Littelfuse Silicon Carbide Products

Power Electronics Summit
Munich, Germany
December 3, 2019

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Semiconductor Business Unit
Agenda

- SiC Portfolio
  - SiC die and standard packages
  - SiC Gate Drivers
- Advanced Packages
- Littelfuse SiC is Mature
  - Performance
  - Reliability and Ruggedness
- Conclusion
SiC Portfolio

- SiC die and standard packages
- SiC Gate Drivers
SiC Die and Standard Packages

**MOSFETs**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>1200 V</th>
<th>1700 V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 mΩ</td>
<td>1 mΩ</td>
</tr>
<tr>
<td></td>
<td>40 mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>80 mΩ</td>
<td>23 mΩ</td>
</tr>
<tr>
<td></td>
<td>120 mΩ</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>120 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>160 mΩ</td>
</tr>
</tbody>
</table>

**Diodes**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>650 V *</th>
<th>1200 V</th>
<th>1700 V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 A</td>
<td>5 A</td>
<td>10 A</td>
</tr>
<tr>
<td></td>
<td>8 A</td>
<td>8 A</td>
<td>10 A</td>
</tr>
<tr>
<td></td>
<td>10 A</td>
<td></td>
<td>25 A</td>
</tr>
<tr>
<td></td>
<td>16 A</td>
<td>15 A</td>
<td>50 A</td>
</tr>
<tr>
<td></td>
<td>20 A</td>
<td>20 A</td>
<td></td>
</tr>
</tbody>
</table>

* 650 V Diode family is AEC-Q101 qualified

- Planar MOSFET
- Diode configurations that enable up to 120 A total device current rating
- Multi-die configurations
  - Common Cathode
  - Phase Leg
  - Buck / Boost

TO-247-3L TO-247-4L TO-252-2L TO-253-2L TO-263-7L TO-268-2L
SiC Gate Drivers

IXD_600 Series:
- 35V operating voltage
- -40°C to +125°C
- AEC Q100 qualified: IXD_604SI, IXD_609SI, IXD_614SI

New IX4351NE: Specifically designed to drive SiC MOSFETs

Features:
- Separate 9A Sink and Source Outputs
- Operating voltage range of +25V/-10V
- Programmable Charge Pump Regulator for Negative Gate Drive
- TTL/CMOS Logic Level Inputs (referenced to GND)
- Desaturation Detection with Soft Shut Down
- Undervoltage lockout (UVLO)
- Thermal shutdown (TSD)
- Open drain FAULT output
- Regulator output to supply discrete optocoupler
- Thermally enhanced SOIC package

IX4351NE: Samples now!
Gate Driver Evaluation (GDEV) Platform

Key features:
- Half bridge configuration with full driver design
- Full thermal solution for continuous operation
- Easy and accurate measurement
- Optimized gate and power loop design
- Evaluation of MOSFET/Diode performance under continuous switching
- Reference phase leg design for system level performance evaluation

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
</tr>
</thead>
</table>
| IXDN609     | - Wide operating voltage range: 4.5V to 35V  
- Wide operating temperature range: -40ºC to +125ºC  
- Thermally enhanced SOIC package  
- Robust and reliable  
- Available with inverting, non-Inverting and enable logic |
| IXDN614     | - Driver board coming soon to the GDEV platform |
| IX4351NE    | - Driver board coming soon to the GDEV platform |
SiC Advanced Packages
Packaging and power stage layout add parasitic inductance and capacitance.
SiC MOSFETs in TO-247

Comparison 3 Leads vs. 4 Leads

Switching Loss Difference: 25 mΩ, 4L vs. 3L

Switching Loss Difference: 40 mΩ, 4L vs. 3L

Switching Energy Savings: 25 mΩ

Switching Energy Savings: 40 mΩ
SiC Advanced Package Portfolio

Advanced package portfolio:
- Different configurations
- Can use SiC / Si parts
- Combination of MOSFETs, diodes, IGBTs

Advantages of ISOPLUS™ SMPD:
- SMPD in Tape & Reel
- Cost Reduction in Assembly:
  - Standard Solder processes
  - Standard Pick & Place Equipment

Half bridge  Half bridge + NTC/ RTD  Boost + Bypass
Boost  Dual boost
ISOPLUS™ Family
Surface Mount Power Device

ISOPLUS 247

- 2500V isolation voltage (UL recognized)
- Improved current capability
- Low thermal resistance
- Reduces parasitic inductance and capacitance

Power Cycling test:
- 80C temperature cycle (TJ 45 ºC - 125 ºC - 45 ºC)
- IC = 18.3A for 20A / 1200V rated IGBT
- Result:
  High power cycling capability. More than 160,000 cycles without wire bond lift-off!

