FOR ENERGY EFFICIENT INNOVATIONS

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ON Semiconductor WBG Ecosystem

Mehrdad Baghaie Yazdi

Head of WBG Applications

Webinar Overview

SiC Ecosystem:

- MOSFET
- Diodes
- Driver

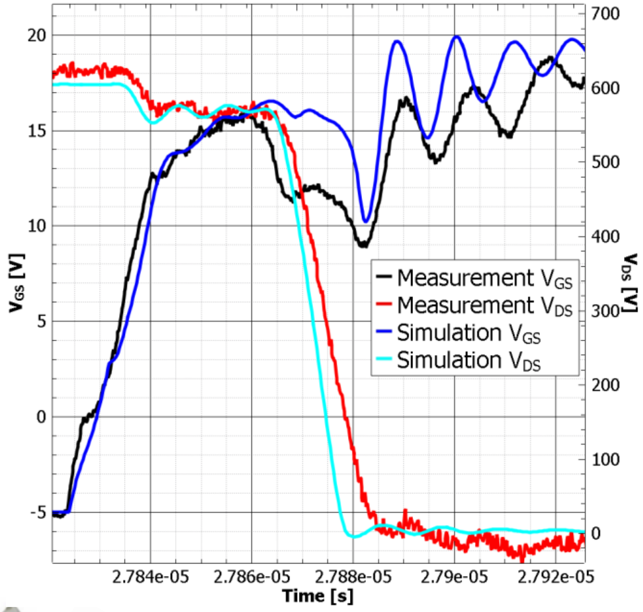
GaN Ecosystem:

- GaN Development
- GaN Driver

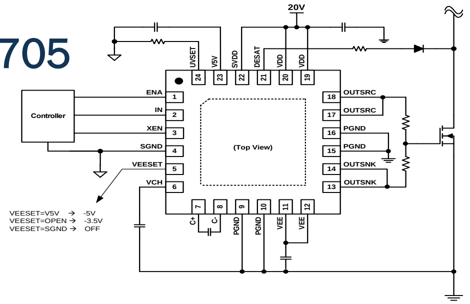
ON Semiconductor WBG Ecosystem - SiC

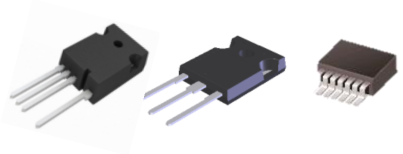
ON Semiconductor provides a unique Ecosystem focused around WBG solutions

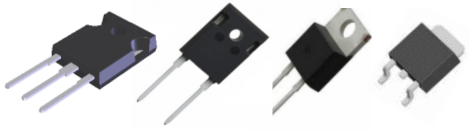
- SiC Diodes geared towards ruggedness
- SiC MOSFETs geared towards ruggedness and speed
- SiC drivers designed for WBG devices
- SPICE based Physical Models for MOSFETs and Diodes



NCP51705







* Similar developments for GaN

What do we offer

Device Content	TO220 -2L	TO220 -3L	TO220 -FP-2L	TO247 -2L	TO247 -3L	TO247 -4L	DPAK	D2PAK	D2PAK -7L	8x8 PQFN	A1HPM	A3HPM	Q0	Q1	Q2	F1	F2	I/APM -650V	I/APM -1200V
650V	Released	Released	Released	Released	Released	Released	Released	Released		Released						Released		In Development	
1200V	Released			Released	Released	Released	Released	Released				In Development	Released	Released	Released		Released		
1700V				Released															
650V					In Development	In Development			In Development										
900V					Released	Released			Released		In Development	In Development				Released			
1200V					Released	Released			Released		In Development	In Development	Released			Released	Released		In Development
1700V					In Development	In Development			In Development										

✓ In Development ✓ Released

ON Semiconductor SiC MOSFET

Differentiators

We care about Customer Pain

SiC MOSFETs have been around since 2011, however the market adaptation has only been picking up in the last two years. Customers still have many questions and there are no JEDEC or AEC-Q101 standardizations yet.

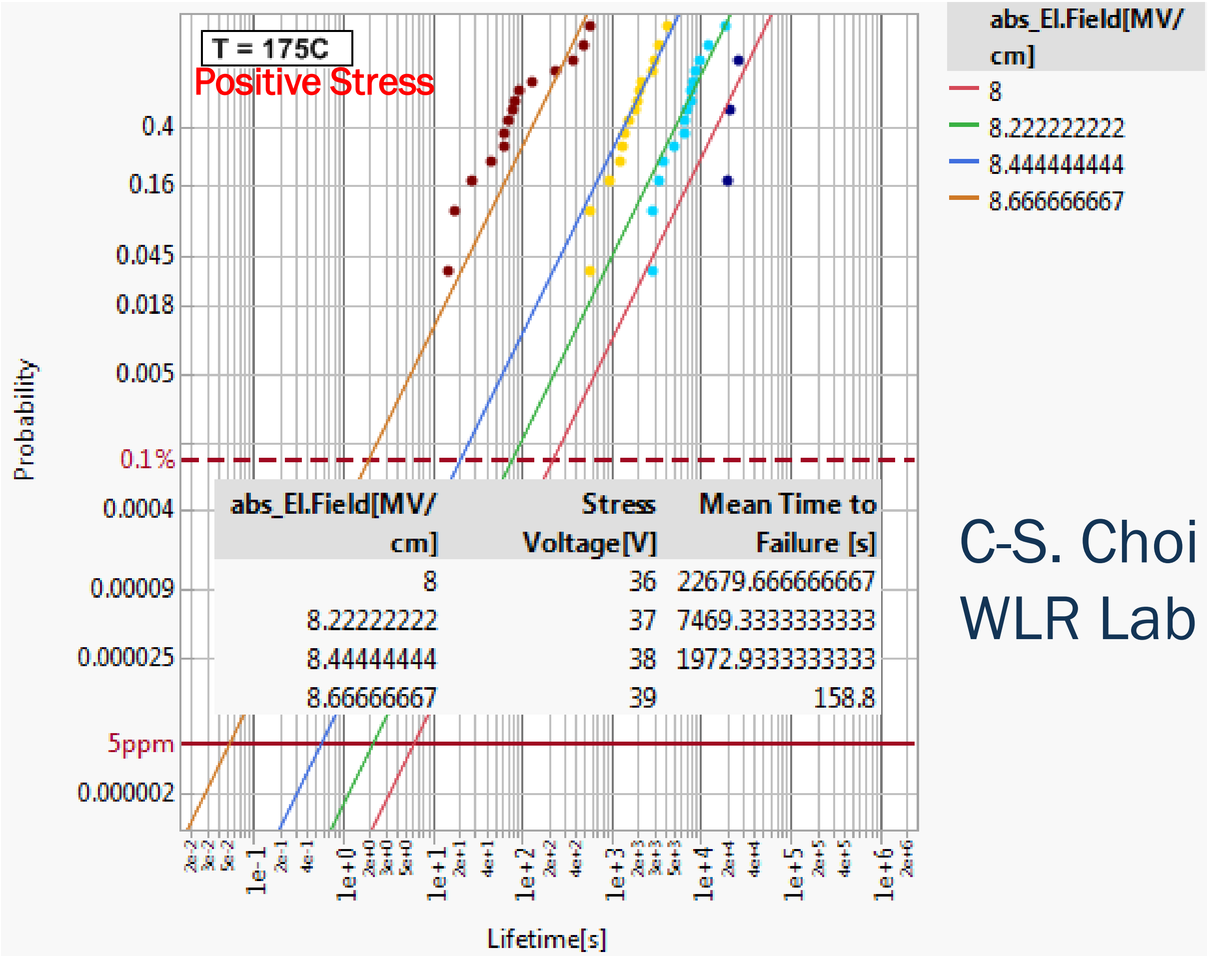
Common Concerns:

- Reliability: Oxide
- Reliability: V_{th} drift
- Reliability: Switching speed
- Usability: Gate drive
- Usability: dv/dt control
- Usability: Body diode

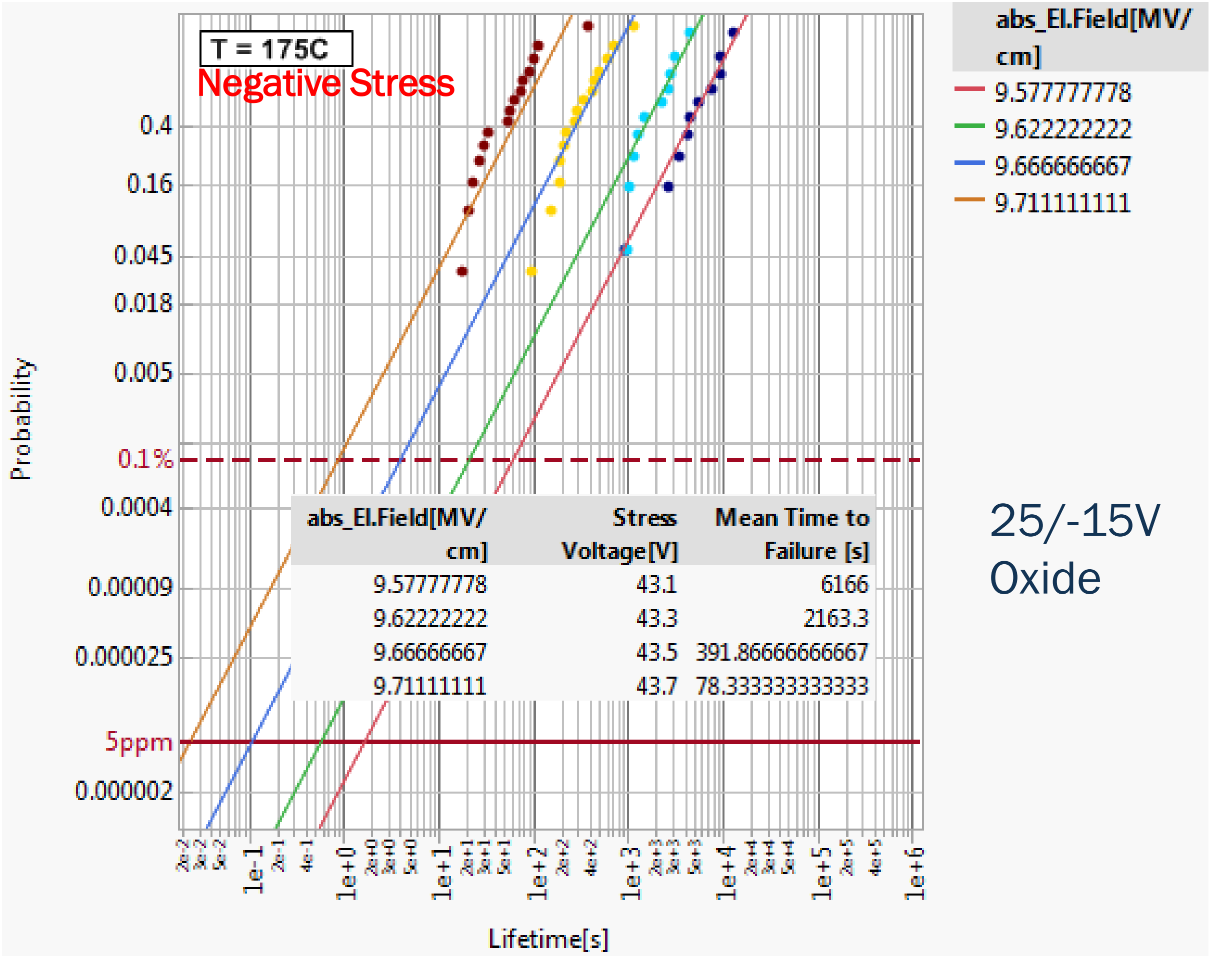
ON Semiconductor has spend a good part of the Gen1 development to study, understanding and fix unkown and newly discovered failure modes.

