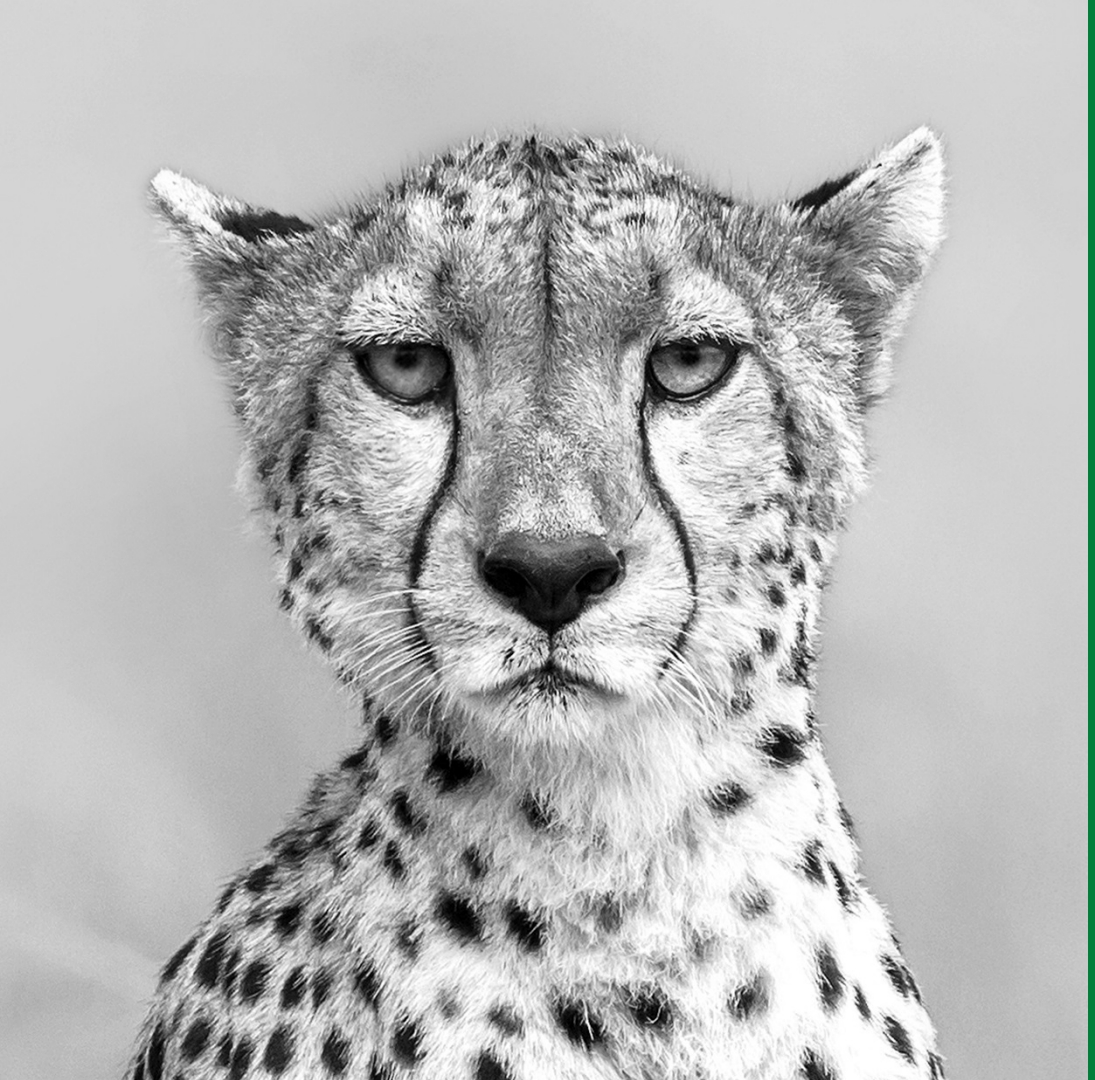

SiC MOSFETs

What it Takes to Create Cost-Effective and Highly Reliable High-Power Solutions

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Power Electronics Conference 2018
Christophe Warin
Product Marketing Manager – SiC

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Expertise Applied | Answers Delivered

Littelfuse / Monolith Semi. Timeline + Partnerships

December 2012
Monolith Semiconductor incorporated

December 2013
Inked agreement with XFab for high-volume manufacturing

August 2014
Demonstrated first SiC MOSFETs made in 150mm CMOS foundry

December 2015
Formed strategic partnership with Littelfuse

March 2017
Availability of fully qualified 1200V SiC diode platform in 150mm CMOS foundry

2013 | 2014 | 2015 | 2017

May 2013
Demonstrated 1700V, 5A SiC MOSFET at Cornell fab

April 2014
Demonstrated 1200V, 10A SiC diodes fabricated in 150mm CMOS foundry

November 2014
Delivered first engineering samples to select customers

March 2017
Littelfuse makes incremental $15 million investment in Monolith

75 mm

150 mm

Jan 2018
Littelfuse®
Purchases
IXYS

Outline

- Motivation for SiC devices
- High-volume 150 mm process
- Performance / Ruggedness Validation
  - HTRB / HTGB
  - Gate Oxide Lifetime
  - Avalanche and short circuit
  - Switching performance
- SiC products

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Reality: Ideal Switch Is Not Enough

Long-term Reliability

Voltage, Temperature, Moisture, Mechanical

Performance

Breakdown Voltage, On-resistance, Switching Loss

Ruggedness

Short-circuit, Avalanche, Surge, ESD

Cost

Manufacturability

Yield, Process Margin

Outline

- Motivation for SiC devices
- High-volume 150 mm process
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  - HTRB / HTGB
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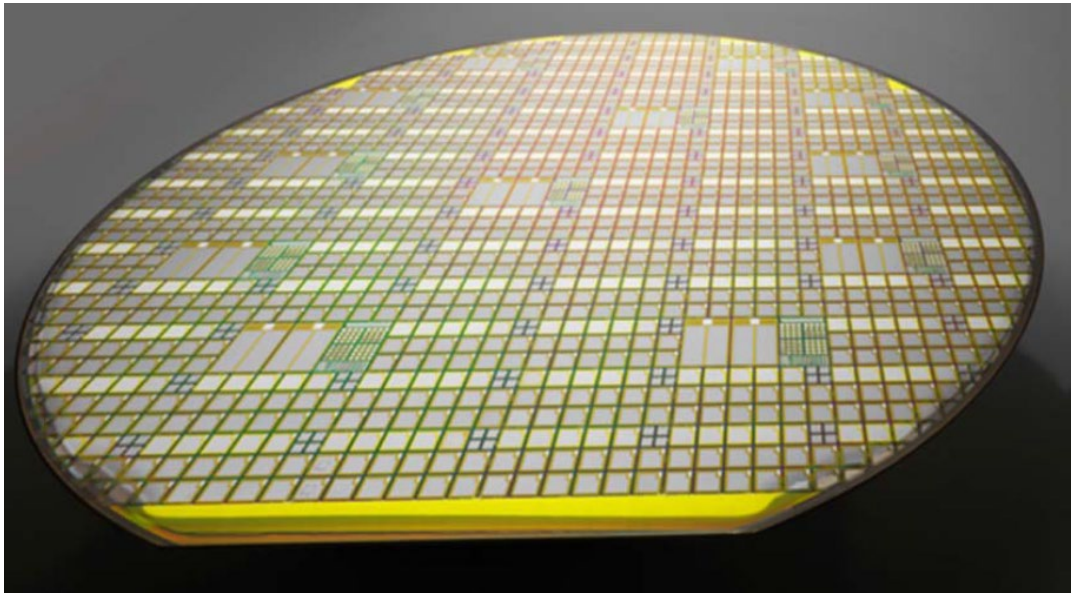
SiC MOSFET in High-Volume 150mm CMOS Fab

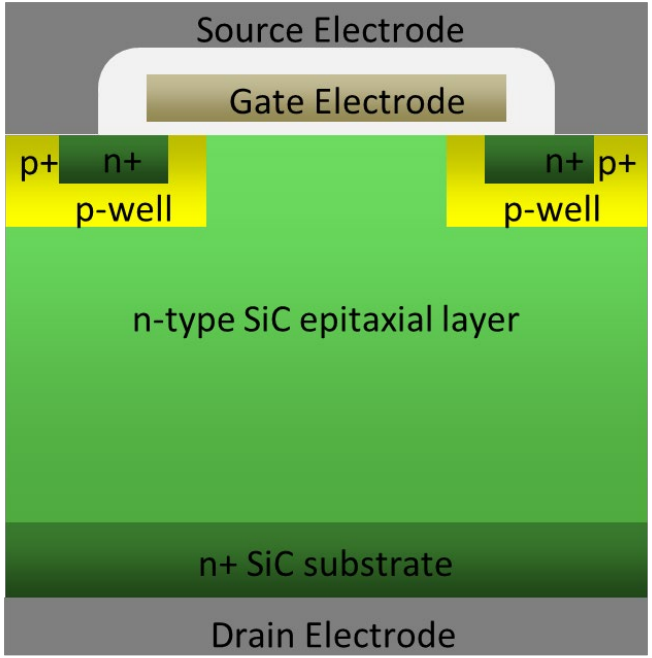
- Compatible material, similar process steps
- Handling challenges: semi-transparent wafer
- High temp. implantation – different species
- High temp. activation



Concurrent manufacturing of Si and SiC – reuse established CMOS processes – minimize special tools.

