Power Electronics for Electric Vehicles

**Main Inverters**
Power: 10kW-200kW

**Auxiliary DC/DC Converters**
Power: 1.5kW-4kW

**On-Board Charger**
Power: 1.5kW-50kW

**Traction Inverter**

**Auxiliary DC/DC Converter**

**Power Technology**
SiC MOSFETs can replace IGBTs with a smaller footprint, reduced losses and greater battery autonomy.

- Usually 3-phase permanent magnet motors are used for traction.
- Operating voltage from 300V to 750V.
- Inverter must be bi-directional:
  - Feeds the electric motor when driving the wheels.
  - Streams energy back on HV Bus when vehicle brakes applied.
- Nominal power ranging from 10kW (ICE assistance) to 200kW (pure EV).
SiC MOSFET Based 80kW Traction Inverter

SiC MOSFETs provide

- More than 50% module/package size reduction
  ✓ Much smaller semiconductor area → ultra compact solution

- >1% efficiency improvement (75% lower loss)
  ✓ Much lower losses at low-medium load → longer autonomy

- 80% cooling system downsize
  ✓ Lower losses at full load → smaller cooling system
  ✓ Lower Delta ($T_j - T_{fluid}$) in the whole load range → best reliability
Power Loss Estimation for 80kW EV Traction Inverter

Switch (S1+D1) implementation

- Topology: Three phase inverter
- Synchronous rectification (SiC version)
- DC-link voltage: $400V_{dc}$
- Current 480Arms (peak) 230Arms (nom)
- Switching frequency: 16kHz
- $V_{gs} = +20V/-5V$ for SiC, $V_{ge} = \pm 15V$ for IGBT
- $\cos(\phi)$: 0.8
- Modulation index (MI): 1
- Cooling fluid temperature: 85°C
- $R_{thJ-C(IGBT-die)} = 0.4^\circ C/W$; $R_{thJ-C(SiC-die)} = 1.25^\circ C/W$
- $T_j \leq 80\% \times T_{j_{max}} ^\circ C$ at any condition

Si IGBT requires antiparallel Si diode, SiC MOSFETs do not

4 x 650V,200A IGBTs + 4 x 650V,200A Si diodes vs.
7 x 650V, 100A SiC MOSFETs SCTx100N65G2
**Power Loss at Peak Condition (480Arms, 10sec)**

SiC MOSFETs run at higher junction temperatures in spite of lower losses. This is due to the exceptional SiC $R_{DSON} \times$ Area FOM.

<table>
<thead>
<tr>
<th>Loss Energy</th>
<th>Si-IGBTs + Si-diodes Solution</th>
<th>Full-SiC Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total chip-area</td>
<td>$400 \text{ mm}^2$ (IGBT) + $200\text{mm}^2$ (diode)</td>
<td>$140 \text{ mm}^2$</td>
</tr>
<tr>
<td>Conduction losses* (W)</td>
<td>244.1</td>
<td>377.9</td>
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<tr>
<td>Turn-on losses* (W)</td>
<td>105.1</td>
<td>24.1</td>
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<tr>
<td>Turn-off losses* (W)</td>
<td>228.4</td>
<td>32.7</td>
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<tr>
<td>Diode’s conduction losses* (W)</td>
<td>45.9</td>
<td>Negligible</td>
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<tr>
<td>Diode’s $Q_{rr}$ losses* (W)</td>
<td>99.5</td>
<td>Negligible</td>
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<tr>
<td>(S1+D1) Total losses* (W)</td>
<td>723</td>
<td>435</td>
</tr>
<tr>
<td>Junction Temperature (°C)</td>
<td>142.8</td>
<td>162.6</td>
</tr>
</tbody>
</table>

* Typical power loss values

4.3x lower

> 4x lower

> 7x lower

40% lower

$T_J \sim 80\% T_{jmax}$
SiC MOSFET Enables Lower Power Dissipation and Higher Efficiency

$f_{sw}=16kHz$, Operating phase current up to $230A_{rms}$

SiC shows much lower losses in the whole load range

Inverter losses vs %load

![Graph showing Inverter losses vs %load]

SiC offers 1% higher efficiency or more over the whole load range!