Oxide Reliability

WLR: TDDB for 20 mohm dies – Oxide reliability



abs_El.Field[MV/cm]	Stress Voltage[V]	Mean Time to Failure [s]
8	36	22679.666666667
8.22222222	37	7469.3333333333
8.44444444	38	1972.9333333333
8.66666667	39	158.8

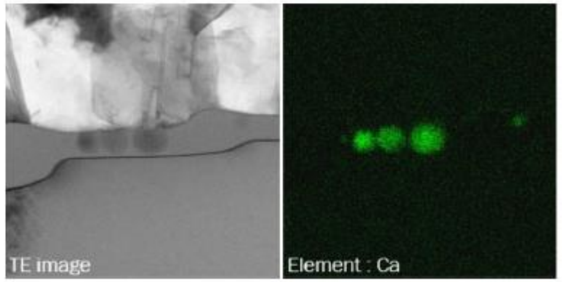


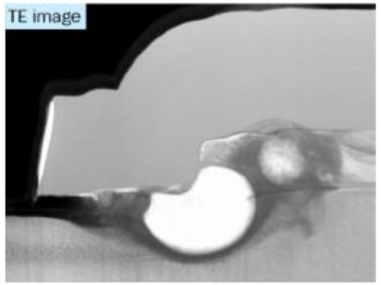
abs_El.Field[MV/cm]	Stress Voltage[V]	Mean Time to Failure [s]
9.57777778	43.1	6166
9.62222222	43.3	2163.3
9.66666667	43.5	391.86666666667
9.71111111	43.7	78.333333333333

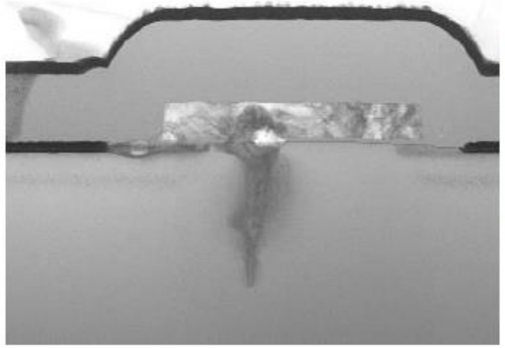
- Good TDDB results both for positive and negative bias TDDB, weak devices not observed with negative bias

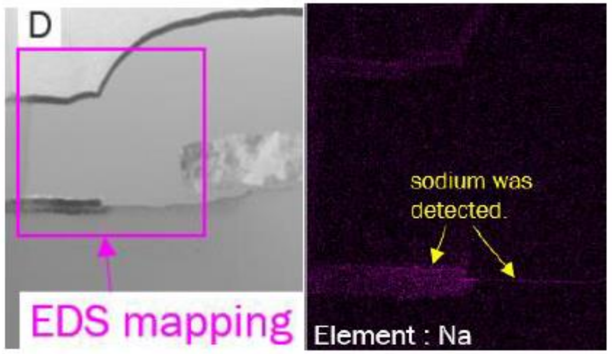
Burn-In

Typical failure cases for GOX (HTGB – burn-in):

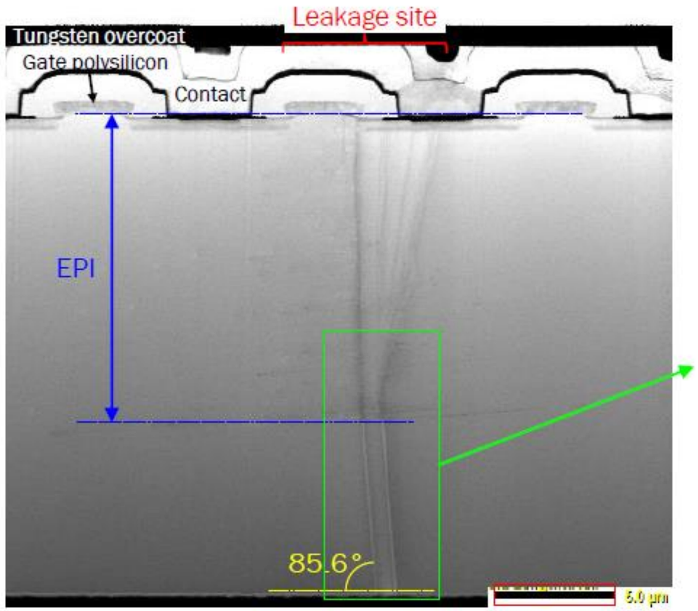








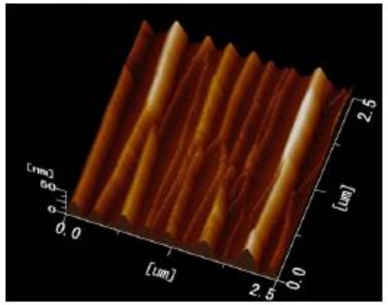
...caused by typical Fab contaminations and process imperfections

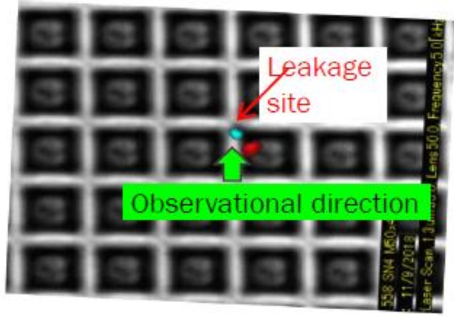


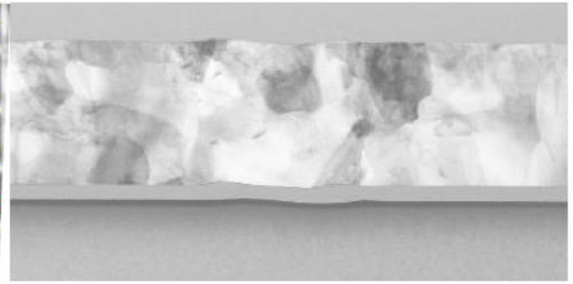
Correlation between surface morphology and breakdown characteristics of thermally grown SiO_2 dielectrics in 4H-SiC MOS Devices

Yusuke Uenishi[a], Kohei Kozono[a], Shuhei Mitani[b], Yuki Nakano[b], Takashi Nakamura[b], Takuji Hosoi[a], Takayoshi Shimura[a], Heiji Watanabe[a]

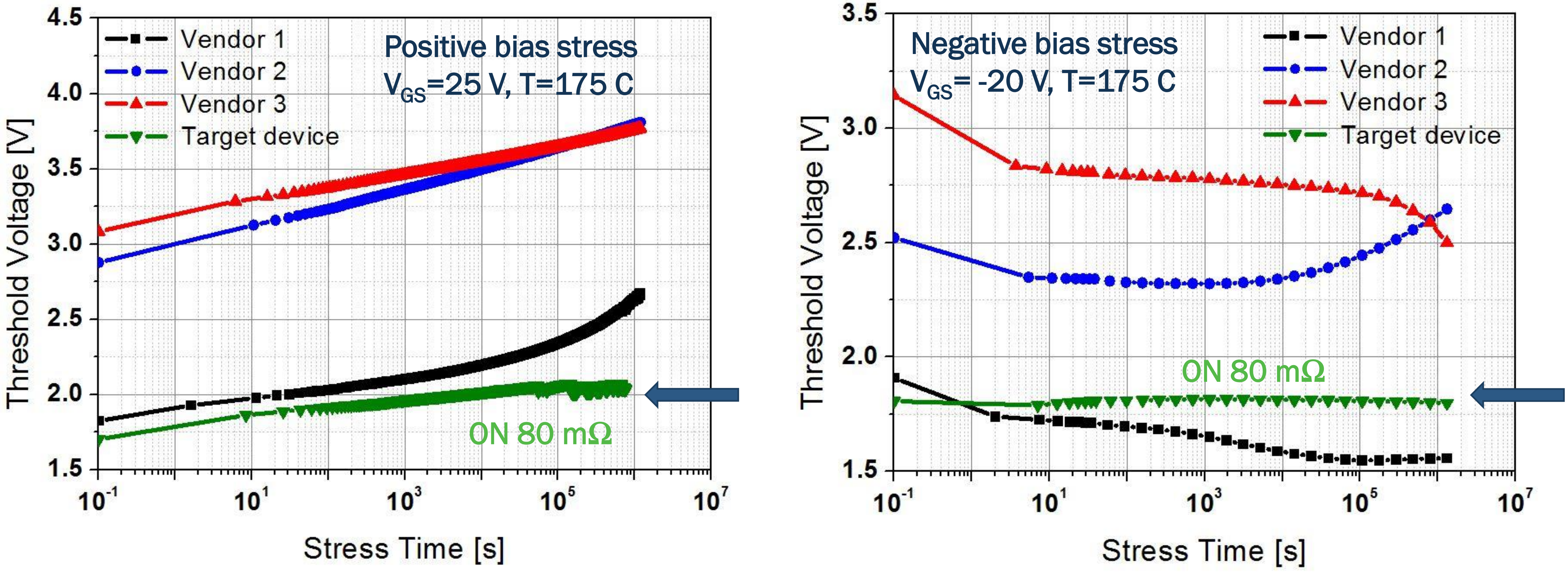
and material defects/roughness







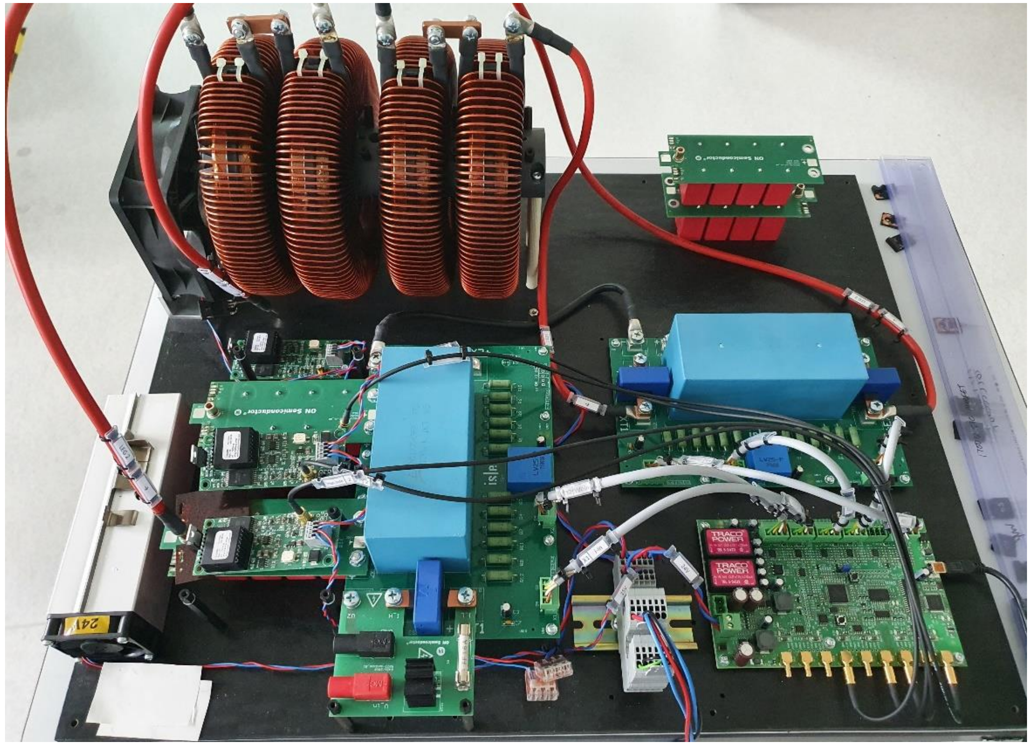
V_{TH} stability during gate bias stress vs. some competitors



- V_{TH} drift comparison with some competitors during gate bias stress
- Very good V_{TH} stability with nearly flat V_{TH} with V_{GS}= -20 V at 175 C
- First ON SiC MOSFET product rated for V_{GS}= -15 V at 175 C