Design Specifications

- Epitaxial layer: Epi doping variation
- Termination design: Dose variation, high field in molding compound
- JFET design: High oxide field
- Channel design: On-resistance vs. device ruggedness
- Source/contact design: Design rule



Designed for manufacturability and ruggedness

Outline

- Motivation for SiC devices
- High-volume 150 mm process
- Performance / Ruggedness Validation
  - HTRB / HTGB
  - Gate Oxide Lifetime
  - Avalanche and short circuit
  - Switching performance
- SiC products

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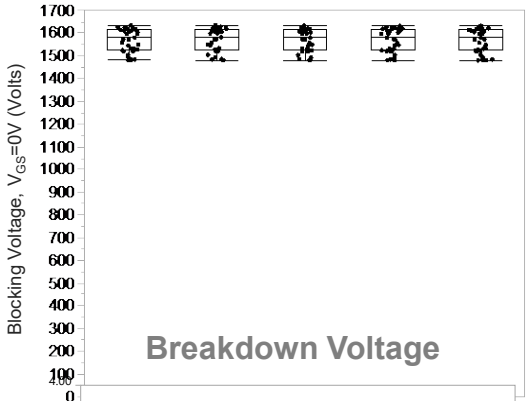
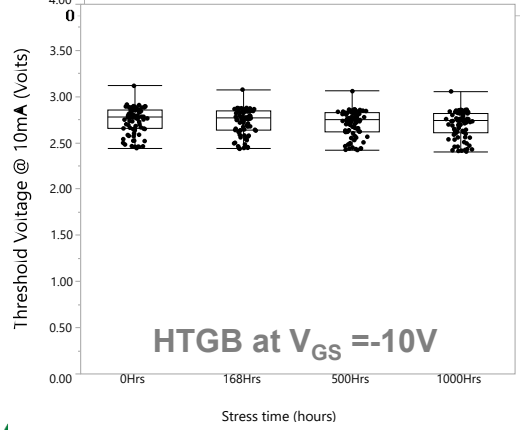
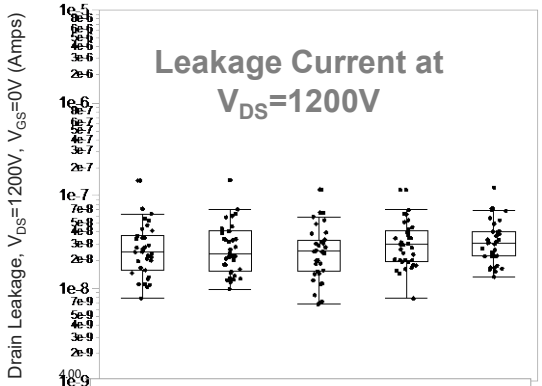
HTRB and HTGB Testing

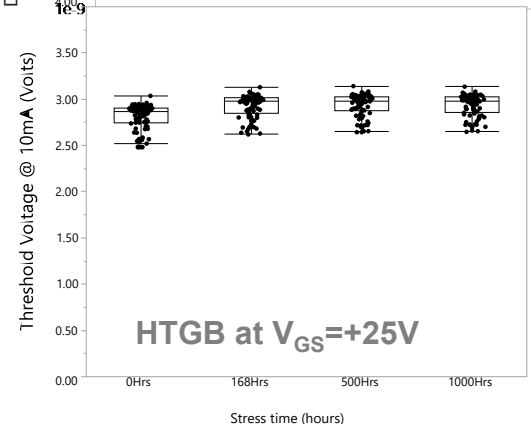




Minimal shift observed for HTRB at 175C, V_{GS} = 0 V, V_{DS} = 960 V

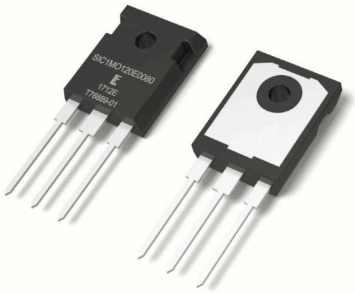
Minimal shift observed for HTGB at 175C, V_{GS} = -10 V and at V_{GS} = +25 V

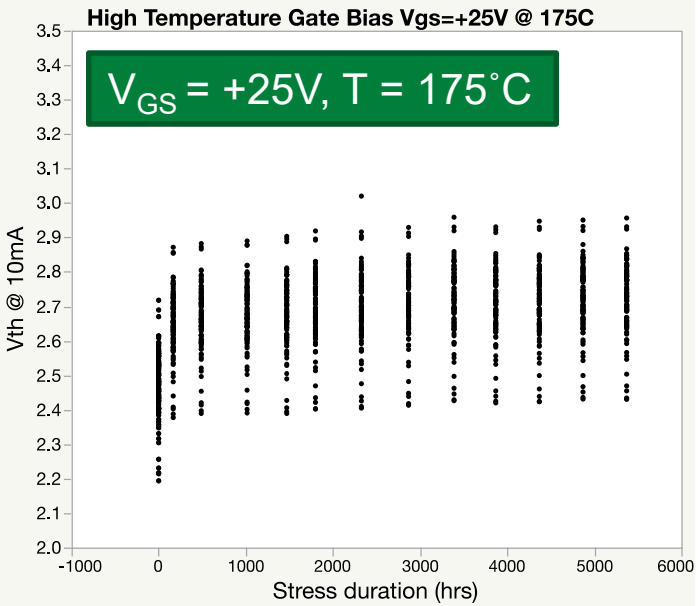


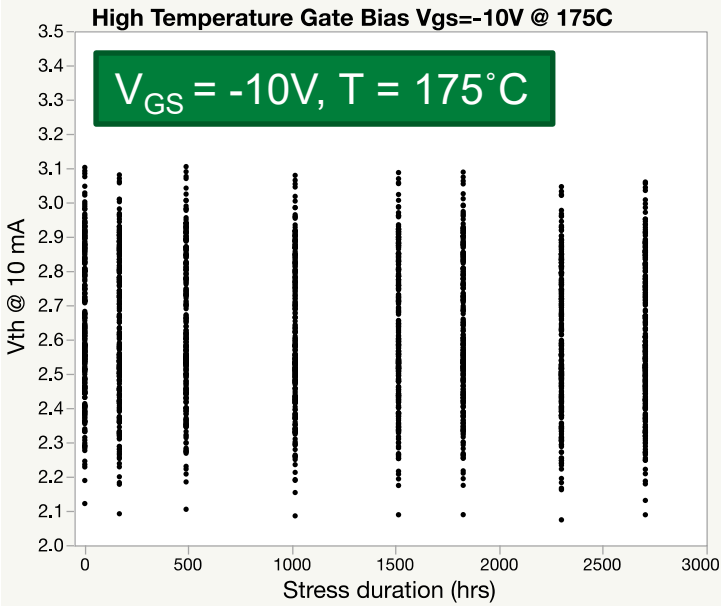


HTGB Testing

LSIC1MO12E0080 1200V, 80 mOhm SiC MOSFET







- Observe +200 mV shift after HTGB+ for 5500hrs (V_{GS} = +25V, T = 175˚C), primary shift occurs at first readpoint
- No significant drift under HTGB- for 2700 hours (V_{GS} = -10V, T = 175˚C)