Inverter efficiency vs %load

![Graph showing Inverter efficiency vs %load]

* Simulated efficiency takes into account only the losses due to the switches and diodes forming the bridge inverter

Lower losses mean smaller cooling system and longer battery autonomy
SiC MOSFETs have the Lowest Conduction Losses

The lowest possible conduction losses can only be achieved with SiC MOSFETs.

When “n” MOSFETs are paralleled the total $R_{DS(on)}$ must be divided by “n” allowing ideally zero conduction losses.

When “n” IGBTs are paralleled the $V_{ce(sat)}$ doesn’t decrease linearly, the minimum achievable on-state voltage drop is about 0.8 – 1V.
# Hard-Switched Power Losses

## SiC MOSFET vs. Si IGBT

<table>
<thead>
<tr>
<th>Parameters &amp; Conditions</th>
<th>Die size (Normalized)</th>
<th>$V_{on}$ typ. (V) @ 25°C, 20A</th>
<th>$V_{on}$ typ. (V) @ 150°C, 20A</th>
<th>$E_{on}$ (µJ) @ 20A, 800V 25°C / 150°C</th>
<th>$E_{off}$ (µJ) @ 20A, 800V 25°C / 150°C</th>
<th>$E_{off}$ 25°C / 150°C difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SiC MOSFET</strong></td>
<td>0.52</td>
<td>1.6</td>
<td>1.8</td>
<td>500 / 450</td>
<td>350 / 400</td>
<td>+15% from 25°C to 150°C</td>
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<tr>
<td><strong>IGBT</strong></td>
<td>1.00</td>
<td>1.95</td>
<td>2.2</td>
<td>800 / 1300</td>
<td>800 / 1900</td>
<td>+140% from 25°C to 150°C</td>
</tr>
</tbody>
</table>

* Including SiC intrinsic body diode $Q_{rr}$  ** Including the Si IGBT copack diode $Q_{rr}$

- Data measured on SiC MOSFET engineering samples;
- SiC MOSFET device: **SCT30N120**, 1200V, 34A (@100°C), 80mΩ, N-channel
- Si IGBT device: 25A(@100°C) 1200V ST trench gate field-stop IGBT ($T_{j\text{max}}$=175°C)
- SiC switching power losses are considerably lower than the IGBT ones
- At high temperature, the gap between SiC and IGBT is insurmountable

> SiC MOSFET is the optimal fit for High Power, High Frequency and High Temperature applications

![SiC die size compared to IGBT](image)
SiC MOSFETs offer more efficient solutions at higher switching frequency and smaller size.

On-Board Charger

Single-phase architecture ➔ SiC MOS 650V
Three-phase architecture ➔ mainly SiC MOS 1200V
Power Rectifiers for OBC

All AEC-Q101 qualified PPAP capable

- **Input bridge**
  - 1000V / 1200V rectifiers and thyristors
  - Auto-grade rectifiers:
    - 1000V diodes
    - 1000V low-\(V_F\) diode
    - 1200V diodes
    - STT6010WY
    - STT8010WY
    - STT1210WY
  - Auto-grade thyristor:
    - Hi temperature 1200V SCR
    - TN5050H-12WY
    - Function: inrush protection in mixed-bridge topology + disconnection of the bridge in idle mode

- **PFC**
  - 600V / 650V rectifiers
  - Auto-grade SiC Schottky rectifiers:
    - STPSC6C065DY
    - STPSC10H066DY
    - STPSC12C065DY
    - STPSC20H065CTY
    - STPSC20H065CWY
  - Auto-grade ultrafast rectifiers:
    - 6A to 20A, 650V SiC
    - STPSC6C065DY
    - STPSC10H066DY
    - STPSC12C065DY
    - STPSC20H065CTY
    - STPSC20H065CWY