Dynamic Reliability

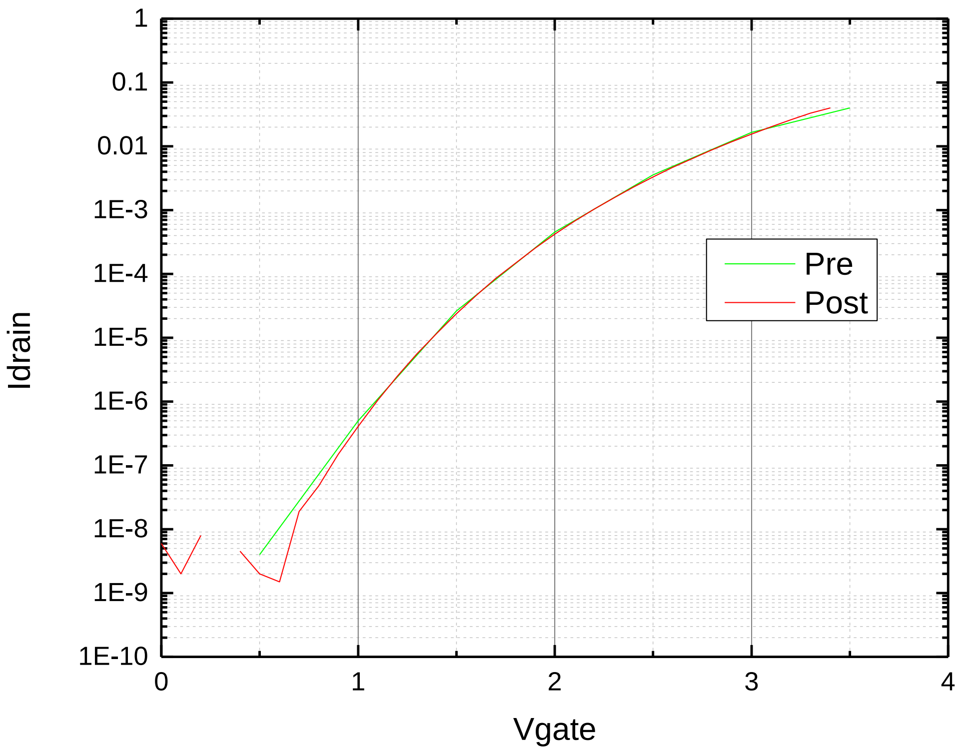
Test Circuit for reliability Testing of MOSFET and Body Diode

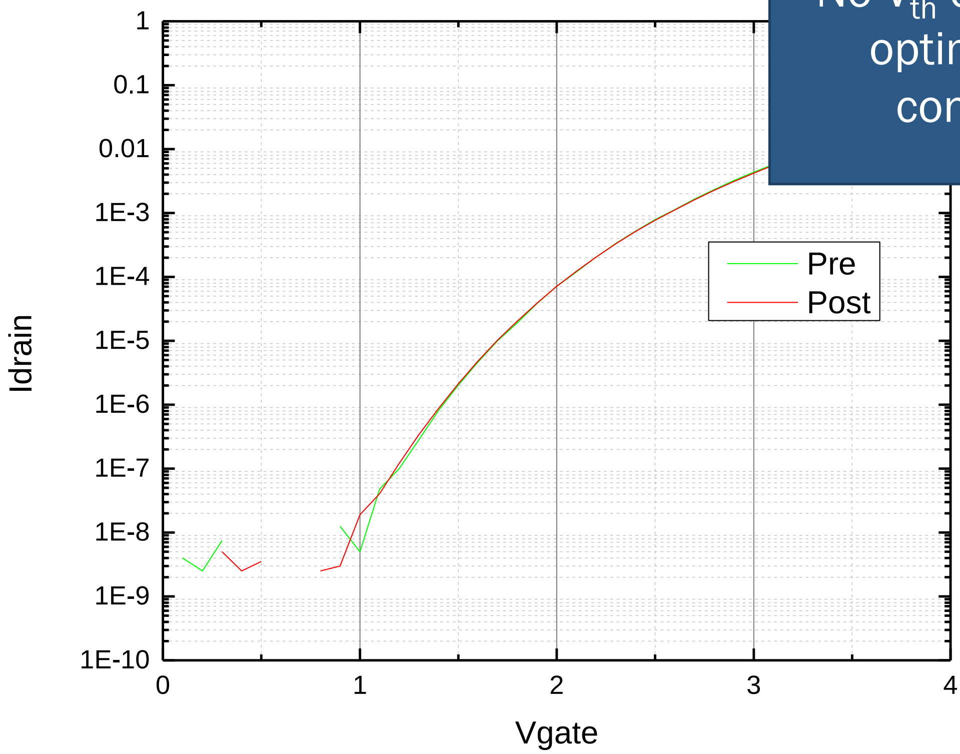


ON Semiconductor requires its SiC MOSFETs to undergo repetitive continuous operation tests (168 h). Where both **Body-Diode** and **MOSFET** are stressed at different **dv/dts**, I_{DS} and **frequencies**

- H-Bridge in Continuous Conduction mode – Hard Switching
- V_{DC} = up to 1000 V
- I_{load} = up to 60 A
- f_{sw} = from 25kHz to 300 kHz
- T_J = from RT to 200 °C
- Test duration = up to months
- R_{gon} = 100-0 Ohm (variable)
- R_{goff} = 100-0 Ohm (variable)
- V_{GS} = +22 to -6 V

Additional Results

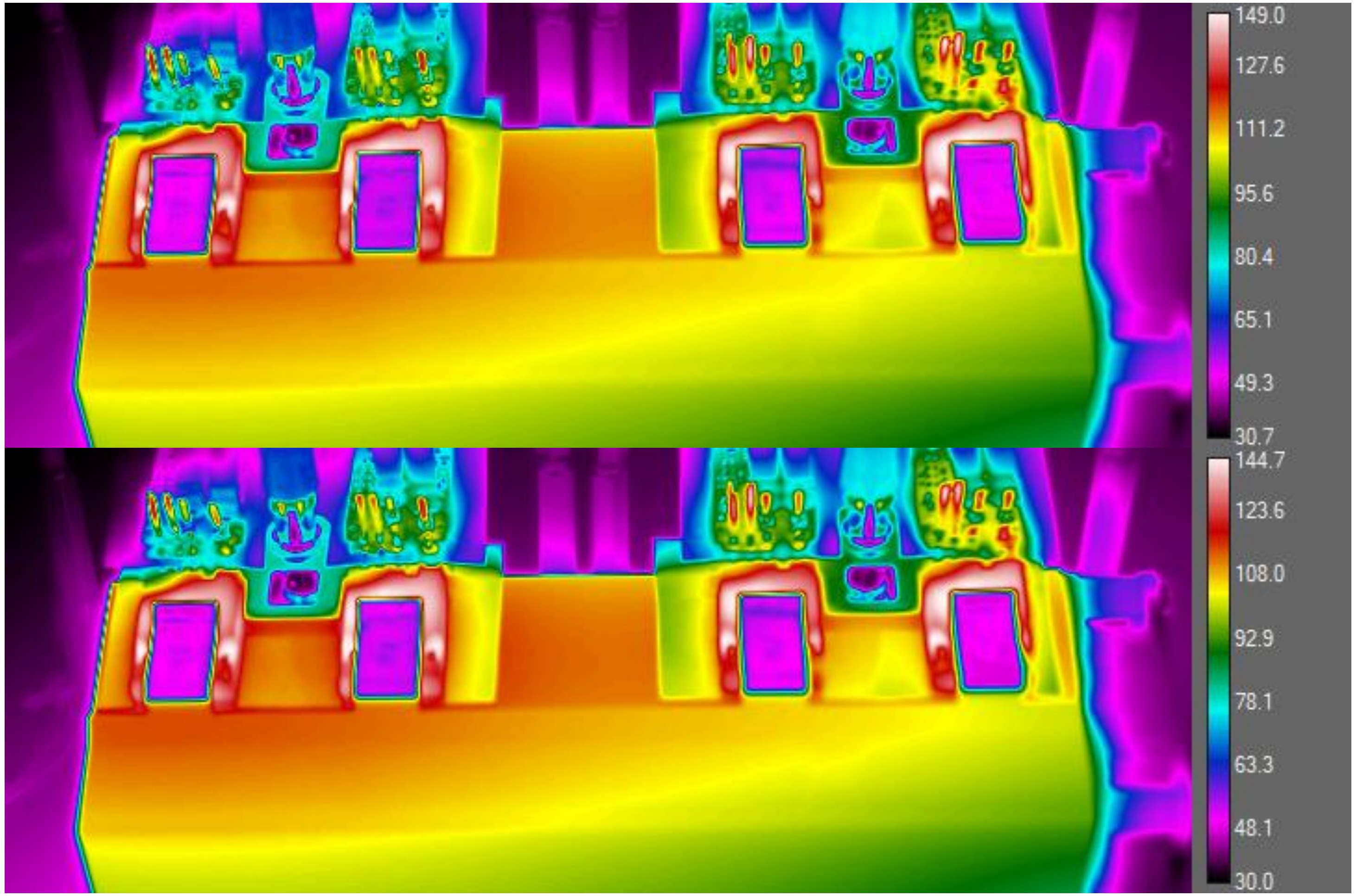


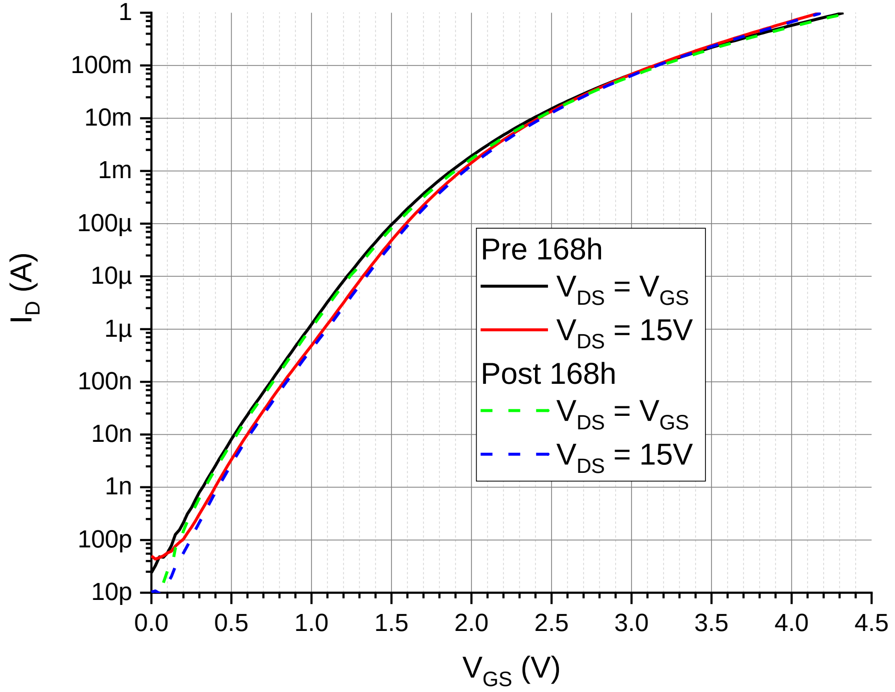


No V_{th} drifts under optimal drive conditions

In addition examining samples for V_{th} shift, at random among all LOTs that have undergone 168 h operation, no drift can be seen. (dv/dt_{max} roughly 50V/ns)

168h continuous switching results





168h switching

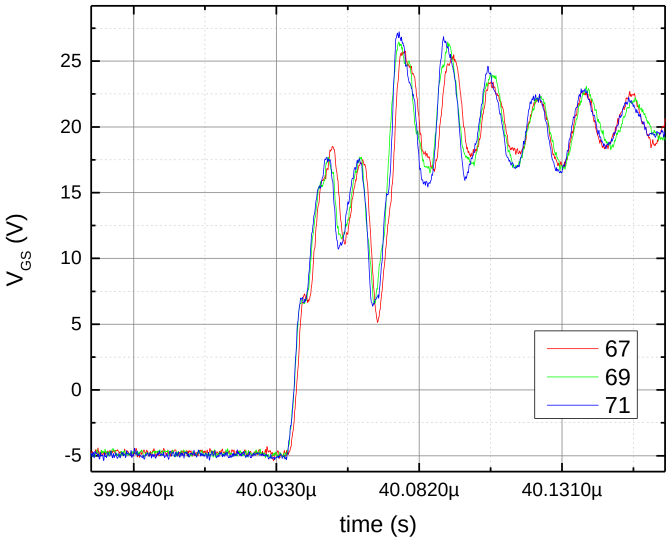
V_{DD}=400V, d=40%, I_{av}=30A, R_G=5.1Ω