Accelerated Gate Oxide Lifetime test

MOS Test structure

Time Dependent Dielectric Breakdown in high quality SiC MOS capacitors

Z. Chbili[1,2], K. P. Cheung[1)*], J. P. Campbell[1)], J. Chbili[1,3)], M. Lahbabi[3)], D. E. Ioannou[2)], K. Matocha[4)],
[1)] NIST, 100 Bureau Dr, Gaithersburg, MD. 20899 USA
[2)] George Mason University, 4400 University Dr, Fairfax,VA 22030. USA
[3)] Laboratoire SSC, Faculté des Sciences et Techniques, B.P. 2202 Fez, Morocco
[4)] Monolith Semiconductor Inc, 408 Fannin Av, Round Rock, TX 78664. USA

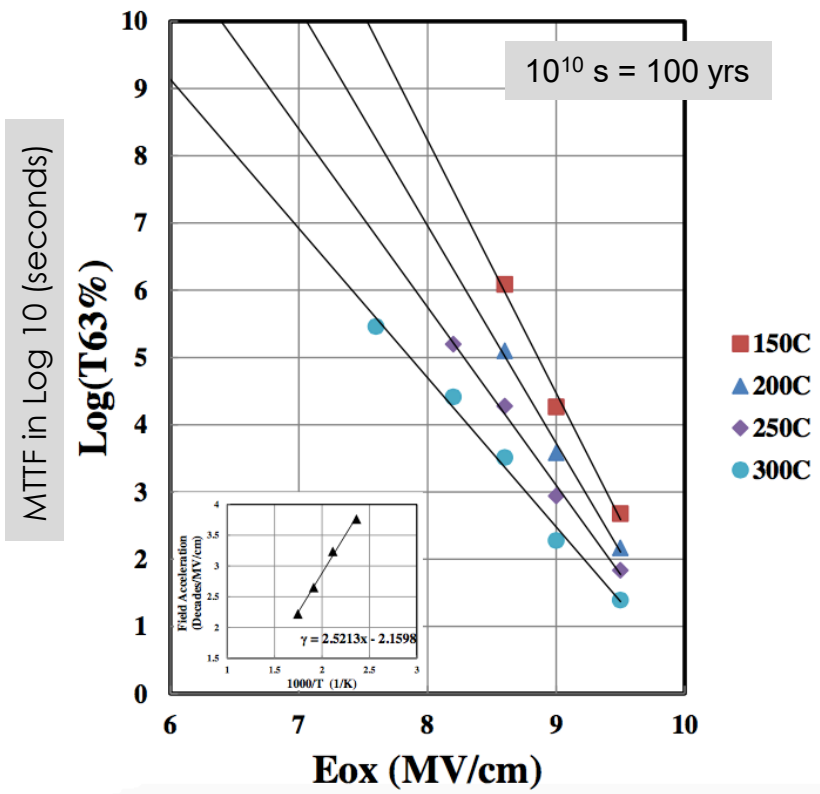
* Kin.Cheung@nist.gov

The deviations of the field accelerations and temperature dependencies from the typically reported SiC TDDB literature and the similarities with the Si/SiO_2 devices of comparable dielectric thickness is consistent with more mature high quality SiO_2 breakdown [7-12]. These observations are the first to demonstrate such high quality SiC/SiO_2 capacitors (absence of extrinsic failure and expected field acceleration and temperature dependencies) with sufficient statistics to confidently speak towards their high TDDB reliability.

To be presented
@ ICSCRM 2015

NIST

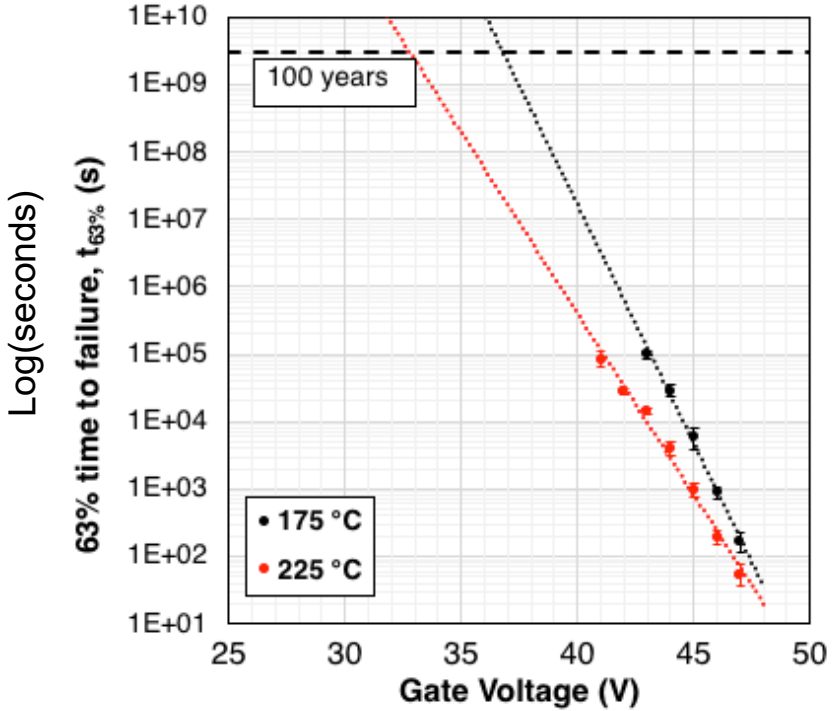
The oxide reliability of Littelfuse's SiC MOSFETs are "silicon-like"



Accelerated Gate Oxide Lifetime test

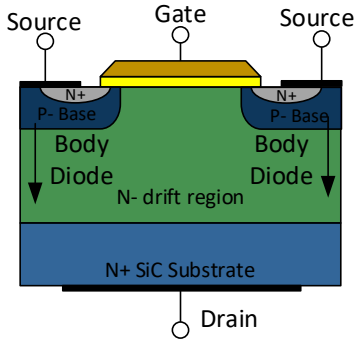
LSIC1MO12E0080 1200V, 80 mOhm SiC MOSFET On-wafer Testing

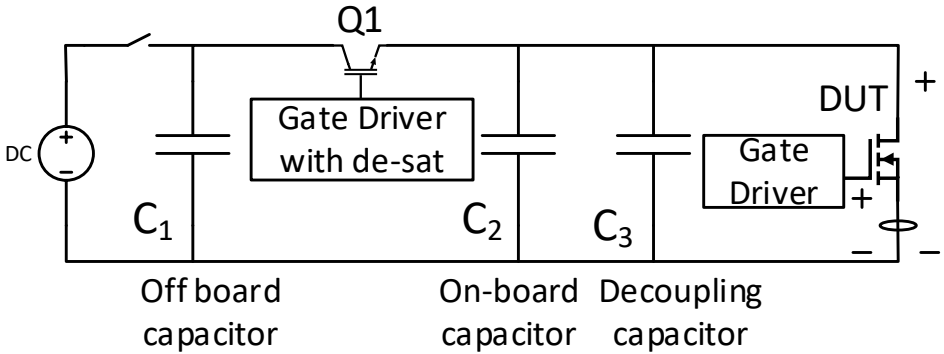
10^{10} sec=300 yrs

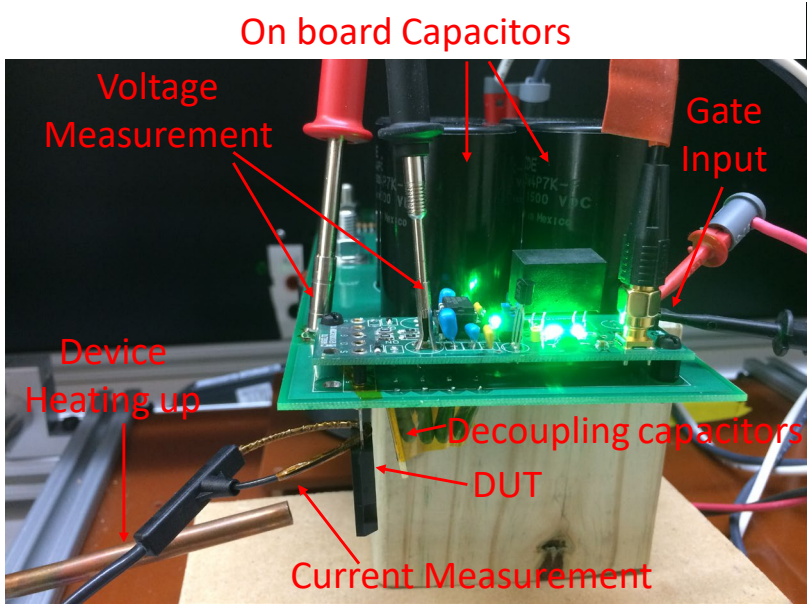


- Close agreement between TDDB data from test structures and fully processed 80mΩ DMOSFETs
- Predict life > 100 years when operating at T=175˚C and VGS=25V.