- **Secondary Rectification**
  - 600V rectifiers
  - Auto-grade ultrafast rectifiers:
    - 5A & 8A, 600V
    - STT6R06-Y
    - STT8R06-Y
    - Low \(Q_R\)
    - STT50ST606-Y
    - Low \(V_F\)
    - STT30L06-Y
    - Low \(Q_R\) Soft recovery
    - STT60T06-Y
  - 30A, 600V
    - STT6R06-Y
    - STT8R06-Y
    - Low \(Q_R\)
    - STT50ST606-Y
    - Low \(V_F\)
    - STT30L06-Y
    - Low \(Q_R\) Soft recovery
    - STT60T06-Y
  - 60A, 600V
    - STT6R06-Y
    - STT8R06-Y
    - Low \(Q_R\)
    - STT50ST606-Y
    - Low \(V_F\)
    - STT30L06-Y
    - Low \(Q_R\) Soft recovery
    - STT60T06-Y

- **Auto-grade rectifiers**:
  - 1000V diodes
  - 1000V low-\(V_F\) diode
  - 1200V diodes
  - STT6010WY
  - STT8010WY
  - STT1210WY

- **Auto-grade thyristor**:
  - Hi temperature 1200V SCR
  - TN5050H-12WY
  - Function: inrush protection in mixed-bridge topology + disconnection of the bridge in idle mode
SiC MOSFET improves PFC Boost Topologies

### Interleaved PFC boost, single phase

VDC(OUT)=400V, Switch: SiC MOSFET, 650V, 25mOhm(25C,typ), Diode: 600V SiC Schottky, 20A (STPSC20H065C-Y), $T_J=125^\circ C$

### Totem-pole semi-bridgeless PFC boost, single phase

VDC(OUT)=400V, Switch: SiC MOSFET, 650V, 25mOhm(25C,typ), $T_J=125^\circ C$

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**PFC Boost Topologies**

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<td>3.67</td>
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<td>240VAC, 27Arms</td>
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<td>220VAC, 32Arms</td>
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<td>144.27</td>
<td>39.87</td>
<td>97.951%</td>
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</tbody>
</table>

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**More compact, Lower Power Loss**
Auxiliary DC/DC converter

ST can cover the whole system with state-of-the-art technologies including SiC and Isolated GAP drivers.

**High voltage MOSFETs**
- **MDmesh™ M2 series**
  - Not automotive grade yet
  - Proves to be the best choice in resonant converters while representing the best option for low/medium power PFC
- **MDmesh™ M5 series**
  - For higher power density designs & very low Rdson
- **FDmesh™ II**
  - For Full Bridge Phase Shifted ZVS

**Sensors and signal conditioning**
- TSX Series op-amp
- TSC10 current sensor

**Power Mng**
- LDO, DC/DC converter
- A8834, A6491, GapDRIVE™

**Gate drivers**
- Insulated HB driver
- Dual channel gate driver

**Control unit**

**Diodes**
- STPS family of power Schottky (from 30V up to 150V)
- STripFET VI DeepGATE (40V, 60V)
- STripFET VII DeepGATE (40V, 75V, 100V)

**MOSFETs**
- MDmesh™ M2 series
  - Not automotive grade yet
  - Proves to be the best choice in resonant converters while representing the best option for low/medium power PFC
- **MDmesh™ M5 series**
  - For higher power density designs & very low Rdson
- **FDmesh™ II**
  - For Full Bridge Phase Shifted ZVS

**Low voltage MOSFETs, power Schottky diodes**
New 80/100V MOSFET Series: STripFET F7

ST cover the complete system with state-of-the-art technologies including SiC and Isolated GAP drivers

