power conversion systems could be a simple process making rapid market adoption a likely scenario.

So from whence will they come? There certainly are a number of players working diligently on GaN technology.



Besides the low voltage players, International Rectifier and Efficient Power Conversion, they include Fujitsu, Furukawa Electric, HRL Laboratories, IMEC, Panasonic, Sanken Electric, Toshiba, and Velox Semiconductor. A recent Google Scholar search indicates both Cornell and University of California at Santa Barbara are very active. Most others cite them both as leading the way to significant breakthroughs.

GaN conversation certainly dominated the Power Conversion and Intelligent Motion (PCIM) Conference in Nuremburg, Germany this year. In the race to be first, potential suppliers are announcing that they will have product "soon". Some promise product by Q3 this year while others are sampling a few prototypes with product promised for 2011. My concern is that while promising product qualification, they are still discussing fundamental changes, such as maybe the product should be vertical rather than lateral. If we are going to get to qualified high voltage GaN product soon, then suppliers should put these issues to bed and provide product! I believe the successful winner in this race will be an entirely new player arriving on the scene with qualified products.

#### THE OPPORTUNITY

The bottom line is that GaN high voltage devices offer promise of a quantum increase in efficiency and power density. Compared to other materials, the GaN time-to-market will be much faster. Development will be less because a large fraction of funds will not have to be spent on fabricating "perfect" GaN material. This will enable companies will ramp up to product development and produce working devices sooner.

Unlike its low-voltage counterpart, high-voltage GaN performance is far removed from the market pressures that competitive silicon or silicon superjunction devices face. Thus, the likelihood of success is significantly greater - as long as the supplier has dedicated focus on the power conversion market. High-voltage GaN offers the remarkable opportunity to positively impact the complete ecosystem (economic, performance, and design structures) of possibly every high voltage power electronic product. Relative to other compound semiconductors, GaN-on-silicon high-voltage devices are the best and cheapest next step in power conversion, and therefore offers the most hope. ☺