Short Circuit Robustness





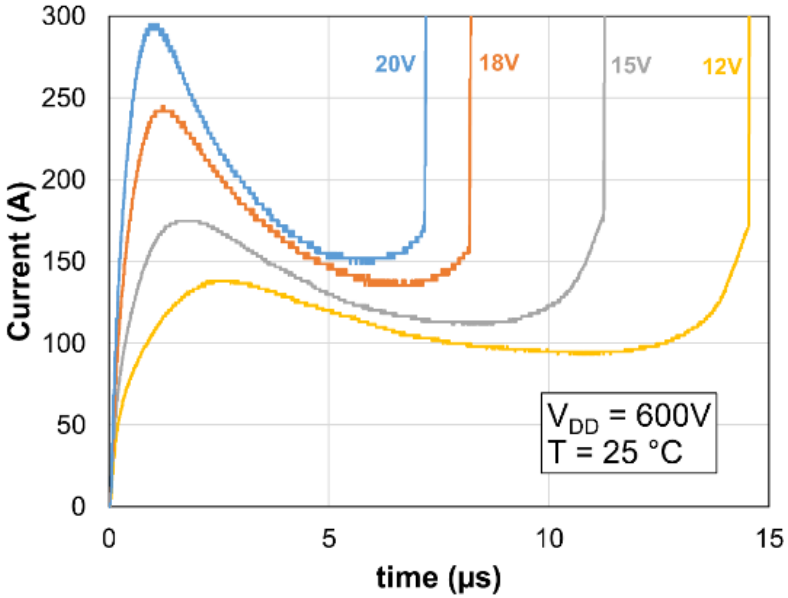


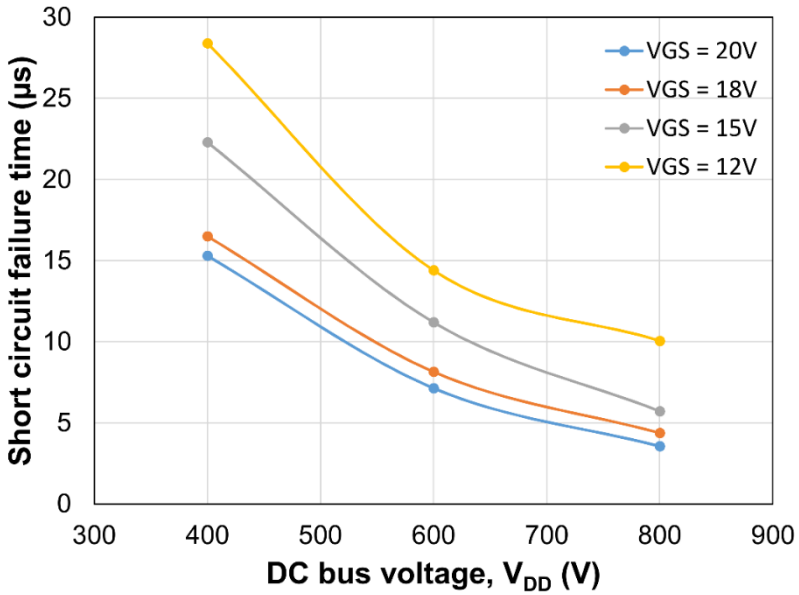
In-Depth Study of Short-Circuit Robustness and Protection of 1200V SiC MOSFETs

Xuning Zhang, Gin Sheh, Levi Gant,Sujit Banerjee

PCIM 2018

Short Circuit Robustness



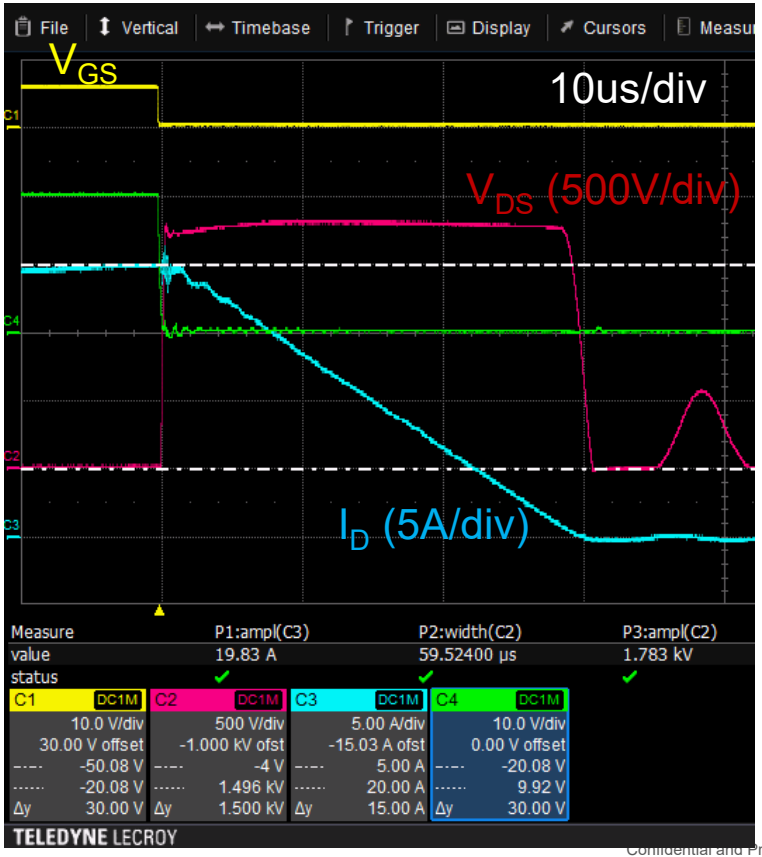


- Short circuit time characterized - Shorter withstand time compared to IGBT
  - Sensitive to dc link voltage and gate voltage
  - Device can be protected using Desat feature in gate driver Ics

Avalanche Ruggedness

Unclamped Inductive Switching 1200 V, 80 mΩ rated SiC MOSFETs

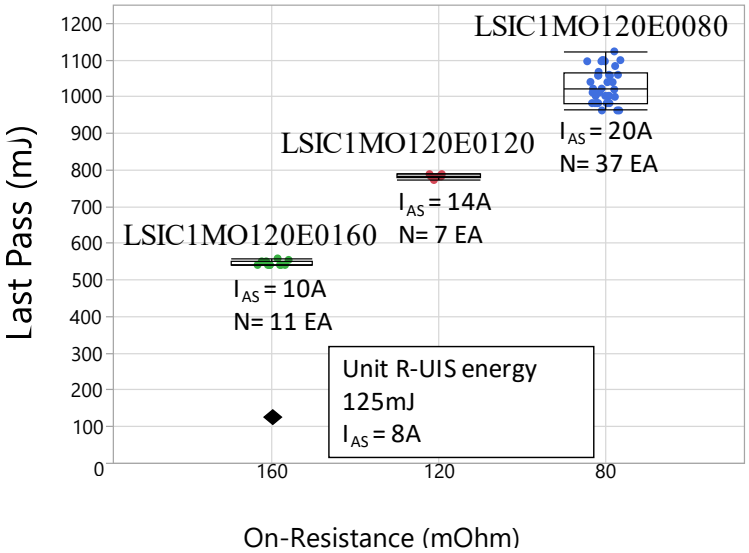
- Avalanche energy (Unclamped Inductive Switching, UIS) shows the ability of the MOSFET to survive transients sometimes incurred when driving inductive loads.