- STH315N10F7-2 / STH315N10F7-6
- $R_{\text{dson}}$ 1.9 mΩ typ
- $V_{\text{DS}} = 100$ V
- $I_D = 180$ A
- 100% avalanche tested
- $T_{\text{jmax}} 175°$ C
- Available in H²PAK-2/6
- AEC Q101 qualified in KGD die form

Already used for 48V DC/DC converters by key customer
Power Technology

ST offers both silicon and silicon carbide discrete power components

- SiC Schottky Rectifiers
- IGBTs
- gapDRIVE™
- SiC MOSFETs
- Silicon MOSFETs
# Automotive Grade Rectifier Portfolio

## Ultrafast, SiC and Schottky

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</table>

- **Ultrafast** (Cyclone
- **SiC**
- **Schottky**

In Development

Qualified (SiC)

Qualification (Ultrafast)

Sept 2016
# Automotive Grade SiC Rectifier

## SiC Schottky

### SiC New blank series 650V

<table>
<thead>
<tr>
<th>Part number</th>
<th>(I_{F(AV)})</th>
<th>(V_F) [max] @(I_0)</th>
<th>(I_{PSM}) [A]</th>
<th>(I_{R}) [(\mu A)]</th>
<th>(Q_{cj}) [nC]</th>
<th>Packages</th>
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<td>300</td>
<td>60</td>
<td>2000</td>
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### SiC 1200V

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<tr>
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<th>(I_{PSM}) [A]</th>
<th>(I_{R}) [(\mu A)] max</th>
<th>(Q_{cj}) [nC] typ</th>
<th>Package</th>
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<td>1.5</td>
<td>2.25</td>
<td>440</td>
<td>110</td>
<td>800</td>
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</tbody>
</table>
SiC 650 V G2 and 1200 V technology: using JBS (Junction-Barrier Schottky)

The addition of P+ implantation in the Schottky structure creates P/N junctions. The surge forward current capability can be increased while keeping $T_J < T_J(\text{MAX})$.

JBS blocking the positive thermal coefficient effect
ST SiC Schottky Rectifiers have Superior Forward Surge Capabilities

The ST advantage

...Clamping effect more efficient for ST device
ST SiC Schottky Rectifiers exhibit Smaller Temperature Swing

Comparing to other vendor (using electro-thermal model)

Better clamping effect and lower $V_F$ permits to significantly reduce the junction temperature during transient phases in the application.

Impact on thermal fatigue

**1000W PFC start-up Pspice simulation**
90V, 70kHz, $C_{out} = 600\mu F$, $L = 270\mu H$, $T_c = 125^\circ C$
ST SiC Rectifier Benefits

The ST SiC advantage

**Soft switching behaviour**
- Low EMC impact → easy design/certification → Good time to market

**High forward surge capability (G2)**
- High robustness → Good reliability of the power converter
- Easy design → Good time to market
- Possibility to reduce diode caliber → BOM cost reduction

**Low forward conduction losses and low switching losses**
- High efficiency → high added value of the power converter
- Possibility to reduce size and cost of the power converter

**High power integration (dual-diodes)**
- BOM cost reduction
- High added value of the power converter
- Gain on PCB and mounting cost
Silicon IGBT Technologies

Switching Frequency vs. Break Down Voltage

- **V** (50 – 100 kHz, 20A - 80A)
- **HB** (16 – 60 kHz, 20A - 80A)
- **H** (20 – 100 kHz, 15A, 25A, 40A)
- **IH** (8 – 50 kHz, 20/30A)

**Switching frequency**
- 100 kHz
- 100 kHz
- 30 kHz
- 30 kHz

**Break Down Voltage**
- 600 V
- 650 V
- 1200 V
- 1250 V

**Applications**
- **Welding**
- **Home Appliances** (fan, pump, washing, dryer)
- **Solar Inverters**
- **Motor Control**
- **UPS, Aircon, Compressor**
- **Solar, Welding, Aircon, Washing, PFC-CCM, Induction Heating, Microwave, Printer**
- **Solar Inverter, Welding, Washing PFC-CCM, UPS Aircon Compressor**
- **Solar Inverter, Welding, PFC-CCM, UPS Aircon Compressor**
- **Induction Heating, Microwave, Printer**