Comparative Current Capability

160k Power Cycle @ 18.3 A - Δ Tj = 80ºC

Typical for std modules
Littelfuse SiC is Mature

- Performance
- Reliability and Ruggedness
1200 V, 80 mOhm MOSFET Comparison

$R_{DS(ON)}$ vs. Junction Temperature

LF: lowest $R_{DS(ON)}$ variation @ high temperature

Lowest conduction loss
1200 V, 80 mOhm MOSFET Comparison

$R_{\text{DS(ON)}}$ vs. Gate Drive Voltage

Conditions:
- $I_{DS} = 20A$
- $t_p < 400 \mu s$

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

20 V: lowest $R_{\text{DS(ON)}}$

18 V: $R_{\text{DS(ON)}}$ is ~5% > @ 150 °C

Flexible gate drive
1200 V, 80 mOhm MOSFET Comparison
Turn-on Losses – Double Pulse Test

Turn-On Loss Comparison

Notes:
• @ recommended gate drive voltage, LFUS = lowest switching loss
• @ +18 V/0 V driving voltage, LFUS switching loss is similar to competitor trench device
  Note: 2 Ohm external gate resistance
Reliability & Ruggedness
HTRB and HTGB Testing

High Temperature Reverse Bias @ 175 °C
$V_{DS} = 960 \text{ V}$, $V_{GS} = 0 \text{ V}$
LSIC1MO120E0080

High Temperature Gate Bias @ 175 °C
$V_{GS} = -10 \text{ V}$ & $V_{GS} = +25 \text{ V}$
LSIC1MO120E0080

As of 2018-Sep-28
Avalanche Ruggedness
Unclamped Inductive Switching (UIS) and Repetitive UIS

- Repetitive UIS 1200 V, 160 mΩ SiC MOSFET
  - UIS test solution with R-UIS test capabilities
  - Waveforms during R-UIS cycle: period = 20 msec
  - The energy of the unit UIS cycle = 125 mJ

UIS: 1200 V, 80 mΩ SiC MOSFET
Short Circuit Ruggedness & De-sat Protection
Unclamped Inductive Load (UIL)

- X. Zhang, G. Sheh, L. Gant and S. Banerjee, "In-Depth Study of Short-Circuit Robustness and Protection of 1200 V SiC MOSFETs," PCIM Europe 2018
# Body Diode Current Stress

## Test Platform and Test Results After 504 hrs.

**DUT:** up to 30 pcs

**High power current pulse generator**  
Key adjustable parameters  
- Peak Isd  
- Duty  
- Frequency

No sign of shift in any key parameter was observed.  
Sample size: 20 EA

### Accumulated Stress time (Hr)  
<table>
<thead>
<tr>
<th>Time (Hr)</th>
<th>24</th>
<th>48</th>
<th>120</th>
<th>168</th>
<th>336</th>
<th>504</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Isd (A)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>*Duty cycle (%)</td>
<td>9</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>800</td>
</tr>
</tbody>
</table>

![Diagram](image-url)
Terrestrial Cosmic Radiation Data
1200 V, 80 mOhm SiC MOSFET (LSIC1MO120E0080)

- To ensure a FIT rate of 100, the applied voltage should not exceed 1100 V
- For similar current rating, the 1200 V, 80 mOhm SiC MOSFET has a much lower failure rate compared to the Si IGBT at a given reverse voltage:
  - At $V = 1000$ V, FIT rate of Si IGBT is 10,000 vs. 50 for SiC MOSFETs

Experimental FIT rate LSIC1MO120E0080 scaled to neutron flux at sea level as a function of reverse voltage
SiC MOSFET Reliability and Ruggedness

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

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

- Body Diode: Robust, no performance degradation in time

- Terrestrial Cosmic Radiation: Better than Si IGBTs
Conclusion and Key Takeaways

- SiC Technology is Mature and ready for Mass Production

- Littelfuse proposes State of the Art SiC MOSFETs and Diodes in a large variety of packages
  - Discrete & Power Modules, Surface mount & Through hole

- Littelfuse IX4351NE gate driver is specifically designed for SiC MOSFETs and incorporates an internal regulator for selectable negative gate drive bias.

- Littelfuse offers tools and development kit to evaluate its SiC devices and drivers in an actual application
Thank You!

Questions?