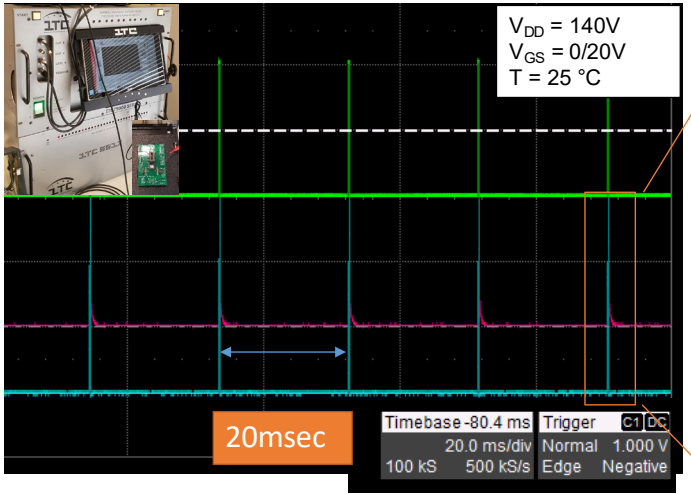


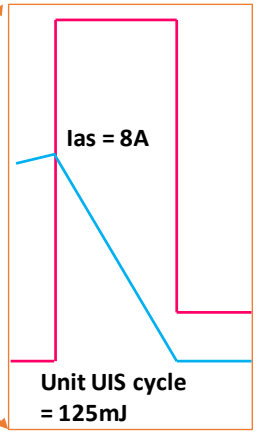
I_{AS} = 20A
E_{AS} = 1100mJ
$V_{DS,max}$=1793V
PASS

Avalanche Ruggedness

Repetitive unclamped inductive 1200V, 160mΩ rated SiC MOSFETs







- UIS test solution with R-UIS test capabilities
- Waveforms during R-UIS cycle : each UIS period = 20msec.
- The energy of the unit UIS cycle = 125mJ

Avalanche Ruggedness

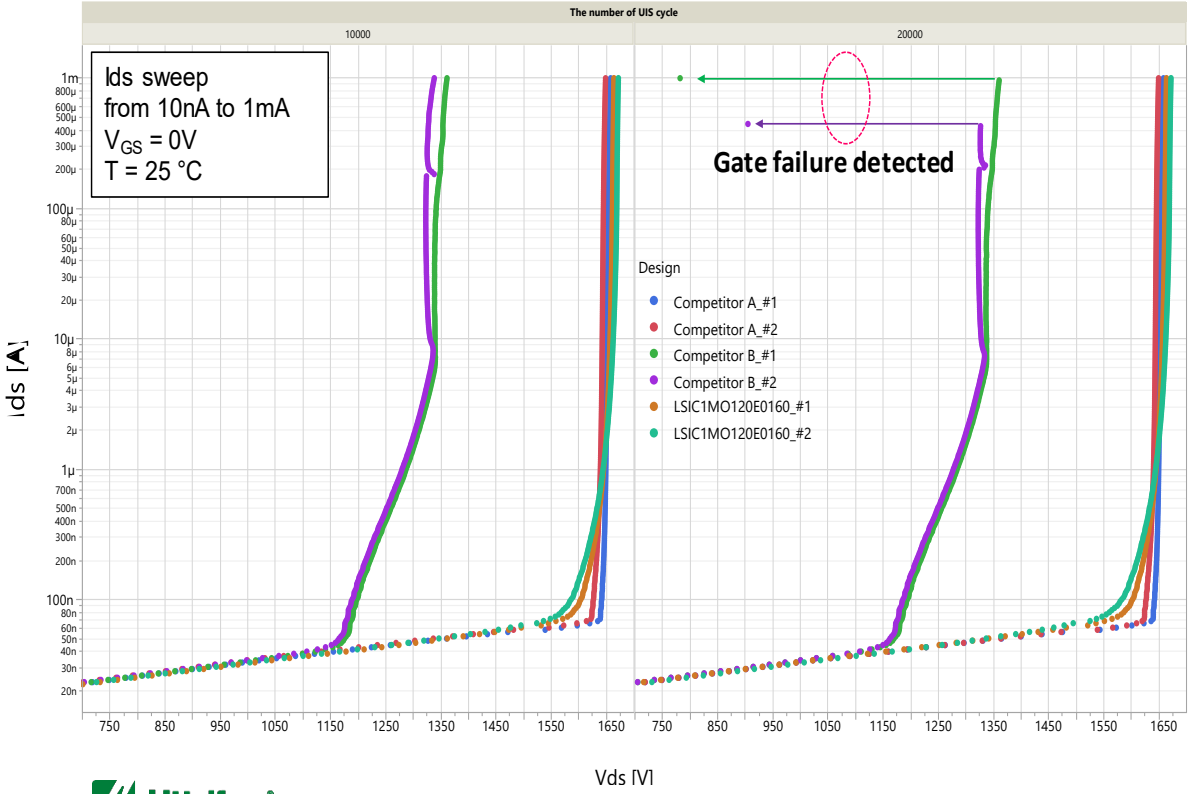
Repetitive unclamped inductive 1200V, 160mΩ rated SiC MOSFETs

Design	Post stress parameter drift (R-UIS robustness)	DC Parameter shifts after 100,000 cycle of R-UIS stress				
		ΔVt [mV]	ΔRdson [mOhm]	ΔVsd[mV]	ΔBVdss[V]	ΔIdss [nA]
Competitor A_#1	Negligible (Good)	-20.1	-2.0	22.4	0.0	-0.2
Competitor A_#2	Negligible (Good)	-27.9	-0.7	8.9	0.7	2.0
Competitor B_#1	N/A	N/A	N/A	N/A	N/A	N/A
Competitor B_#2	N/A	N/A	N/A	N/A	N/A	N/A
Competitor C_#1	N/A	N/A	N/A	N/A	N/A	N/A
Competitor C_#2	N/A	N/A	N/A	N/A	N/A	N/A
LSIC1MO120E0160_#1	Negligible (Good)	-55.4	3.2	28.4	-0.1	-1.1
LSIC1MO120E0160_#2	Negligible (Good)	-38.0	2.2	30.8	-1.8	-1.2

LSIC1MO120E0160 demonstrated excellent R-UIS capabilities: no parametric shift on key electrical performances such as on-resistance, threshold voltage, breakdown voltage and drain leakage current after 100000 cycles of R-UIS stress.

Avalanche Ruggedness

Repetitive unclamped inductive 1200V, 160mΩ rated SiC MOSFETs



- Competitor A and LSIC1MO120E0160 were robust up to 100K cycle.
- Competitor B showed BV collapse during I-V measurement after 20K cycle
- Competitor C (80 mOhm trench gate) didn't show any R-UIS capability

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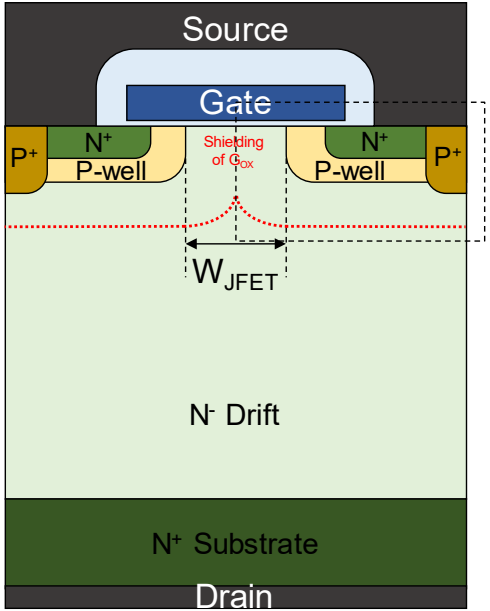
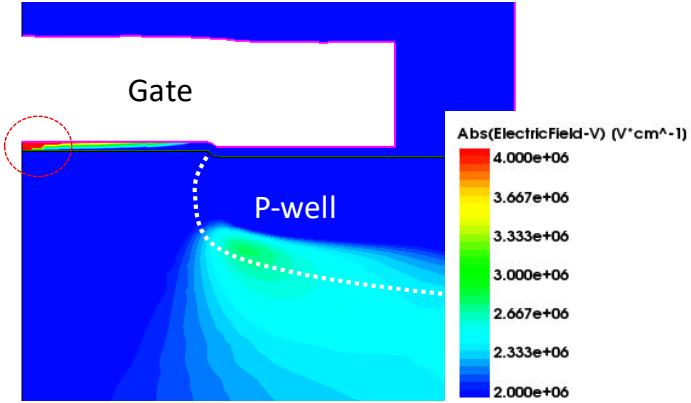
Avalanche Ruggedness

Repetitive unclamped inductive 1200V, 160mΩ rated SiC MOSFETs





Electric field at Vds = 1600V
Highest e-field at gate oxide in JFET region
: Eox ~ 4 MV/cm

- Gate oxide shielding capability is critical to ensure R-UIS robustness
- LSIC1MO120E0160: state-of-art ruggedness under repetitive UIS conditions

SiC MOS reliability and ruggedness

- What is the wearout lifetime of SiO_2 grown on SiC?
  Gate oxide wearout for thick oxides can be extrapolated from constant voltage TDDB.
  Predict gate oxide wearout life > 100 years when operating at T=175˚C and V_{GS}=25V.