**Packages**
- TO-247/TO-247 (LL)
- MAX-247 LL
- TO-3P
- TO-3PF
- TO-220FP
- TO-220
- DPARK2PAK
- TO-220
- TO-3P
- TO-247/TO-247 (LL)
- MAX-247 LL

**Development**
- AG
- AG
- Development
650V “M” Series IGBTs

Trench field stop technology

Thin IGBT wafer technology at 650 V for a more rugged, efficient and reliable power drive system. For EV/HEV motor control

Key Features

- A wide Product Range up to 120A
- 175°C max junction temperature
- Very Low VCE(sat) (1.55V typ) at ICN 100°C
- Self ruggedness against short circuits events
- Low switching-off losses
- Safe paralleling
- Optimized co-packed free wheeling diode option
- AEC-Q101 qualified for die form in T&R KGD
Auto Grade Thyristors

In-rush current limiting SCR for OBC

<table>
<thead>
<tr>
<th>Features</th>
<th>TN5050H</th>
<th>TN3050H</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DRM} / V_{RRM}$</td>
<td>1,200 V</td>
<td>1,200 V</td>
</tr>
<tr>
<td>Max $T_J$</td>
<td>-40°C to +150°C</td>
<td>-40°C to +150°C</td>
</tr>
<tr>
<td>$V_{DSM} / V_{RSM}$</td>
<td>1300 V</td>
<td>1400 V</td>
</tr>
<tr>
<td>$I_{TRMS} (T_e=125°C)$</td>
<td>80 A</td>
<td>30 A</td>
</tr>
<tr>
<td>$I_{TSM} (10ms,25°C)$</td>
<td>580 A</td>
<td>300 A</td>
</tr>
<tr>
<td>$V_{TO} (150°C)$</td>
<td>0.88V</td>
<td>0.88V</td>
</tr>
<tr>
<td>$R_D (150°C)$</td>
<td>6 mΩ</td>
<td>14 mΩ</td>
</tr>
<tr>
<td>$I_{GT} (25°C)$</td>
<td>10 to 50 mA</td>
<td>10 to 50 mA</td>
</tr>
<tr>
<td>$dV/dt (800V-150°C)$</td>
<td>1 kV/µs</td>
<td>1 kV/µs</td>
</tr>
</tbody>
</table>

A better way to turn on your system

Design Value
- AEC-Q101 PPAP Available on request
- High switching life expectancy
- Enable system to resist 6kV surge
- High speed power up / line drop recovery
# Existing Isolation Technologies

## Isolation technologies

<table>
<thead>
<tr>
<th>Polymeric/Ceramic Isolation</th>
<th>Thick Oxide Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isolation:</strong> film of <em>polymer</em> (or other dielectric such as DAF, glass). Custom assembly process required.</td>
<td><strong>Isolation:</strong> <em>Silicon Oxide</em> grown on top of active silicon area (standard silicon IC technologies)</td>
</tr>
</tbody>
</table>

### RF Couplers
- Good parametric stability over time
- Good CMTI immunity
- Limited communication speed
- Assembly complexity

### Optocouplers
- Dielectric ageing: parametric instability over time
- Limited CMTI immunity

### Capacitive coupling
- Good parametric stability over time
- Limited CMTI immunity
- Sensitive to electric fields

### Magnetic coupling
- Good parametric stability over time
- Very good CMTI immunity
- Good immunity to magnetic and electric fields
gapDRIVE™: Galvanically Isolated Gate Driver

Main Applications

- **Industrial Drive**
- **EV / HEV**

Galvanically Isolated Gate Driver technology

- **Automotive (Hybrid/Electric Vehicles)**
  - Motor Control
  - DC/DC Converters
  - Battery Chargers
- **Industrial**
  - 600/1200 V Inverters
  - Automation, Motion Control
  - Welding
- **Power Conversion**
  - Solar Inverters
  - UPS Systems
  - AC/DC, DC/DC Converters
  - Windmills
- **Home/Consumer**
  - Induction Cooking
  - White goods

The STGAP1S *galvanically isolated* gate driver, features advanced controls, protections and diagnostic.