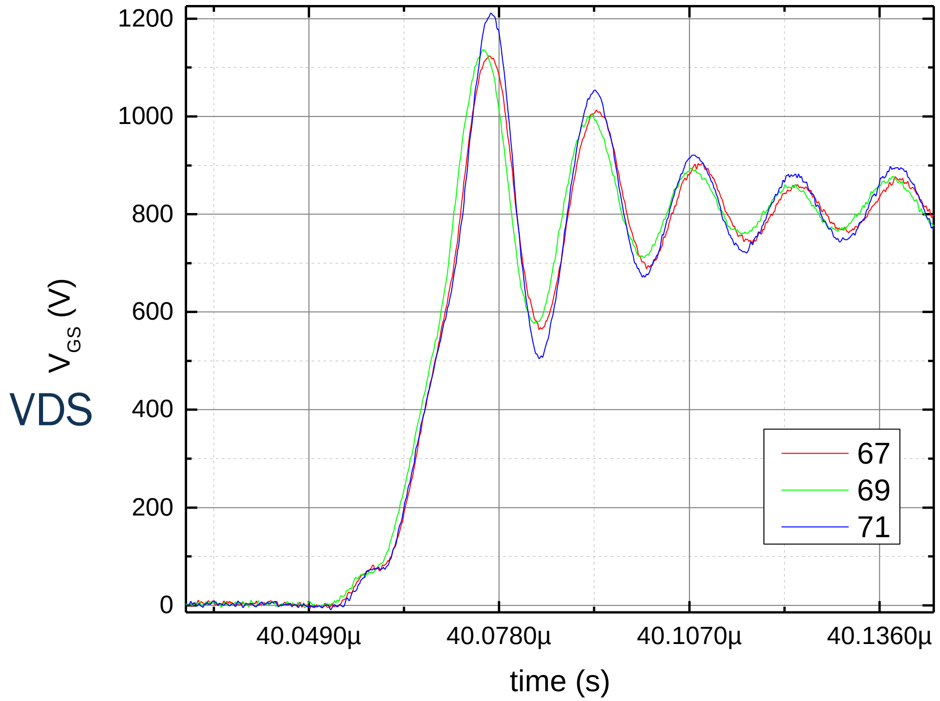
T_C=140°C…149°C

No gate leakage or parameter drifts after 168h

Dynamic Controllability

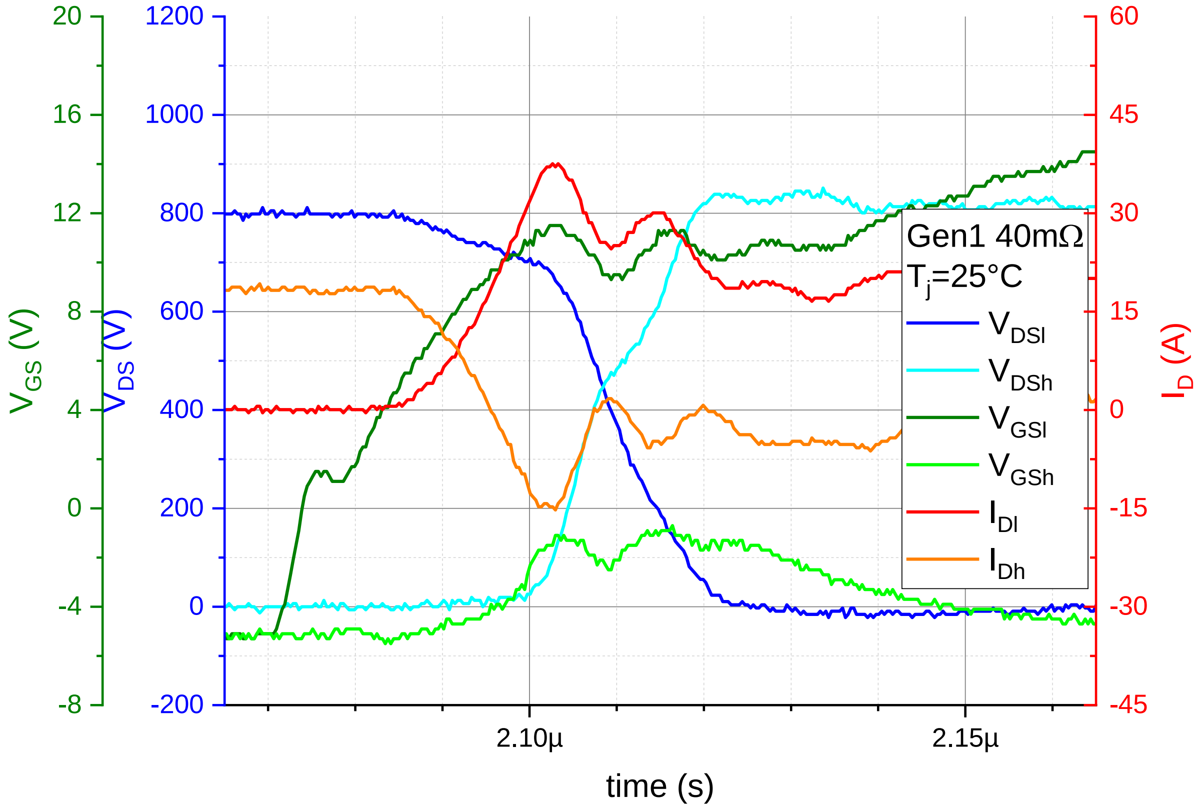
ON Semiconductor SiC MOSFETs dv/dt stability

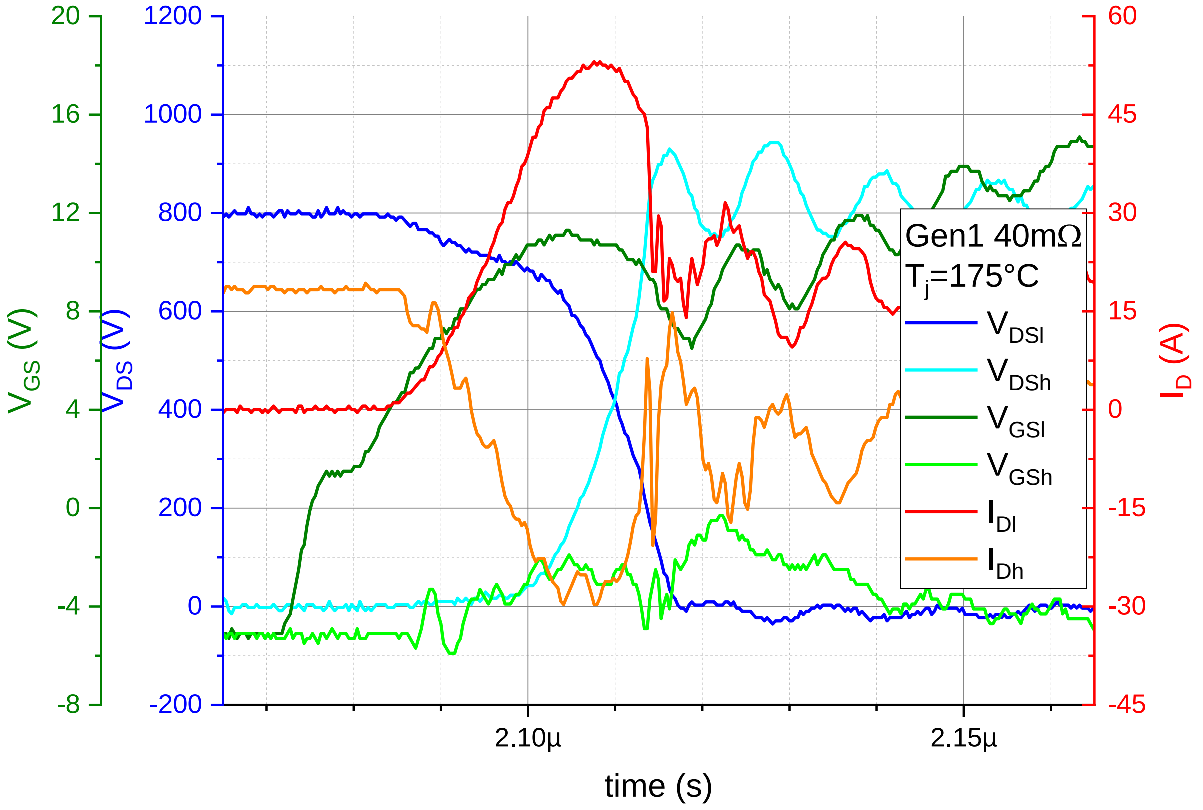




Thanks to advanced testing and robust design ON Semiconductor SiC MOSFETs are immune to transients up to and above 100 V/ns