- How does long-term stress impact the SiC MOSFET threshold voltage stability?
  We have shown stable operation under:
  V_{GS}=+25V for 5500 hrs (+200mV) and V_{GS}=-10V for 2700 hrs at T=175˚C.

- Are SiC MOSFETs stable under unclamped inductive switching (simultaneous voltage+current)?
  Maximum UIS capability scales with die active area:
  E_{AV}=1000 mJ for 1200V, 80 mOhm (~10 J/cm^2).
  No parametric change observed for:
  Single shots of 80% of Max UIS.
  100k shots of 25% of Max UIS

Outline

- Motivation for SiC devices
- High-volume 150 mm process
- Performance / Ruggedness Validation
  - HTRB / HTGB
  - Gate Oxide Lifetime
  - Avalanche and short circuit
  - Switching performance
- SiC products

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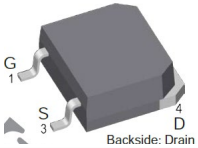
SiC MOSFET Standard Package Portfolio

In production

In qualification.



	R_{DSON} (mΩ)	TO247-3L	TO247-4L	TO263-7L (D2PAK)	TO268-2L (D3PAK)
1200V	160	LSIC1MO120E0160	LSIC1MO120G0160	LSIC1MO120T160	
	120	LSIC1MO120E0120	LSIC1MO120G0120	LSIC1MO120T120	
	80	LSIC1MO120E0080	LSIC1MO120G0080	LSIC1MO120T080	
	40	LSIC1MO120E0040	LSIC1MO120G0040		
	25	LSIC1MO120E0025	LSIC1MO120G0025		
1700V	750	LSIC1MO170E1000		LSIC1MO170T0750	LSIC1MO170H0750

- TO247-3L : Most common
- TO247-4L : With Kelvin connection
- TO263-7L : Surface mount with Kelvin connection
- TO268-2L : High creepage
- Other R_{DSON} and voltages being developed
- Bare die available on request.
- Competitive performance and price with best-in-class delivery in market
- Samples available for evaluation

Littelfuse® Power Semiconductors

SiC Diode Standard Package Portfolio

In production

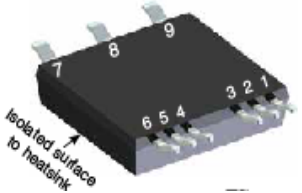
In qualification.

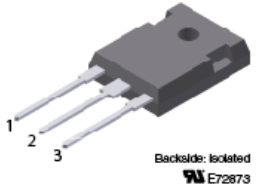
		TO252-2L (DPAK)	TO263-2L (D2PAK)	TO220-2L	TO247-3L
650V (2018 Q4 release)	6A	LSIC2SD065C06	LSIC2SD065D06	LSIC2SD065A06	
	8A	LSIC2SD065C08	LSIC2SD065D08	LSIC2SD065A08	
	10A	LSIC2SD065C10	LSIC2SD065D10	LSIC2SD065A10	LSIC2SD065E10CC
	12A				LSIC2SD065E12CC
	16A	LSIC2SD065C16	LSIC2SD065D15	LSIC2SD065A16	LSIC2SD065E16CC
	20A	LSIC2SD065C20	LSIC2SD065D20	LSIC2SD065A20	LSIC2SD065E20CC
	32A				LSIC2SD065E32CC
	40A				LSIC2SD065E40CC
1200V (In Production)	5A	LSIC2SD120C05		LSIC2SD120A05	
	8A	LSIC2SD120C08		LSIC2SD120A08	
	10A	LSIC2SD120C10	LSIC2SD120D10	LSIC2SD120A10	LSIC2SD120E10CC
	15A		LSIC2SD120D15	LSIC2SD120A15	LSIC2SD120E15CC
	20A		LSIC2SD120D20	LSIC2SD120A20	LSIC2SD120E20CC
	30A				LSIC2SD120E30CC
	40A				LSIC2SD120E40CC

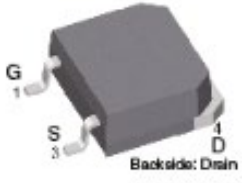
- Wide portfolio of 650V and 1200V diodes
- 650V are AECQ-101
- Both surface mount and through-hole
- Other package options : TO-247-2L, SOT-227, ISOPLUS, bare die etc.
- Competitive performance and price with best-in-class delivery in market
- Samples available for evaluation.

SiC Offerings Cont. (Packaging Highlights)

- SMPD packages
  - High current capability
  - High creepage distances
  - Tape-and-reel packing option for pick-and-place







- SOT-227 packages
  - Superior cooling performance (AlN substrate)
  - Kelvin source connection to decouple gate loop
- TO-268 HV packages
  - Very high creepage distances
- TO-247 HV packages
  - For new 1700 V designs
  - >7.6 mm Drain-Source spacing
- ISO-247
  - DCB isolation

Summary

- SiC MOSFETs starting to gain customer acceptance
  - Multiple suppliers
  - Wider offering of voltage, current and package

- Littelfuse SiC MOSFETs have exhibited industry leading performance and reliability

- Littelfuse SiC MOSFETs are in strong position
  - Solid technology, extensive manufacturing resources, global distribution network

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Thank You!

SPEED. FLEXIBILITY. POWER.

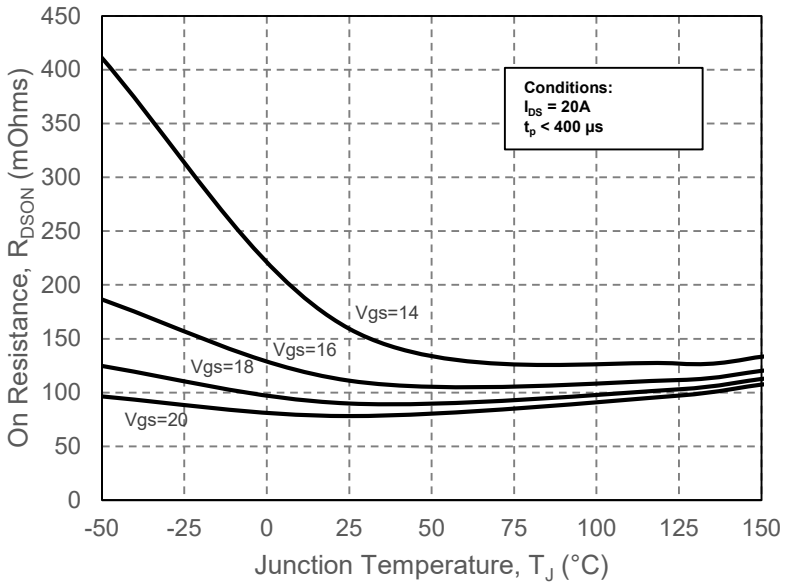
Fast and agile just got stronger

Come see us at Hall 9, Booth 305

PowerSemiSupport@Littelfuse.com

1200V, 80 mOhm MOSFET Comparison

Rdson versus Gate Drive voltage



20V: lowest Rdson

18V: Rdson is ~5% > @ 150C

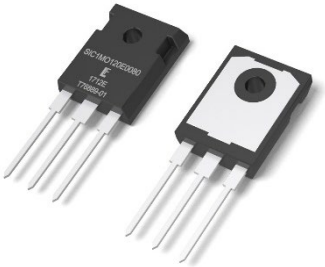
Flexible gate drive

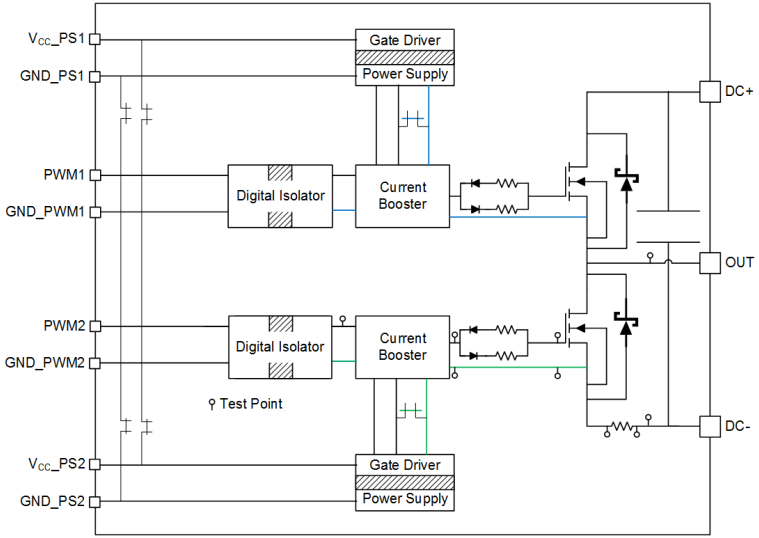
Notes:

