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650 Volt GaN Quality and Reliability- Readiness for Automotive Applications

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Abstract

With its proven ability to reduce size and save energy 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 to multi kilowatt power converters and inverters, GaN HEMT's high switching speed and high efficiency make it a natural choice instead of Silicon devices reaching their physical limits of performance. Transphorm has already commercialized JEDEC qualified GaN HEMT power switches manufactured in automotive grade 6 inch Si-CMOS fab [1,2]. With this strong base and its ability to reduce size and improve efficiency, GaN HEMTs are extensively being investigated for EV & HEV applications such as on-board-chargers. In this paper we present results for highly stressed robustness tests and Cosmic-ray induced single event burnout(SEB), demonstrating suitability of GaN for automotive applications.

1. Introductions

We have conducted several AEC-Q101[3] based qualification and robustness tests such as extended HTRB and HAST, high voltage intrinsic life-test, Cosmic-ray SEB. In this paper we demonstrate successful preliminary results. These strong results are based on our robust GaN HEMT manufacturing process with defect density improved to match automotive Si-CMOS LSI devices in the same wafer fab.

2. Experiment Procedure and Results

Fig. 1 and 2 show the 650 V normally-off cascode GaN HEMT utilizing a high voltage GaN HEMT on Silicon device grown by MOCVD, and an integrated low voltage Si-MOSFET. Electrical characteristics of the Normally-off cascode GaN power switch are summarized in Table I with low Rds(on), low gate charge (Qg) and low capacitance (Coss) that enable high efficiency, small form factor power systems. The Ron*Qg or Ron*Coss figure of merit is already better than mature Silicon Super-junction MOSFETs (Table 1) with superior reliability of our 650 V GaN. Fig. 3 shows the defect density trend normalized to Si CMOS products in the same fab using over one year data illustrating same defect density as Si-CMOS products for last seven months. Table II shows summary of the JEDEC qualification successfully completed for 77 samples, 3 Lots, a first for 650V GaN. We have extended this to 5,000 hours of HTRB (5x JEDEC) with no degradation in Rds(on), Idss or Vth. Accelerated SEB results in table III show the terrestrial SEB rate less than 1.5 FIT at 600V while commercial Si power MOSFETs have more than several hundred FIT error[4]. Systematic high voltage off-stage (HVOS) acceleration at over 1100 volts was done to determine intrinsic lifetime of over 100M hours (MTF) and 1% failure of more than 1M hours (Fig 4). These results show our GaN power switch is reliable and ready for automotive applications. Full results of the first GaN AEC-Q101 qualification will be presented at the conference.

3. Conclusions

More than JEDEC qualification, HVOS test and the terrestrial cosmic ray SEB results show commercial GaN power transistor is reliability for automotive applications. It is noted the SEB is much better than commercial Si power MOSFETs.

References

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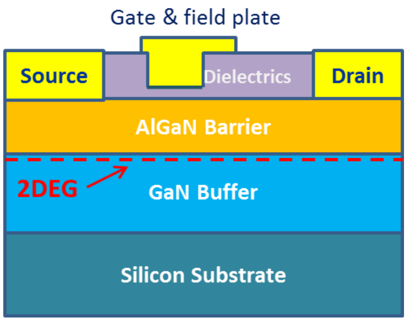

Fig. 1: Simplified cross sectional view of the 650 V GaN HEMT.

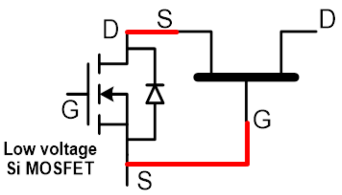

Fig. 2: Cascode configuration using a 650 V normally-on GaN HEMT and a low voltage Si-MOSFET driver: Benefits include Robust solution, Use of standard drivers with high safety margin, Adjustable Vt

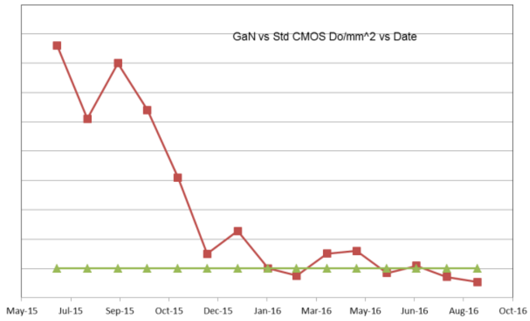

Fig. 3: Defect density normalized to Si CMOS products in the same fab.