- **CONTROL**: A SPI interface to enable, disable and configure several features → Optimize your driving conditions.
- **PROTECTION**: Several features to manage anomalous conditions (OCP, DESAT, 2LTO, VCE_Clamp) and to prevent them (UVLO, OVLO, ASC, MillerCLAMP)
- **DIAGNOSTIC**: The SPI interface allows access to registers containing information about the status of the device.
STGAP1S – Main Features

Galvanically Isolated Gate Driver technology

**AEC-Q100 grade 1**
Wide operating range (-40°C -125°C)

- **SPI Interface**
  Parameters programming and diagnostics
  Daisy chaining possibility

- **Advanced features**
  5A Active Miller clamp, Desaturation,
  2-level turn-off, VCEClamp, ASC

- **Short propagation delay**
  (100 ns typ.; 130 ns max over temperature)
  5 A sink/source current

- **Fully protected – System safety**
  UVLO, OVLO, Over-Current, INFilter,
  Thermal Warning and Shut-Down

- **High Voltage Rail up to 1.5 kV**
  Positive drive voltage up to 36 V
  Negative Gate drive ability (-10 V)
### STGAP1S Isolation Characteristics

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Test Conditions</th>
<th>Characteristic</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Working isolation Voltage</td>
<td>$V_{IORM}$</td>
<td>Method a, Type and sample test $V_{PR} = V_{IORM} \times 1.6$, $t_m = 10$ s</td>
<td>1500</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial discharge $&lt; 5$ pC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Method b, 100% Production test $V_{PR} = V_{IORM} \times 1.875$, $t_m = 1$ s</td>
<td>2400</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial discharge $&lt; 5$ pC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input to Output test voltage</td>
<td>$V_{PR}$</td>
<td>$2400$ VPEAK</td>
<td>2400</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2815$ VPEAK</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transient Overvoltage</td>
<td>$V_{IOTM}$</td>
<td>Type test; $t_{ini} = 60$ s</td>
<td>4000</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td>Maximum Surge isolation Voltage</td>
<td>$V_{IOSM}$</td>
<td>Type test;</td>
<td>4000</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td>Isolation Resistance</td>
<td>$R_{IO}$</td>
<td>$V_{IO} = 500$ V at $T_S$</td>
<td>$&gt; 10^9$</td>
<td>Ω</td>
</tr>
<tr>
<td>Isolation Withstand Voltage</td>
<td>$V_{ISO}$</td>
<td>1 min. (type test)</td>
<td>2500/4356</td>
<td>$V_{rms}/PEAK$</td>
</tr>
<tr>
<td>Isolation Test Voltage</td>
<td>$V_{ISO, test}$</td>
<td>1 sec. (100% production)</td>
<td>3000/4242</td>
<td>$V_{rms}/PEAK$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creepage (Minimum External Tracking)</td>
<td>CPG</td>
<td>8</td>
<td>mm</td>
<td>Measured from input terminals to output terminals, shortest distance path along body</td>
</tr>
<tr>
<td>Comparative Tracking Index (Tracking Resistance)</td>
<td>CTI</td>
<td>≥ 400</td>
<td></td>
<td>DIN IEC 112/VDE 0303 Part 1</td>
</tr>
<tr>
<td>Isolation group</td>
<td></td>
<td>II</td>
<td></td>
<td>Material Group (DIN VDE 0110, 1/89, Table1)</td>
</tr>
</tbody>
</table>
SiC MOSFET Technology Roadmap