- Threshold voltage is high enough (typ 3V) for 0V gate drive. Good layout required
- -5V add noise margin and speed

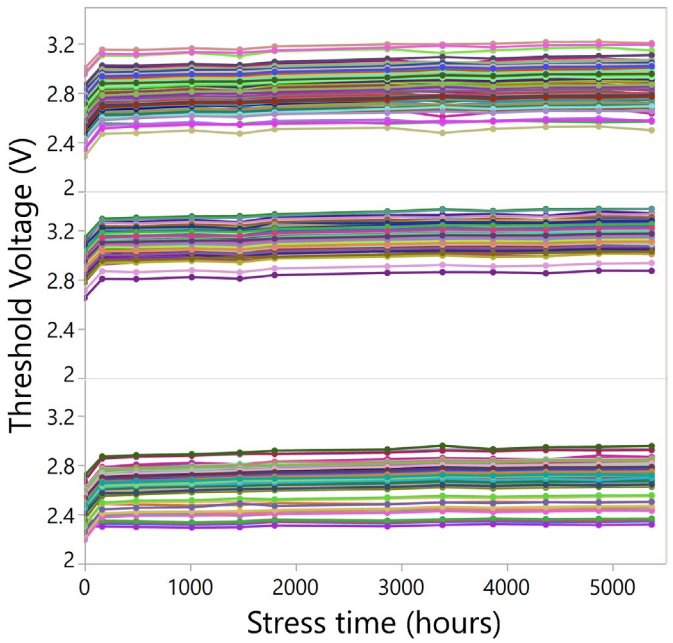
Switching Performance

- Switching energy
- Switching time
- Gate charge
- Reverse recovery

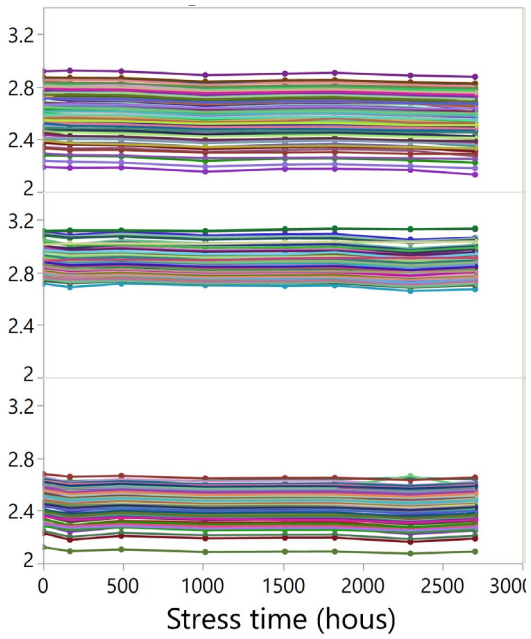




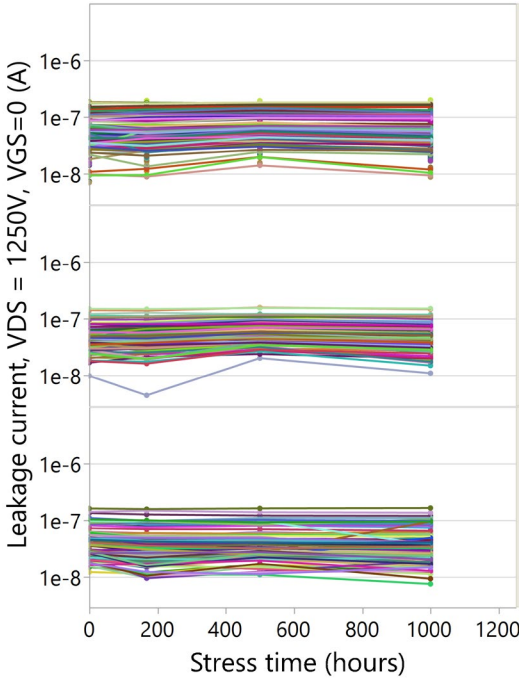
High Temperature Reverse Bias Test



HTGB Test (25V)



HTGB Test (-10 V)

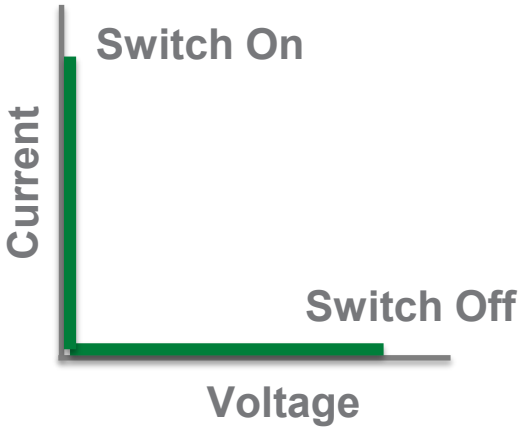


HTRB Test (960 V)

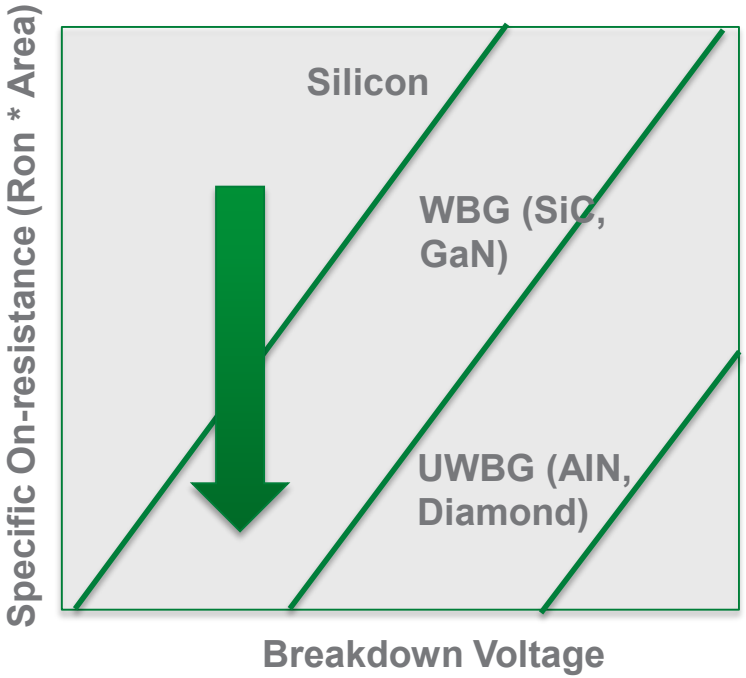
Auxiliary Slides

The Ideal Device

- Ideal Switch
  - Zero leakage in off-state
  - Zero voltage in on-state
  - Zero switching loss



Lower Ron * Area, closer to ideal switch



Littelfuse SiC Strategy

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MONOLITH SEMICONDUCTOR INC.