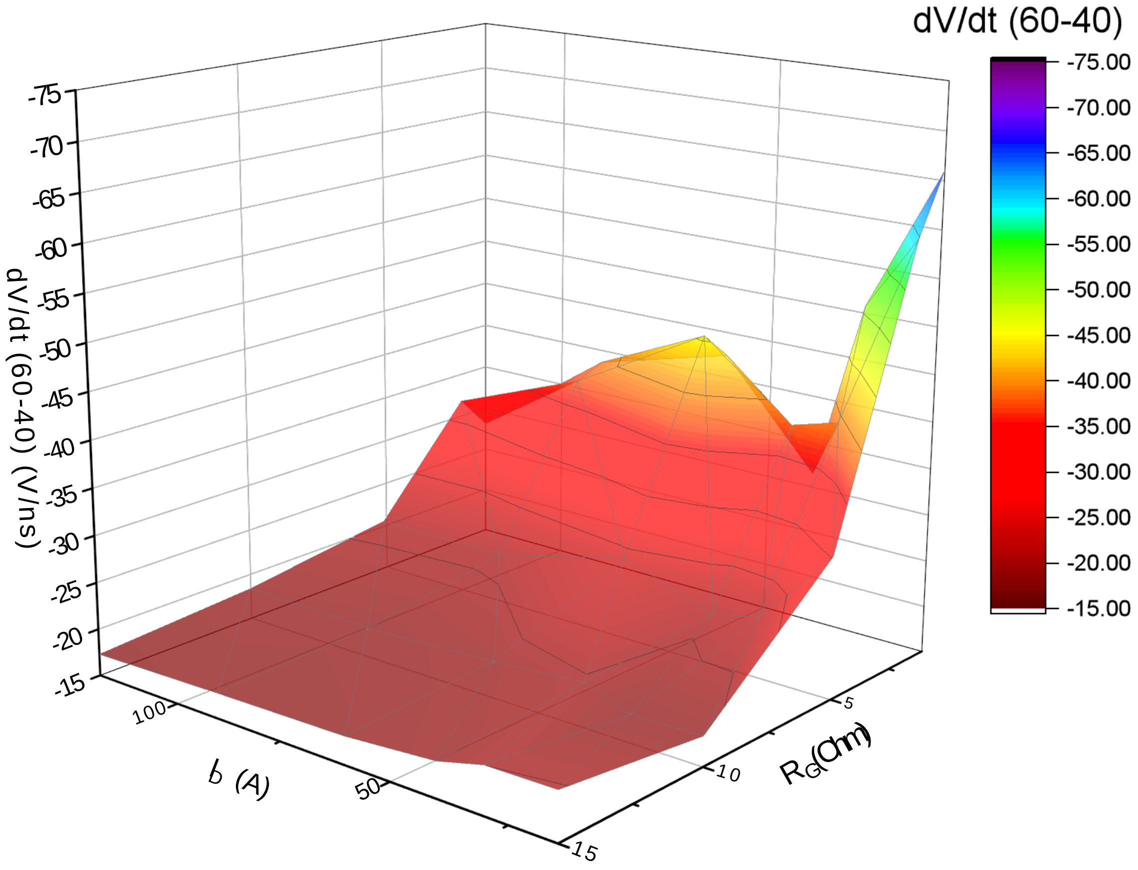
Gen1 1200V 40mOhm Turn-On

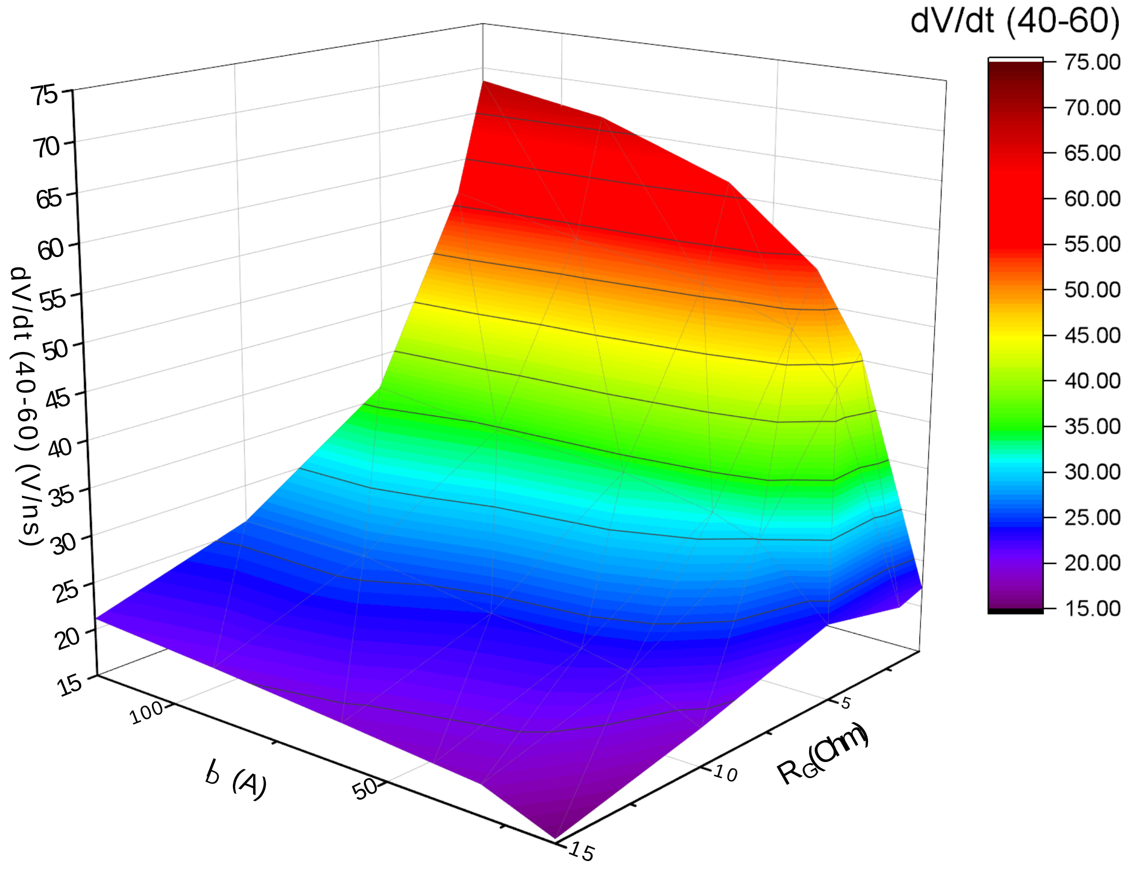




- Gen1 40 mOhm, no observable overshoots beyond SOA
- Low snappyness of the body diode

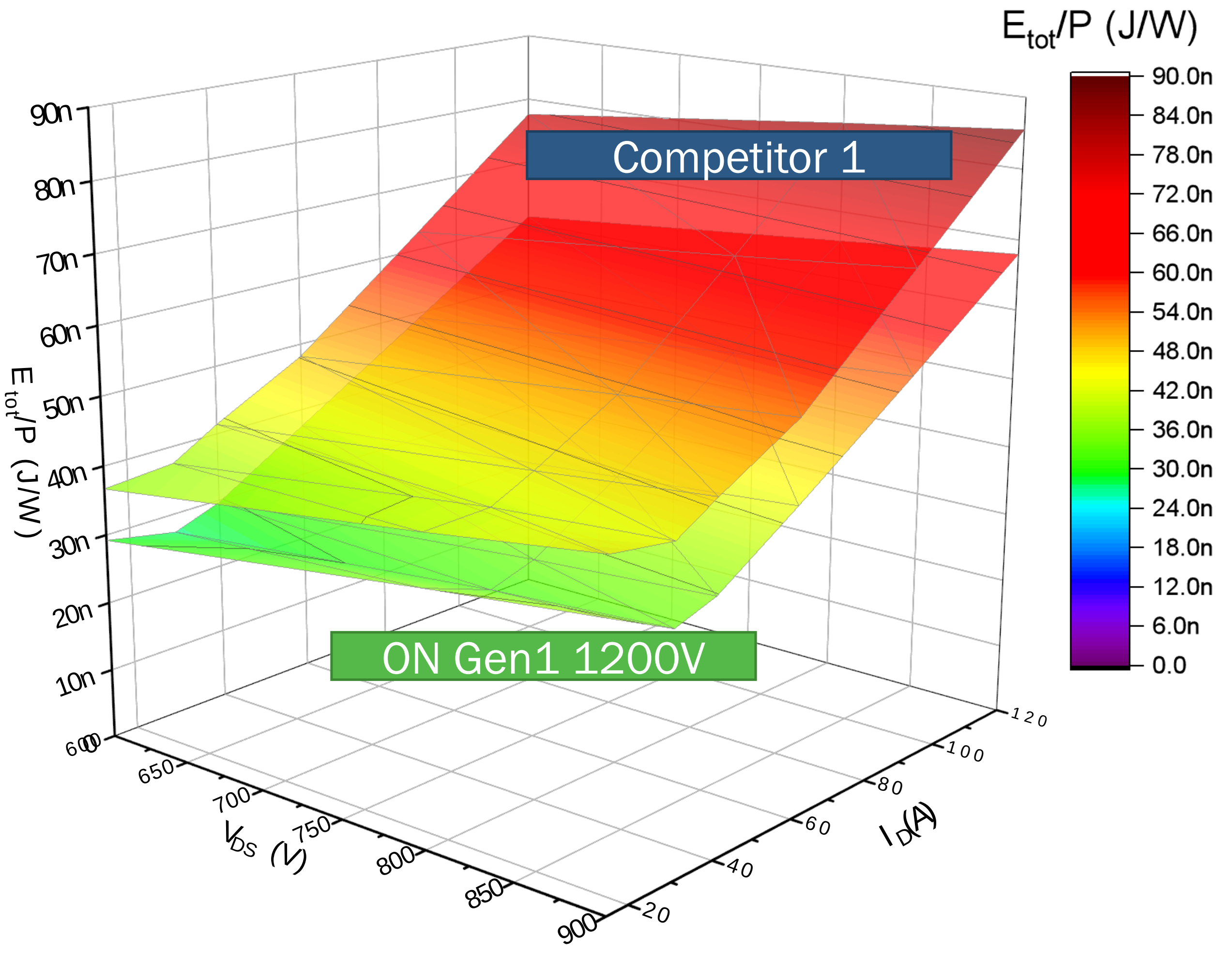
Device speed over R_G and I_D





Both voltage slopes (60-40%) can easily be adjusted by the external R_G. Both slew rates can be controlled in all current regions with dominating R_G influence. Even with low R_G values, the switching remains stable despite parasitic oscillations.

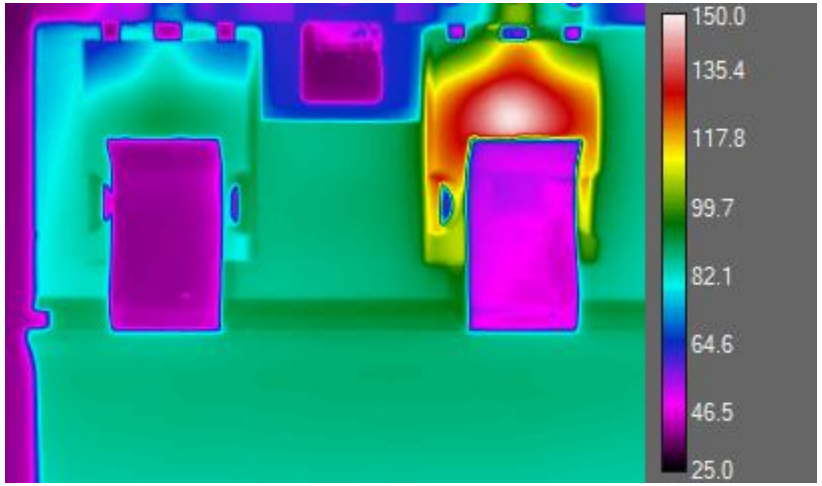
Switching energy comparison



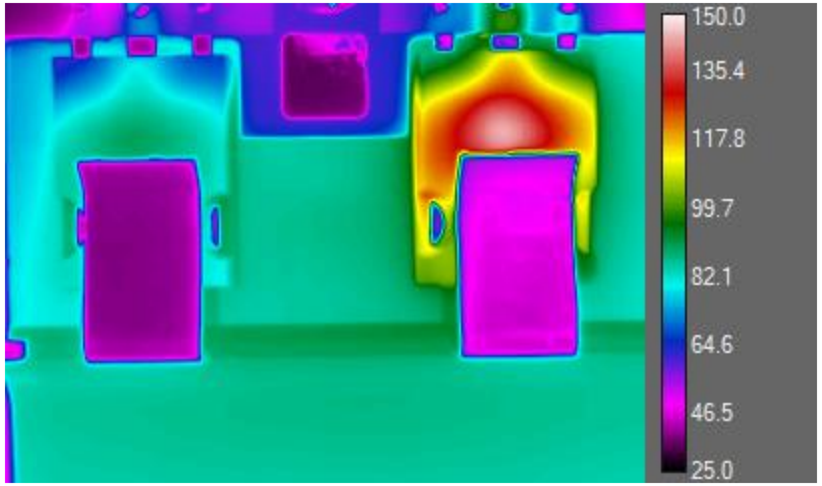
Looking at the entire switching loss matrix over various load conditions ON Semiconductors Gen1 shows excellent behavior compared to other similar planar SiC MOSFETs.

Body Diode Operation

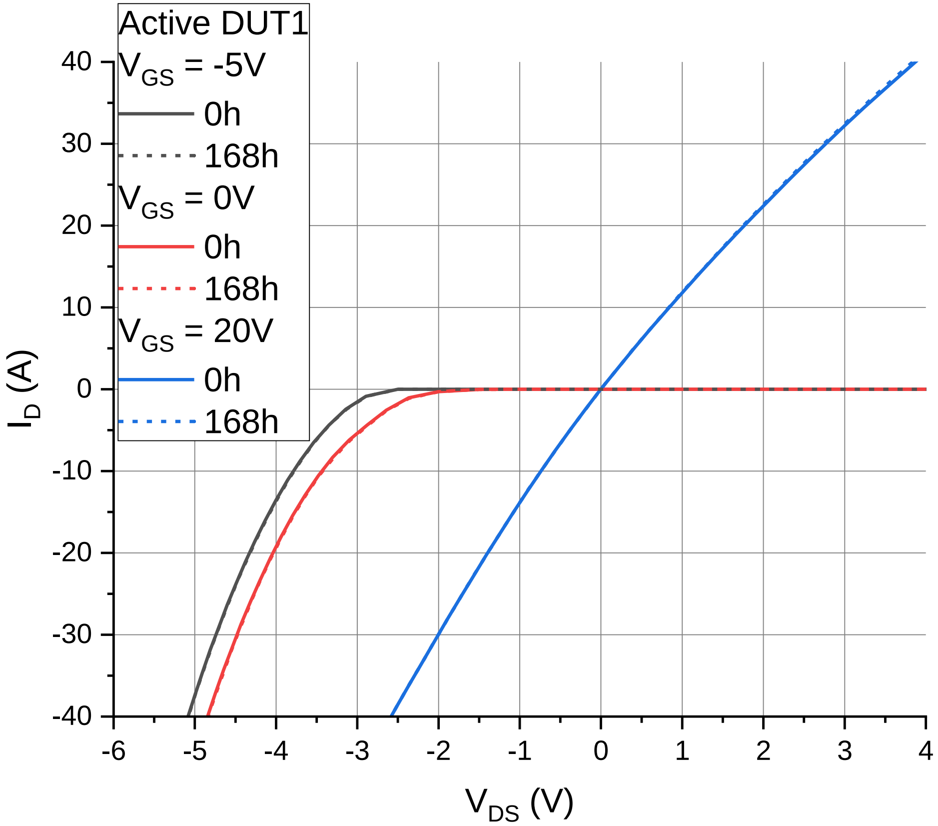
Reliability under worst operating conditions



