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Commercialization of 600V GaN HEMTs

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Abstract

With its proven ability to reduce size (form factor) and save energy (high efficiency) Gallium Nitride (GaN) is now no longer a nice to have, it is a must-have for power conversion. In applications ranging from sub 100 watt ultra-compact high frequency adapters to multi kilo-watt highly efficient PV inverters, GaN makes it possible to do what Silicon cannot. High voltage GaN on Silicon HEMT switches are now a reality, following successful completion of JEDEC qualification as well as establishment of a high voltage lifetime of >10M hours. A large area (6inch) GaN on Si technology and the ability to manufacture in existing high volume Si foundries makes GaN commercially attractive. We will discuss the commercialization of the 600V GaN HEMT at Transphorm - enabled by a superior product, strong IP across the full value chain and a team with deep rooted experience in GaN technology and business. Ultimately GaN will significantly reduce conversion losses endemic in all areas of electricity conversion, ranging from power supplies to PV inverters to motion control to electric vehicles, enabling consumers, utilities and governments to contribute towards a more energy efficient world.

1. Introduction

GaN power product developers have to completely understand technical issues and effectively and reliably introduce early products to surpass performance of the established Si competition. Applications need to be identified where the overall benefit is sufficient to amortize the inevitably higher initial device cost. Gen-1 600-V class EZ GaN™ HEMTs were successfully produced at Transphorm Inc. with the aforementioned considerations. The low on-resistance, low capacitance and high switching frequency for GaN devices enables high conversion efficiency, hence energy savings, in a compact form factor.

2. GaN HEMT Devices and Modules

The GaN switch incorporates a normally-off low-voltage Si device at the input and a normally-on high-voltage GaN HEMT at the output in a cascode configuration. The hybrid device has +2.1V gate threshold and maximum gate swings of ±18V, easily driven by low-cost MOSFET drivers. The on-resistance ranges from 250 to 30 mΩ based on device/module size. Comparing to similarly-rated state-of-the-art Si super-junction (SJ) MOSFETs, the GaN devices offer significant reduction in gate charge, on-resistance, output capacitance and reverse recovery charge. The finished device in TO-220/TO247 and PQFN packages (Table I) also features the Quiet-Tab™ package scheme, with the package base as a low-dV/dt source/drain terminal. Such a configuration allows 200% increase in switching speed with little compromise in induced EMI noises. The FOM of R_{on}*Q_g ~1nVs and R_{on}*Q_{rr} ~8.5nVs, is a significant enhancement already over the mature Si SJ MOSFETs.

Specification	Discretes			
Product	TPH3006PS/PD	TPH3002PS/PD	TPH3006LS/LD	TPH3002LS/LD
	Source Tab (PS) Drain Tab (PD)		Source Dep (LS) Drain Dep (LD)	
Package	TO220	TO220	PQFN88	PQFN88
RDS(ON)Typ. (OHM)	0.15	0.29	0.15	0.29
ID25°C (A)	17	9	17	9
Co(er) (pF)	56	36	56	36
Co(tr) (pF)	110	63	110	63
Qg (ns)	6.2	6.2	6.2	6.2
Trr (ns)	30	30	30	30
Qrr (nC)	54	29	54	29
Vgs(V) (Gate Voltage)	+/- 18	+/- 18	+/- 18	+/- 18

Table I. Transphorm's Qualified 600V GaN Products

The hybrid GaN HEMT is also capable of 3-quadrant operation and has 20 times less reverse recovery charge vs. best Si SJ MOSFETs, making diode-free hard-switched bridge possible. 600-V 2-in-1 modules with on-resistance of 30 mΩ were developed for operation up to several 100 kHz, about 10 times higher than traditional power modules. While advanced packages can be considered as technology develops, they are not gating market adoption. The myth that conventional TO2XX/PQFN/Module packages are not adequate for GaN is untrue. Transphorm products in these packages are reliable with exceptional performance and designed into end applications today.

3. Manufacturing of GaN HEMTs

GaN epi-layers on 4" and 6" Si substrates, were developed to have a low defect density, high 2-DEG mobility and high charge density such that both high breakdown and low channel resistance is achieved. D-mode GaN HEMTs were then manufactured in wafer fabrication facilities available in standard Silicon process lines. The typical breakdown voltage of our packaged 600V rated devices is in excess of 1000V, high temperature leakage is actually lower than Si CoolMOS and all our devices are rated for a spike voltage tolerance of 750Volts [Fig. 1]. Contrary to the popular myth, dislocations do not impact the leakage current levels or reliability in otherwise well designed and optimally manufactured lateral GaN devices.

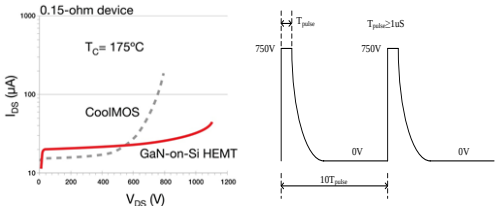


Figure 1. 600V GaN HEMT with low leakage and V_{bd}>1000V along with a standard spike rating of 750V.

4. Control in Production, Qualification and Reliability

High uniformity across the wafer and repeatability across wafer lots are required to enable mass production. This has been systematically achieved by optimized processing and epitaxial growth. Our automated SPC systems monitor several hundred control parameters, including 92 for the standard device for the TPH3006PS (150mohm) HEMT. Amongst these, Fig. 2 shows the SPC of dynamic R_{on} that highlights good dispersion control essential to realizing low on-resistance in switching applications.

