Advanced SiC MOSFETs for High Power Applications


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Device Performance
MOSFET Stability at High Temperature
Threshold voltage drift at 150°C, after -20 V on the gate
Improved Temp. and Current Rating

Higher Temperature

Higher Current

GE12N15

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
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<tbody>
<tr>
<td>$I_D$</td>
<td>Continuous drain current</td>
<td>$V_{GS}=20 \text{ V}, T_C=25^\circ \text{C}$</td>
<td>20.5</td>
<td></td>
<td></td>
<td>A</td>
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<tr>
<td>$I_D$</td>
<td>Continuous drain current</td>
<td>$V_{GS}=20 \text{ V}, T_C=125^\circ \text{C}$</td>
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<tr>
<td>$I_{D,\text{puls}}$</td>
<td>Pulsed drain current $1^1$</td>
<td>$T_C=25^\circ \text{C}$</td>
<td>65</td>
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<tr>
<td>$P_{\text{diss}}$</td>
<td>Power dissipation</td>
<td>$T_C=25^\circ \text{C}$</td>
<td>200</td>
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<td></td>
<td>W</td>
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GE12N20

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<tr>
<td>$I_D$</td>
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<td>$I_{D,\text{puls}}$</td>
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30% reduction in $$/A
Avalanche Ruggedness: UIS
Superior to silicon

\[ Ea = 1.33 \text{J} \]

900V/23A Si CoolMOS\textsuperscript{TM} \((Ea = 1.9\text{J})\)

GE’s 1200V/20A SiC MOSFET \((Ea > 1\text{J})\)

Reduced variability through process optimization

![Graph showing frequency distribution of \(Ea\) over years 2011 and 2012]
Short-Circuit Capability

- Fault detection improves system safety and uptime
- Short-circuit test capability established
- 960V results show $t_{sc}$ between 3.5 and 4us. At lower voltages, $t_{sc}$ increases → sufficient for majority of applications

- Short-circuit test results:

![Graph showing short-circuit time vs. Vds and Id pk vs. time]
SiC MOSFET Body Diode

Buck-Boost: 200 kHz 600V, 6 kW

Assembled a rack with six Buck-Boost converters (total of 24 MOSFETs) for testing of body diode’s long term stability.

Cont. test started mid-2012
Vsd recorded periodically during test

- Diode conducts only 5% of time (250ns out of 5uS). Tj = ~100°C
- No failures after 4500 hrs
- Diode Vsd stable (< 4% increase)
GRC Fab Manufacturing Readiness - MRL7
GRC SiC Pilot Production Line
Installed and Validated Dedicated Toolset in 2011-12

Polyimide coat/develop

Resist coat/develop

RTA

Implant Activation

Metal Deposition

Asher

Caros, HF Acid Bench

Al Etch Acid Bench

Solvent Bench

ICP Etch

Rinser Dryer
Product Introduction Timeline

D=4”

D=3”

D=2.375”

TRL: Tech Readiness Level
MRL: Mfg Readiness Level

Product launch: 3Q2013
Device Reliability
On-wafer MOSFET Reliability Testing
Accelerated stress testing: gate field and temperature

- Extrinsic failures, bottom of bathtub curve (FITs)
- Time=0 failures
- Intrinsic wearout
Lifetime Model
Developed using full MOSFETs

Accelerated stress parameters:
• Gate voltage
• Junction temperature

Use conditions:
• 20V @ 175°C

Extrinsics censored

\[ \eta = \exp (\alpha_0 + \alpha_1 E + \alpha_2 \frac{11605}{T}) \]

\[ \alpha_0 = 17.65 \]
\[ \alpha_1 = -3.47 \text{ cm/MV} \]
\[ \alpha_2 = 0.68 \text{ eV} \]

Design exceeds 100 year goal
Reliability and Qualification Summary

Gate Reliability (HTGB) Assessment:

- Good w2w repeatability
- MOSFET intrinsic lifetime far better than $10^6$ hours goal
- Estimated random failure rate < 10 FITs @ 20V/150°C

Ongoing Qual. efforts (per AEC-Q101)

- HTRB at 175°C, 960 & 1200V: 0/80 failures after 1,000 hrs
- Temp cycling (-55 to +200°C): 0/77 failures after 1,000 cycles
- Moisture Sensitivity Level: MSL-2
Device Packaging and Applications
High Performance Power Module

Traditional Design

- Large parasitic inductance causes high switching losses, electrical stresses
- Wirebonds limit number of chips per module, max operating temperature
- Inefficient thermal management

GE's Solution

- Ultra-low parasitic inductance (5nH) enables faster switching
- Power Overlay simplifies paralleling of many small devices; higher temp. limit
- Integrated heatsink with superior thermal performance
75kW SiC Inverter
Dual function: engine starter + ECS compressor drive

\[ V_{\text{IN}} = +/- 270V_{\text{DC}}, \quad V_{\text{OUT}} = 220V_{\text{LN}}, \quad P_{\text{OUT}} = 75kW, \quad F_{\text{FUND_MAX}} = 1.8kHz \]
75kW SiC Inverter - Efficiency Results

SiC Efficiency Compared to Industry

- SiC 20KHz Measured
- Typ Industry

Efficiency vs. Output Power (KW)
Summary of GE SiC Development
Realizing the full benefit of SiC power electronics