IXYS

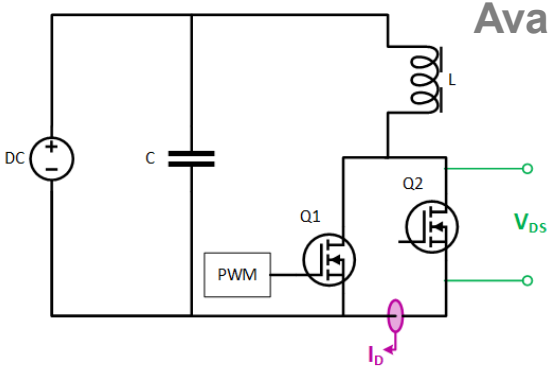
A Littelfuse Technology

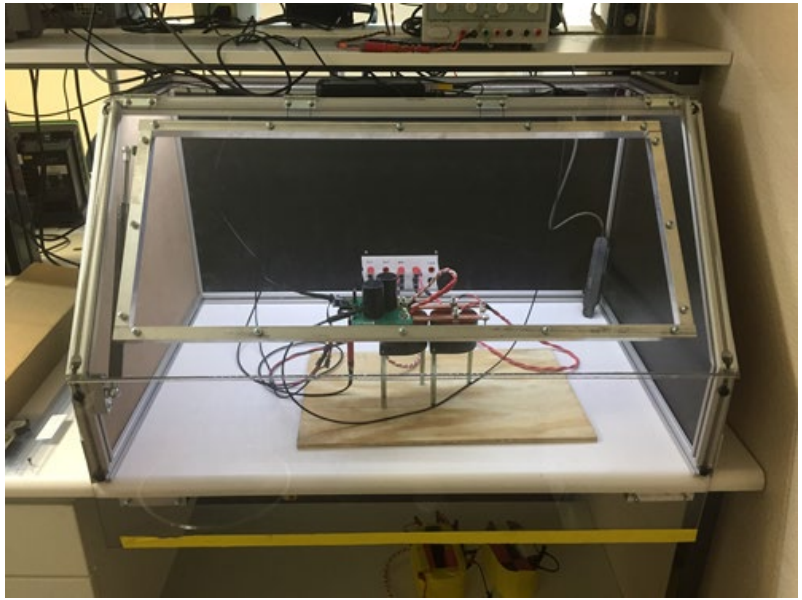
- Industry-leading customer support
- Global manufacturing and supply chain excellence
- Diverse technology portfolio to enrich systems-level engagements
- Extensive industrial and automotive experience

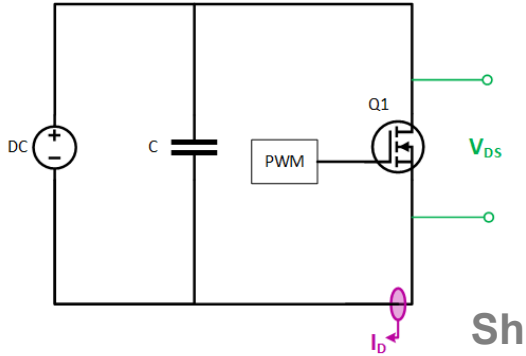
- Deep power semiconductor and applications expertise
- High performance and quality SiC MOSFET and diode technology

UIL Testing Environment

Avalanche Test Circuit

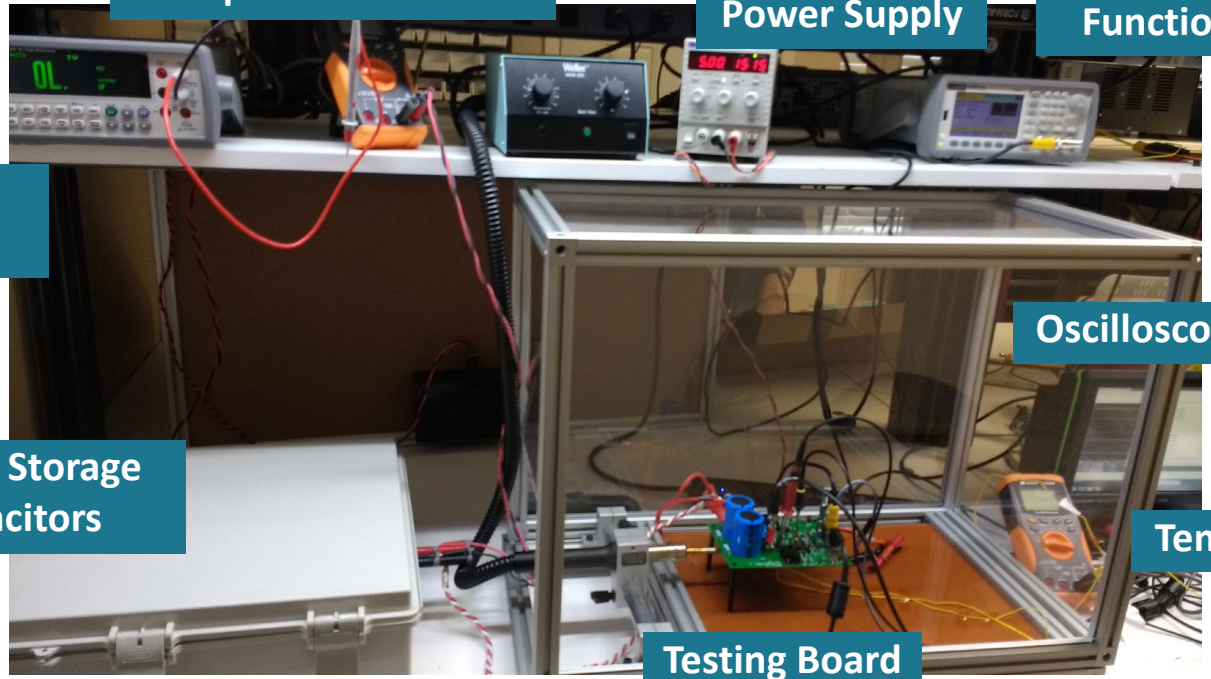






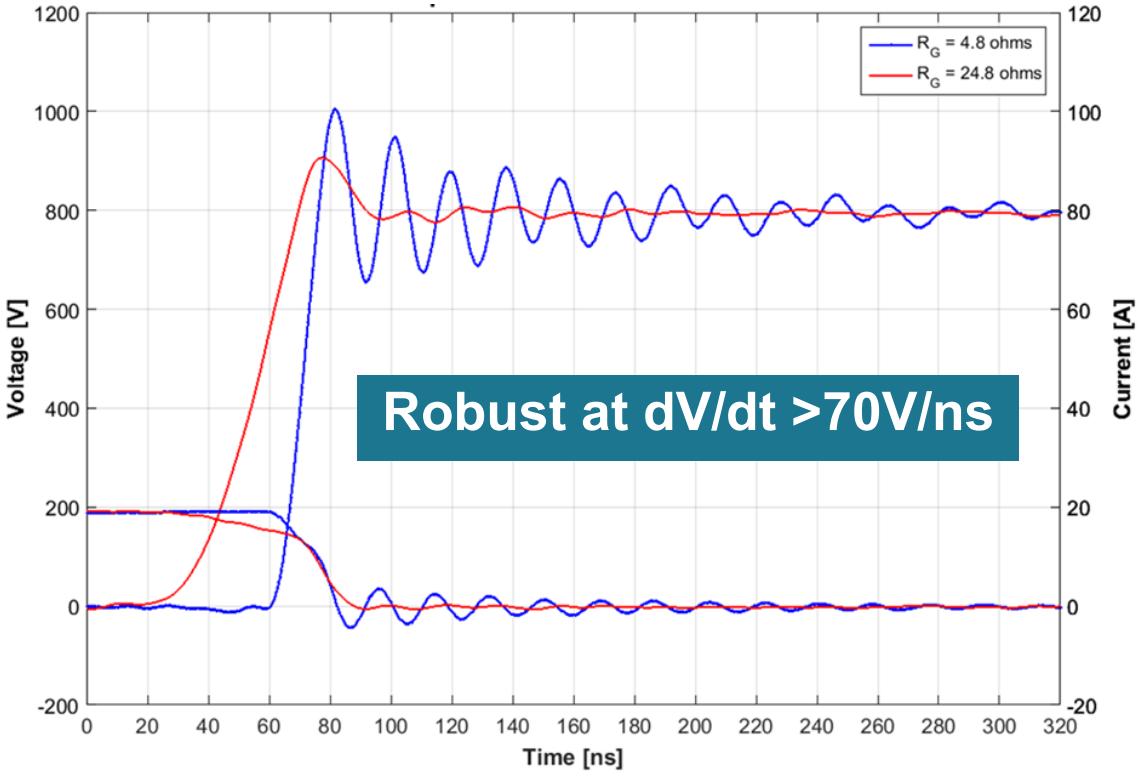
Short-circuit Test Circuit

Dynamic Characterization Testing Environment



Dynamic Characterization

- Switching energy
  - External gate resistance
  - Current
  - Temperature
- Switching times
- Gate charge



Robust at dV/dt >70V/ns

Global Footprint – R&D, Manufacturing & Support

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Beverly, Massachusetts, USA (RD, M)
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S–International Sales
RD–Research & Development
M–Manufacturing