t = 30min

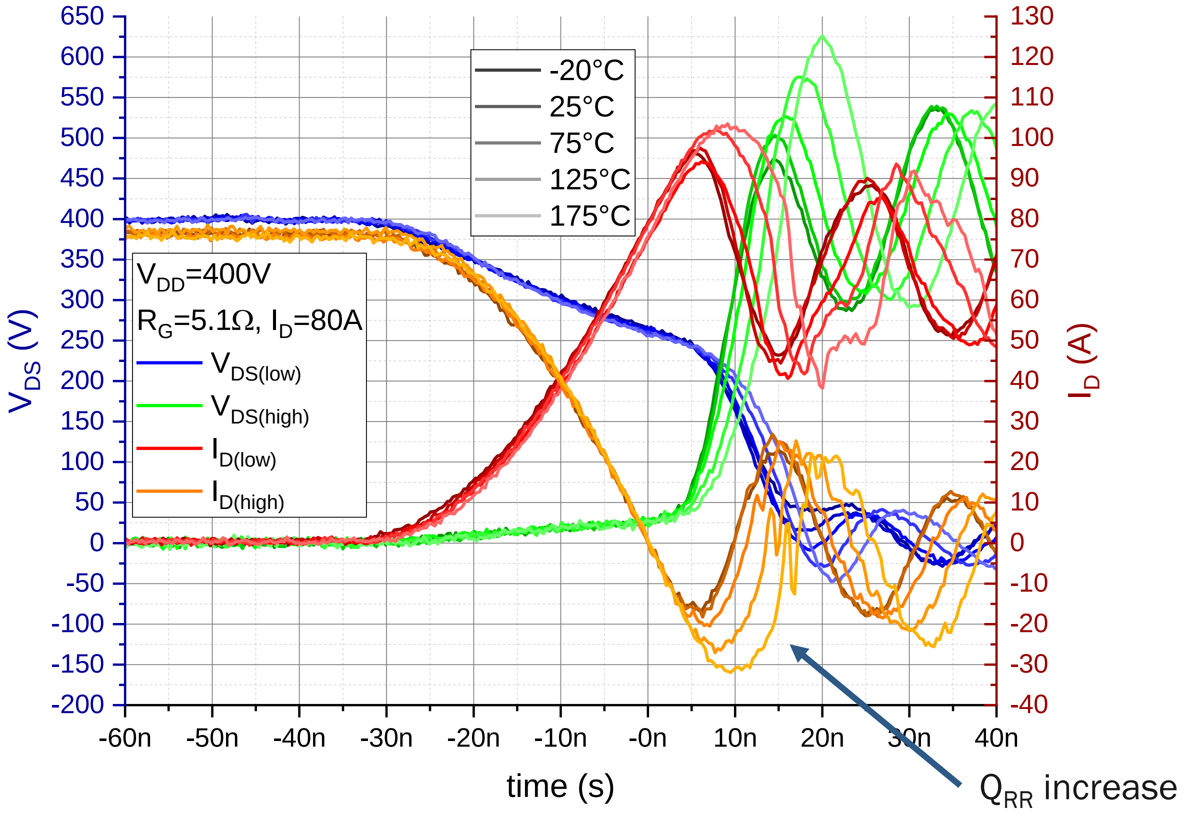


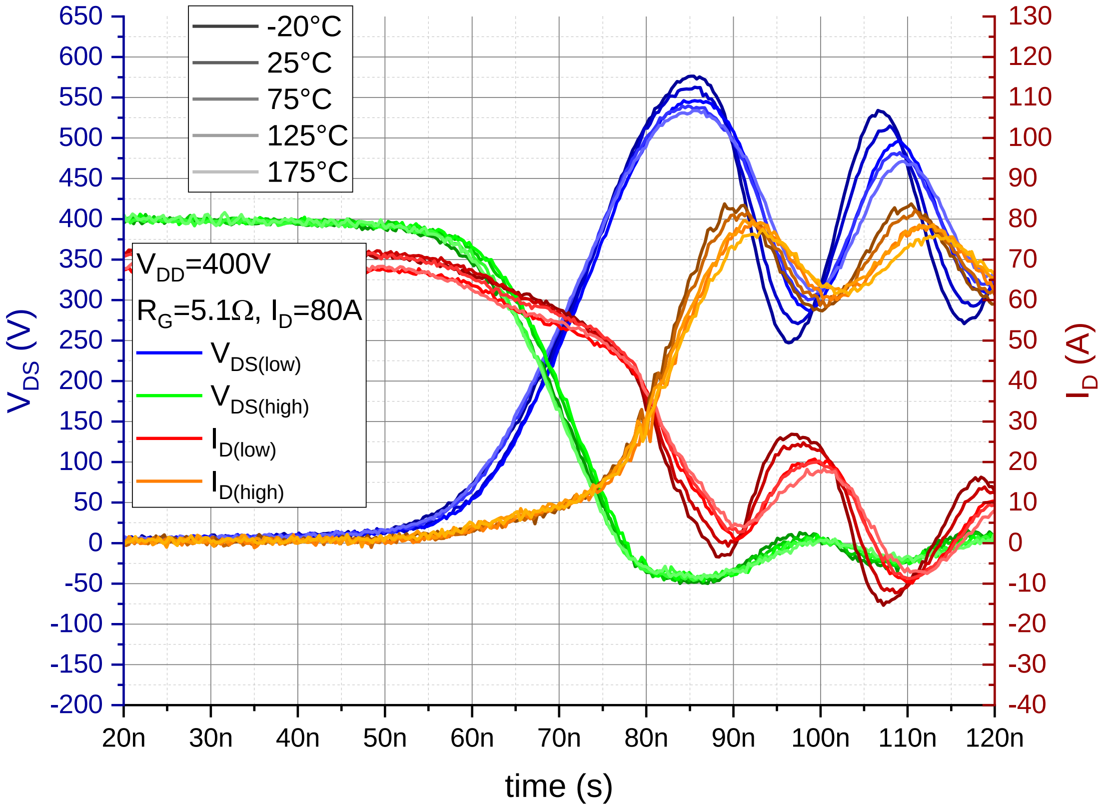
t = 168h



- No measurable drift of body diode characteristics
- Small decrease of R_{DSon} after 168h

SiC MOSFET 650V Body Diode Optimization

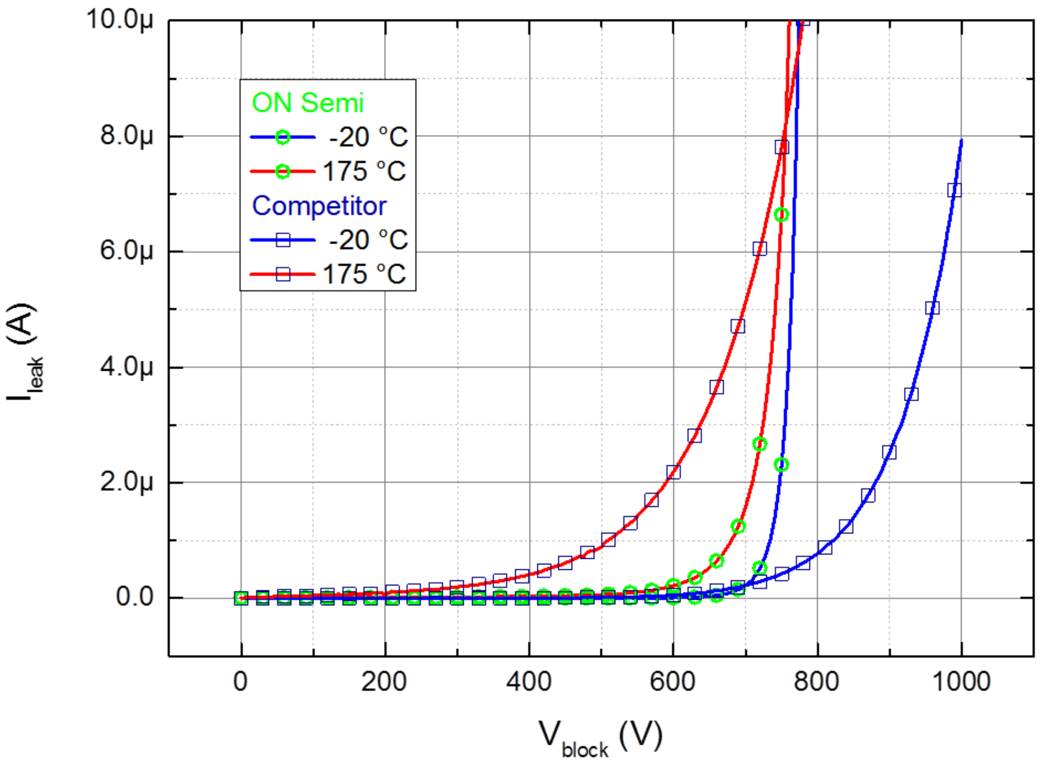


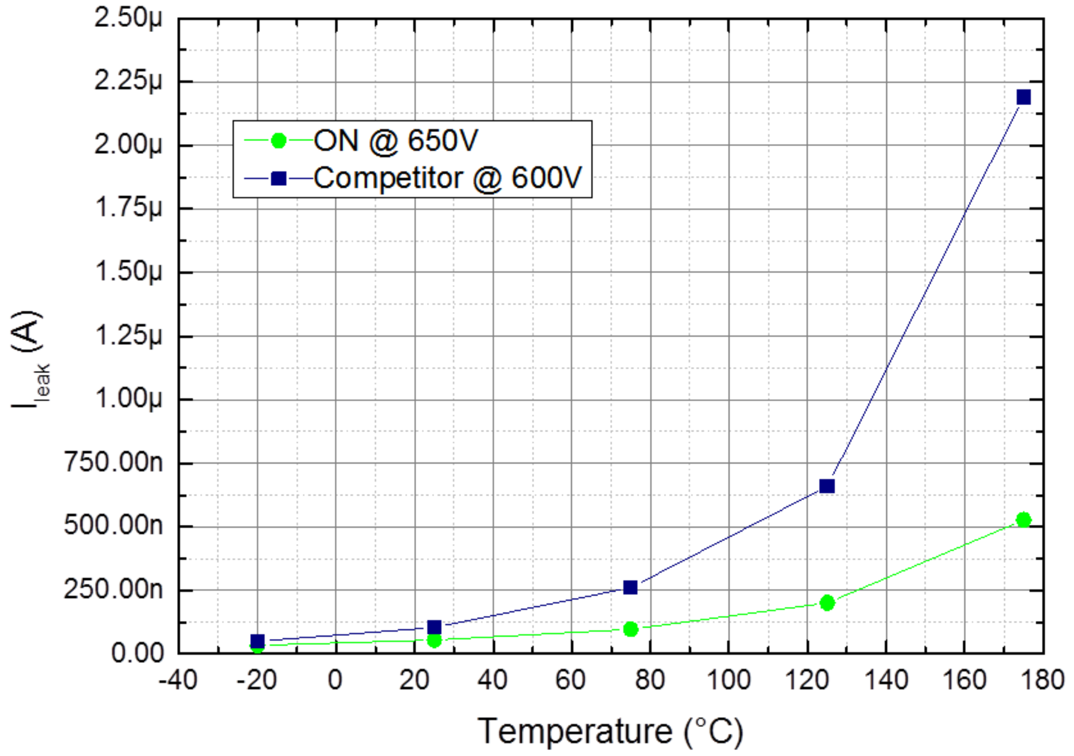


The waveforms above show the impact of varying temperature on the switching. While the off-transition is dominated by slowing down of the current slopes at higher temperatures, resulting in decreasing ringing amplitude, the on-transition is dominated by the low-side Q_{RR} increase towards higher temperatures.