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards

Mass Production

SCT10N120
- 1200V 50mΩ (typ)
- \( T_{j(\text{max})} = 200°C \)

SCT20N120
- 1200V 169mΩ (typ)
- \( T_{j(\text{max})} = 200°C \)

SCT30N120
- 1200V 80mΩ (typ)
- \( T_{j(\text{max})} = 200°C \)

SCT50N120
- 1200V 52mΩ (typ)
- \( T_{j(\text{max})} = 200°C \)

1700V 1st Gen
- \( R_{DS(\text{ON})} \leq 1.0 \Omega \)
- \( R_{DS(\text{ON})} \leq 100 \text{ mΩ} \)

1200V 2nd Gen
- Improved \( R_{\text{on}} \times Q_g \) (30 mΩ)

650V 2nd Gen
- 55 mΩ in H3PAK-7L
- AEC-Q101

650V 2nd Gen
- 55 mΩ
- H3PAK-7L & HiP247

650V 2nd Gen
- 55 mΩ
- H3PAK-7L & HiP247

1200V 3rd Gen
- 10 mΩ
- 50 mΩ

750V 2nd Gen
- 8 mΩ
- 30 mΩ Industrial

Conforms with IEC60664-1, IEC60747-5-2 and UL1577 standards

<2016 2017 2018
Silicon-Carbide MOSFETs

Key Benefits

- Extremely low Energy Losses and Ultra-Low $R_{DS(on)}$ especially at very high $T_j$
  - Higher operating frequency for smaller and lighter systems

- Good Thermal Performance
  - High operating temperature ($T_{j\text{max}} = 200^\circ C$)
  - Reduced cooling requirements & heat-sink, Increased lifetime

- Easy to Drive
  - Fully compatible with standard Gate Drivers

- Very fast and robust intrinsic body diode
  - More compact Inverter
On-Resistance Versus Temperature

ST SiC MOSFET shows lowest Ron at high temperatures

ST is the only supplier to guarantee max Tj as high as 200°C in plastic package

ST (SiC) • Nearest Comp. (SiC) • Silicon MOSFET (900V)
Wide Bandgap Materials

SiC represents a radical innovation for power electronics

<table>
<thead>
<tr>
<th>Property</th>
<th>Si</th>
<th>GaN</th>
<th>4H-SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_g$ (eV) – Band gap</td>
<td>1.1</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>$V_s$ (cm/s) – Electron saturation velocity</td>
<td>$1 \times 10^7$</td>
<td>$2.2 \times 10^7$</td>
<td>$2 \times 10^7$</td>
</tr>
<tr>
<td>$\varepsilon_r$ – dielectric constant</td>
<td>11.8</td>
<td>10</td>
<td>9.7</td>
</tr>
<tr>
<td>$E_c$ (V/cm) – Critical electric field</td>
<td>$3 \times 10^5$</td>
<td>$2.2 \times 10^6$</td>
<td>$2.5 \times 10^6$</td>
</tr>
<tr>
<td>$k$ (W/cm K) – thermal conductivity</td>
<td>1.5</td>
<td>1.7</td>
<td>5</td>
</tr>
</tbody>
</table>

- $E_g$: low on resistance
- $V_s$: Higher switching frequency, Lower switching losses
- $E_c$: low leakage, high Tj
- $k$: Operation > 200 °C, Reduced Cooling Requirements
SiC MOSFETs are not all the same
ST 650V 2nd Gen SiC MOSFETs

ST SiC MOSFET shows lowest Ron increase at high temperatures

ST is the only supplier to guarantee max Tj as high as 200°C

Gate driving voltage = 20V

Full Maturity: July 2016 (Industrial Grade)

Full Maturity: H1 2017 (Automotive Grade)
**Silicon Carbide MOSFET Packages**

**Through hole proposal**
- Able to guarantee 200 °C as max Junction temperature
- The 4L option (with kelvin source) coming soon
- Basically the same of the well known industry standard TO-247 with some improvements on the process.
- HiP247 standard lead and with long leads version already in production