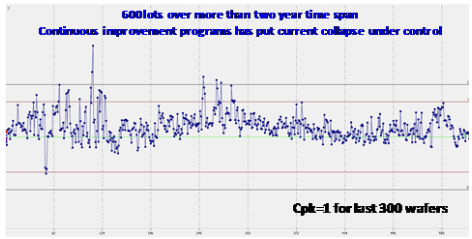
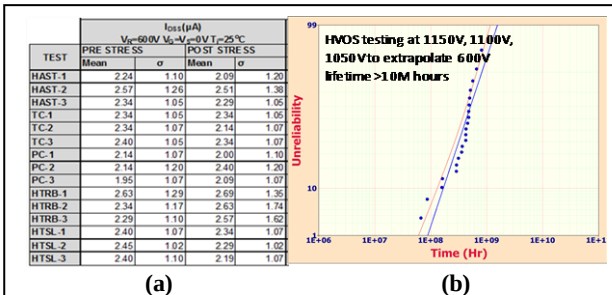


Figure 2. SPC chart of dynamic on-resistance shows well controlled dynamic resistance (at 500V)

Ensuring reliability of products in a new technology is a paramount consideration. Our team has completed both JEDEC qualification of 600V GaN products and for the first time for any power GaN device, established a >10M hour lifetime based on high voltage off state (HVOS) testing, as shown in Fig. 3. Further, through 1:2 400 Watt boost converter testing, we have also completed 3000 hour HTOL with no degradation in any parameter.



TEST	I_{DSS}(μA) V_R=600V V_G=V_S=0V T_C=25°C PRE STRESS Mean	σ	POST STRESS Mean	σ
HAST-1	2.24	1.10	2.09	1.20
HAST-2	2.57	1.26	2.51	1.38
HAST-3	2.34	1.05	2.29	1.05
TC-1	2.34	1.05	2.34	1.05
TC-2	2.34	1.07	2.14	1.07
TC-3	2.40	1.05	2.34	1.07
PC-1	2.14	1.07	2.00	1.10
PC-2	2.14	1.20	2.40	1.20
PC-3	1.95	1.07	2.09	1.07
HTRB-1	2.63	1.29	2.69	1.36
HTRB-2	2.34	1.17	2.63	1.74
HTRB-3	2.29	1.10	2.57	1.62
HTSL-1	2.40	1.07	2.34	1.07
HTSL-2	2.45	1.02	2.29	1.02
HTSL-3	2.40	1.10	2.19	1.07

(a) (b)

Figure 3(a). Pre and post stress 600V off state leakage mean and standard deviations showing little change across all qual tests and lots. (b) HVOS testing demonstrating >10M hours lifetime

5. Demonstrated application and system benefit

Powered by higher performance, reliability proven product, Transphorm GaN is being adopted in variety of applications ranging from power supplies to adapters to PV inverters. Fig. 4 shows a 200 Watt power supply reference board that is significantly smaller and more efficient than a similar rating state-of-the-art Si based power supply.

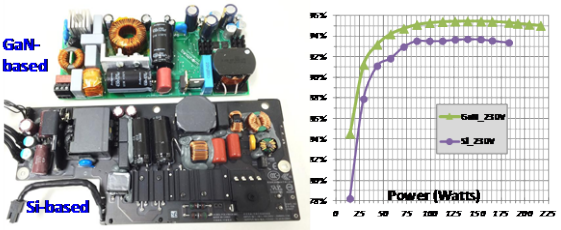


Figure 4. A compact 200W "All-in-One" power supply reference kit with Transphorm 280 mohm GaN product: 45% size reduction and 1.5-3% efficiency improvement vs. Si super-junction solution.

Fig. 5 shows key value of GaN in PV Inverter systems, where Transphorm GaN modules enable a 40% size reduction and 98% efficiency (40% loss reduction) for a 4.5kW PV power conditioner vs. an IGBT based solution (developed by Yaskawa Electric). The significant size and performance improvement enables a cost effective system.

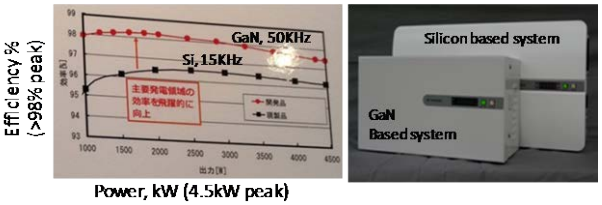


Figure 5. GaN modules designed into compact 4.5kW PV power conditioner with 98% efficiency and 40% reduced volume as well as fan-free, low noise operation (Data Courtesy Yaskawa Electric)

6. Scaling Manufacturing

Through our integration with Fujitsu's GaN business, the subsequent formation of Transphorm Japan and a partner foundry relationship with Fujitsu Semiconductor, we are successfully transferring our qualified process into Fujitsu's mass production foundry (automotive class qualified) in Aizu Wakamatsu. A fully CMOS fab-line compatible gold free 6-inch GaN on Silicon process is already running with data till date indicating excellent yields and good performance in early qualification testing.

7. Intellectual Property

A key enabler behind the successful commercialization of our GaN products has been the deep and broad IP ranging from materials to device structures to fabrication process to packaging and circuit applications. As seen before in the business case of GaN LEDs, it is nearly impossible for companies with weak IP to enter the market in any significant fashion. To that end, Transphorm, with its dominating portfolio with 1100+ patents/patent applications is a clear leader, well poised to ramp the GaN power business.

8. Summary

These first generation GaN power products are just the beginning of a long journey in redefining power conversion for a more energy efficient world. Transphorm has established GaN as a new power conversion platform and is ready to meet its customer needs for this exciting mission.