Table I: Electrical characteristics of the cascode GaN power switch (52mohm typical Rds(on) device) compared with a similar class Silicon CoolMOS

Technology	GaN	CoolMOS	CoolMOS
Part #	TPH3205WS	IPW65R08CFD	IPW65R065C7
Ron (mohm)	52	72	58
Qg (nC)	28	167	64
Qrr (uC)	0.14	1.00	10.00
Ron*Qg (nVs)	**1.46**	**12.02**	**3.71**
Ron*Qrr (nVs)	**7.02**	**72**	**580**

Table III: Accelerated cosmic ray SEB test results equivalent for 10^8 hours demonstrate the terrestrial SEB rate less than 1.5 FIT at 600V. Neutron source was RCNP at Osaka University.

Test	Condition	1.3×10^9 n/cm²
Accelerated cosmic ray SEB	600V	0 fail/3 parts
	800V	0 fail/3 parts

Table II: Summary of key JEDEC qualification test results.

TEST	SYMBOL	CONDITIONS	SAMPLE	PASS CRITERIA
High Temperature Reverse Bias	HTRB	TJ=150°C, V_{DS} = 520V 1000 HRS	3 lots, 77 parts per lot 231 total parts	0 Fails
Highly Accelerated Temp and Humidity Test	HAST	130°C, 85% RH 33.3 PSI, Bias = 100V, 96 HRS	3 lots, 77 parts per lot 231 total parts	0 Fails
Temperature Cycle	TC	-55°C / 150°C, 2 Cycles / HR, 1000 Cycles	3 lots, 77 parts per lot 231 total parts	0 Fails
Power Cycle	PC	25°C / 125°C ΔT = 100ºC, 7500 Cycles	3 lots, 77 parts per lot 231 total parts	0 Fails
High Temperature Storage Life	HTSL	150°C 1000 HRS	3 lots, 77 parts per lot 231 total parts	0 Fails

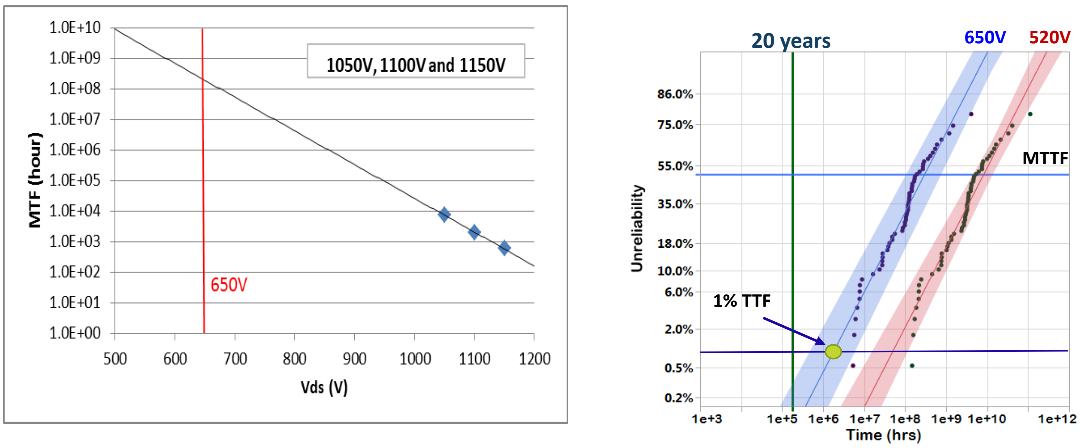

Figure 4. Intrinsic lifetime under high electric field (Voltage) stress by HVOS testing: 1% life of > 1 Million hours at 650 volts, sufficient for automotive applications