SiC Diodes

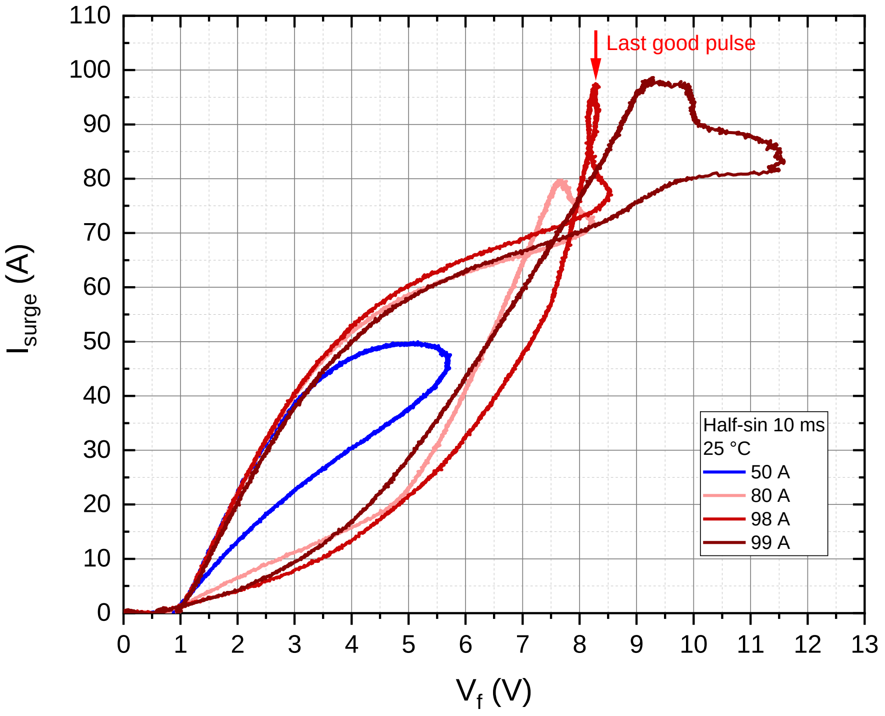
Device Reverse Performance

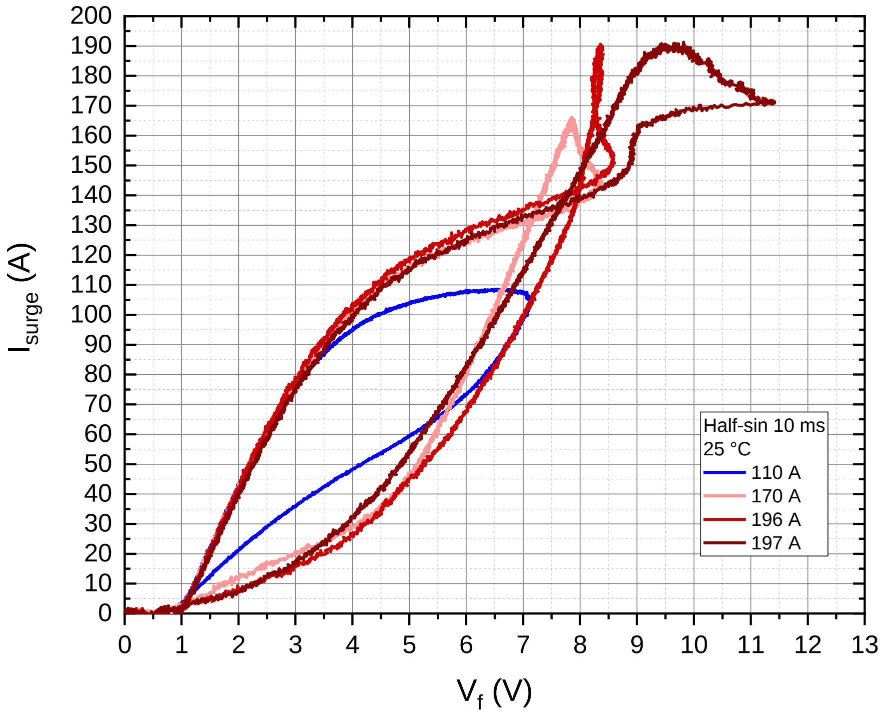




- FFSP0865A is clearly much better than the Wolfspeed C3D08060A (competitor). Due to the large temperature dependence of the diode leakage, Wolfspeed needs to over-engineer the break-down at low temperatures, because once the device temperature goes up leakage becomes very poor.

Surge Profile of 1200 V/10A diodes



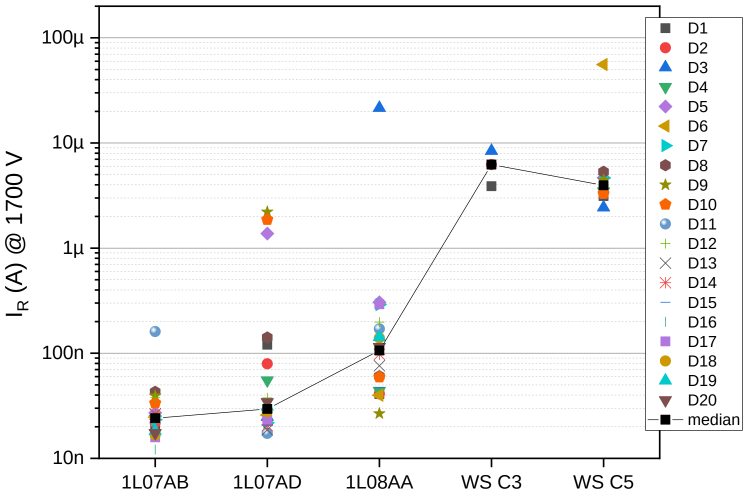


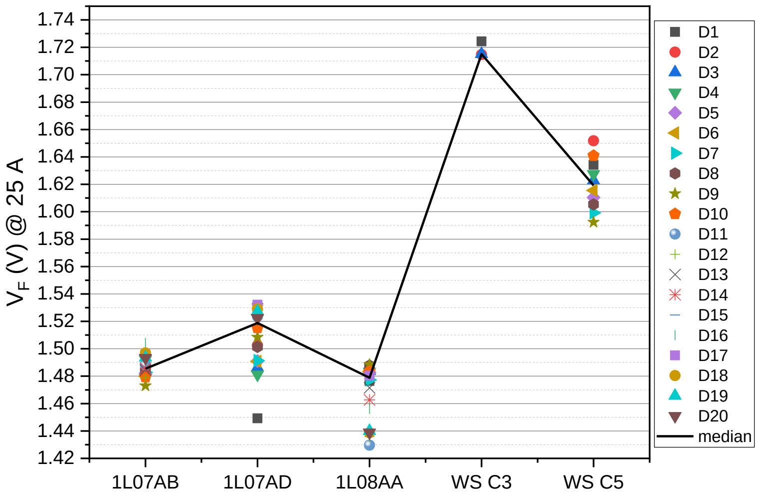
Company	Rating	Surge (10 ms Halfsine)	Comment
ON Semiconductor	10 A/ 1200 V	95 A	Single die TO package
Competitor 1	10 A/ 1200 V	100 A	Single die TO package
Competitor 2	10 A/ 1200 V	50 A	Single die TO package
Competitor 3	10 A /1200 V	70 A	dual die package

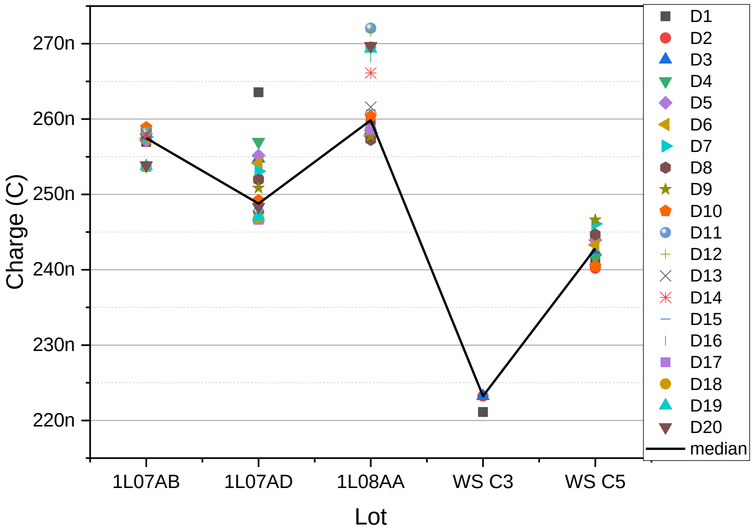
ON Semiconductor diodes, have a clean failure to short during surge. Unlike other competitors which have a degrading surge, some diodes in the list seem to have higher surge ratings however the diodes show partial degradation in the form of higher leakage during reverse and a shift in BV. This doesn't happen to ON Semiconductor SiC Diodes which gives them a clean surge behavior.

* Measured on same setup

1700 V Best in-Class Diode

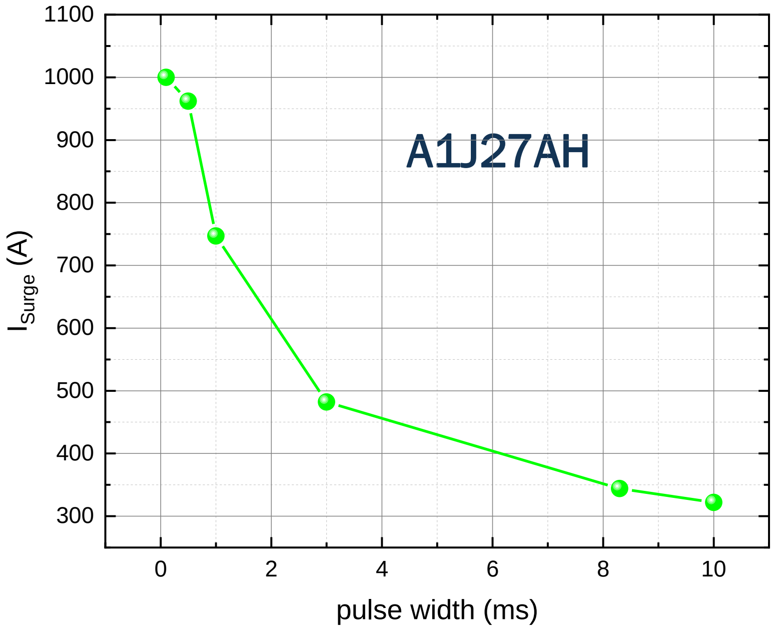




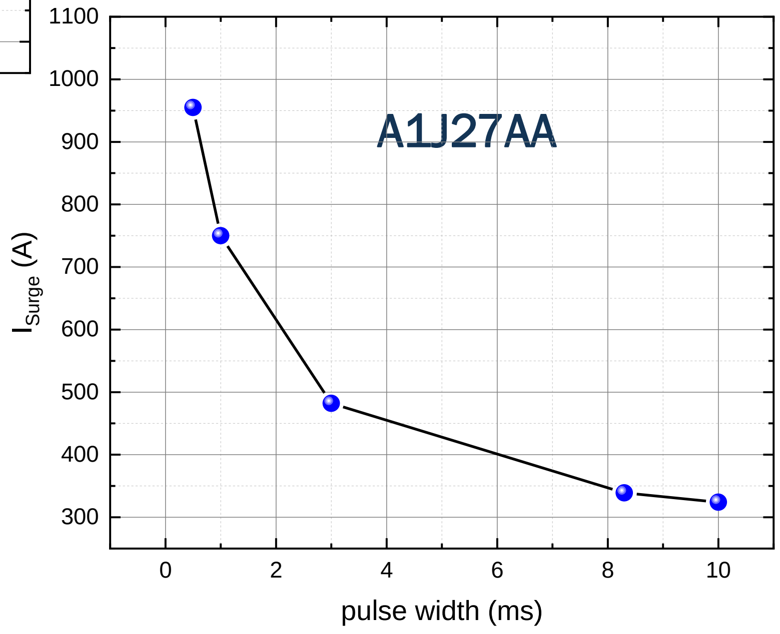


The 1700 V SiC JBS Diode market is dominated by the Wolfspeed C3 family of products, recently the C5 (5th generation) was introduced and is the representative of Wolfspeeds newest development in 1700 V technology. All our data indicates that our 1700 V diodes can outperform Wolfspeeds C3 and C5 catalogue. Surge current data, V_f and reverse leakage is considerably better than Wolfspeed. The marginally lower capacitance of the C5 (about 5% change in median) should not translate into considerable switching loss advantage in high power IGBT driven systems where the V_f will be dominant.

1700 V Best in-class Diode



Pulse width dependent
Surge Performance



	Surge current at 25 ° C– 10 ms half sine
ON Semi	311 A
Competitor 1	286 A
Competitor 2	173 A

Excellent Surge vs. competitor
* We tested five devices per Lot, across 10 Lots. 330-290 A has been upper and lower bounds until now.

SiC Driver NCP51705

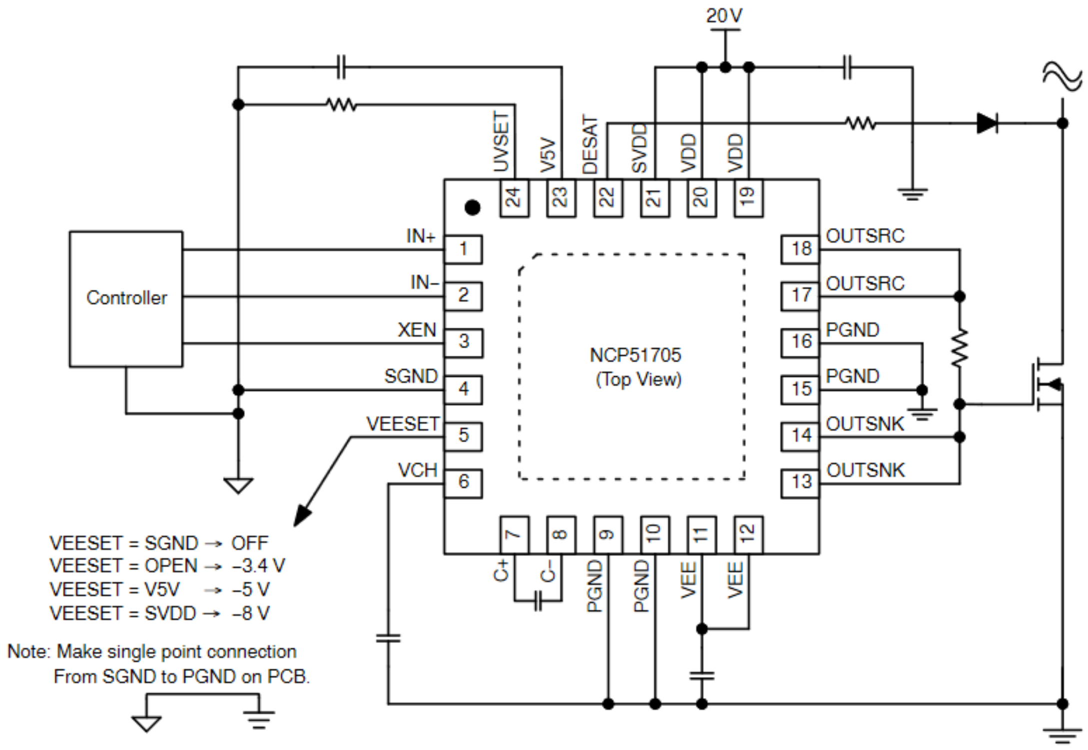
Features

- High Peak Output Current with Split Output Stages
- Extended Positive Voltage Rating up to 28 V Max
- User-adjustable Built-in Negative Charge Pump (-3.3 V to -8 V)
- Accessible 5 V Reference / Bias Rail
- Adjustable Under-Voltage Lockout
- Fast Desaturation Function
- QFN24 Package 4 x 4 mm

Benefits

- Allow independent Turn-ON/Turn-OFF Adjustment
- Efficient SiC MOSFET Operation during the Conduction Period
- Fast Turn-off and Robust dV/dt Immunity
- Minimize complexity of bias supply in isolated gate drive applications
- Sufficient VGS amplitude to match SiC best performance
- Self protection of the design
- Small & Low Parasitic Inductance package

NCP51705



(a) Low Side Switching Configuration

GaN development

GaN Application Testing beyond JEDEC

GaN Stress Testing

Device Level Testing Static Testing

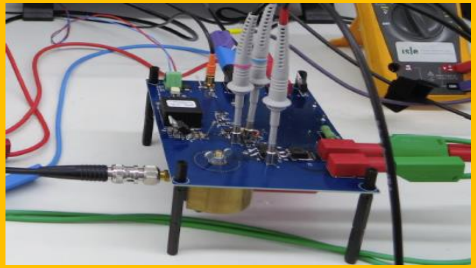
We stress test the devices beyond Datasheet specs:

- Investigate temp dependence of capacitances
- Temp dependence of breakdown
- Self-heating effects
- High current region

Device Level Dynamic Testing

We have developed a unique, true dynamic R_{DSON} tester

- Inductive and Resistive switching
- Temp dependence of $DynR_{DSON}$
- Load dependence of $DynR_{DSON}$
- Time dependence of $DynR_{DSON}$



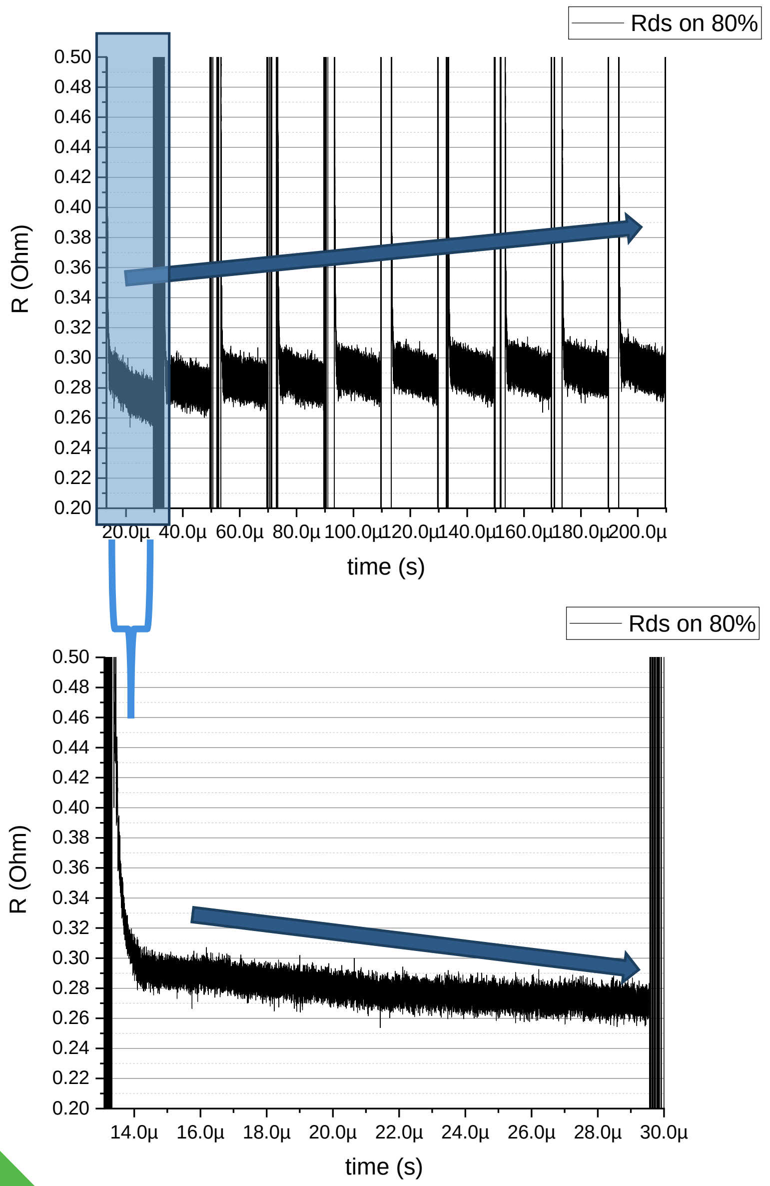
Application Testing

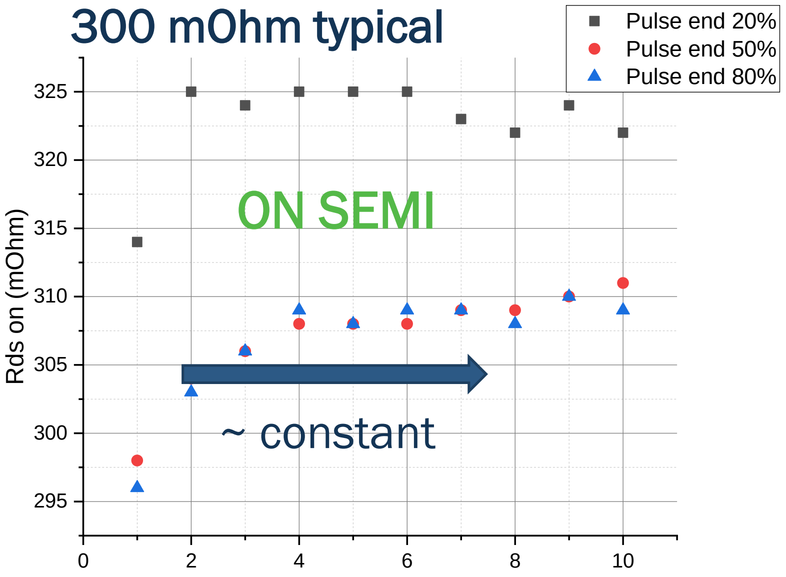
We are developing high dv/dt testers and a novel repetitive switchable H-bridge Converter for continuous operation in HS or ZVS for 1000 of hours at loads beyond 10 kW. Both driver and device can be tested and stressed in this setup, with various application emulation conditions

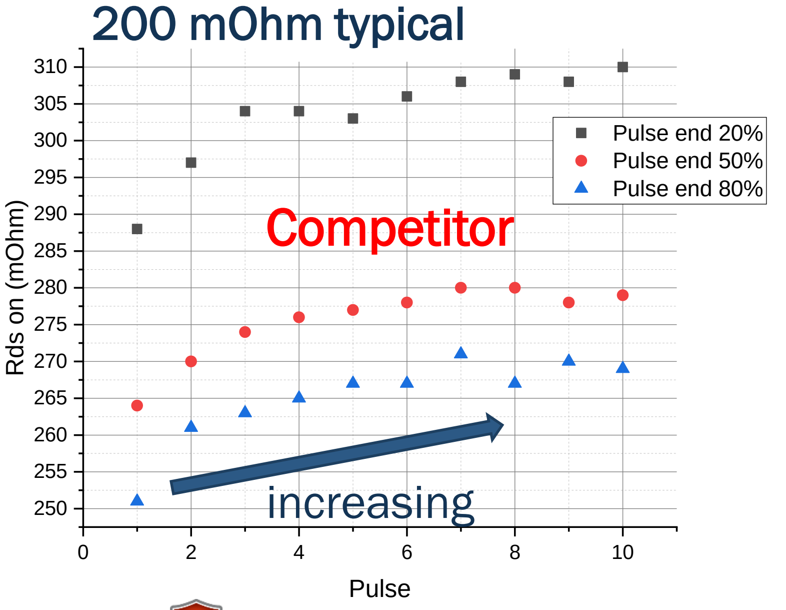
Radiation Testing

We conduct radiation testing, to understand reliability of parts under cosmic radiation.The device ruggedness under particle energies above 100 MeV is studied

Charge Trapping and dynamicR_{DSON}







ON Semiconductors GaN design incorporates smart structures in order to minimize dynR_{DSON} and assure stable operation of the device.

Confidential

GaN Driver NCP51820

Features
- 650 V, high side and low side gate driver
- Fast propagation delay of 50 ns max
- Matched propagation delay of 5 ns max
- 200 V/ns dV/dt Rating for all SW and PGND Referenced Circuitry
- Separate source and sink output pin
- Regulated 5.2 V gate driver with independent UVLO for high side and low side output stages
- QFN 4 mm x 4 mm 15 pin packaging and optimized pin out

Benefits
- Design margin for AC/DC design
- Suitable for high frequency operation
- Increased efficiency and allow paralleling
- Robust design for high switching frequency application
- Allow control of rise and fall time for EMI tuning
- Optimum driving of GaN power switches and simplify design
- Small PCB foot print, reduced parasitic, suitable for high frequency operation

Applications
- Resonant converters
- Half bridge and full bridge converters
- Active clamp flyback converters
- Totem pole bridgeless PFC

End Products
- Power supply for OLED TV
- High power gaming adapter
- USD PD cellphone and notebook travel adapter
- Server / Cloud Data-center Offline power
- Industrial inverter and motor drive

NCP51820

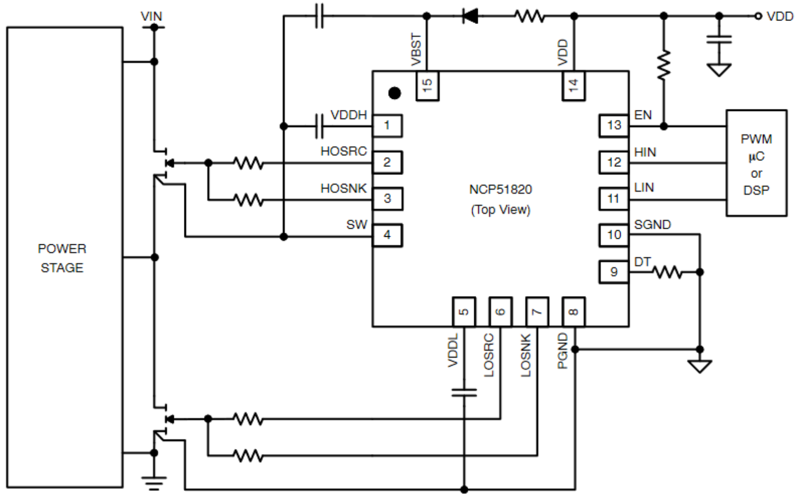


Figure 1. Typical Application Schematic

Thank You for your Attention

Questions: mehrdad.baghaie@onsemi.com