**SMD**
- Compatible with H2PAK package used for Silicon MOSFET
- Rated @ 175 °C
- H2PAK 7L option with kelvin source to improve the switching performance
- Qualification on going

**NEXT STEP:** PowerFLAT™ 8x8 qualification
HV Silicon Power MOSFET Technologies

MDmesh™ M5-Series
- The leading technology for hard-switching topologies
  
  **Key Features**
  - Industry's lowest $R_{DS(on)}$ in the Market
  - High switching speed
  - 550 / 650V classes

  **Benefits**
  - Highest efficiency in the application
  - Smaller form factor of final system
  - Especially targeted for hard switching (PFC, Boost, TTF, Flyback)

MDmesh™ M2-Series
- The best fit for resonant / LLC topologies
  
  **Key Features**
  - Up to 30% lower $Q_g$ (equivalent die size)
  - Optimized $C_{oss}$ profile
  - 400 / 500 / 600 / 650V classes

  **Benefits**
  - Reduced switching losses through optimized ($Q_g$) ($C_{iss}$, $C_{oss}$)
  - Enhanced immunity vs ESD & Vgs spikes in the application
  - Especially targeted for HB LLC, TTF, Flyback..)

SuperMESH™ K5-Series
- State-of-the-art in the VHV (Very-High-Voltage) Class
  
  **Key Features**
  - Extremely good $R_{DS(on)}$ at very high $BVDSS$
  - High switching speed
  - 800 / 850 / 950V classes available now
  - 1050 / 1.2k / 1.5kV classes in development

  **Benefits**
  - High efficiency with lower design complexity
  - Especially targeted for flyback LED topologies and high voltage range in the application

MDmesh™ DM2-Series
- The best fit for F/B ZVS topologies
  
  **Key Features**
  - Integrated fast body diode
  - Softer commutation behavior
  - Back-to-Back G-S zener protected
  - 500 / 600 / 650V classes

  **Benefits**
  - Reduced switching losses through optimized ($Q_g$) ($C_{iss}$, $C_{oss}$)
  - High peak diode $dV/dt$ capabilities
  - Best use in Full Bridge ZVS

MDmesh™ M2-Series
- The leading technology for hard-switching topologies
  
  **Key Features**
  - Industry’s lowest $R_{DS(on)}$ in the Market
  - High switching speed
  - 550 / 650V classes

  **Benefits**
  - Highest efficiency in the application
  - Smaller form factor of final system
  - Especially targeted for hard switching (PFC, Boost, TTF, Flyback)
Silicon: MDmesh™ 600-650V SJ Technologies

Short Term Roadmap

Hard switching

- **MDmesh™ M5**
  - Lowest $R_{DS(on)}$ per package

Resonant

- **MDmesh™ M2-EP**
  - Ultra low $Q_G$

- **MDmesh™ DM2**
  - Fast Diode

- **MDmesh™ M6**
  - First 600V 99mΩ under devel.
  - ES in April 15

Next Gen for Resonant Topologies

- **MDmesh™ M6**
  - First 600V 99mΩ under devel.
  - ES in April 15
LV Silicon Power MOSFET Technologies

Mass Production

STripFET F7 [100V]
- Low on-state resistance
- High current capability
- Extremely low thermal resistance
- Reduced EMI for motor control

STripFET H7 [30V]
- Low on-state resistance
- High quality & reliability

STripFET H6 [30V]
- Low on-state resistance
- High quality & reliability

STripFET F7 [40V]
- Low on-state resistance
- SOA/Rdson balance
- ESD and EMI best in class

STripFET F7 LL [40-45V]
- Low on-state resistance
- Extremely low thermal resistance
- High quality & reliability

Automotive Grade

STripFET F7 [150V]
- Low on-state resistance
- High current capability
- Extremely low Rth
- High quality & reliability

STripFET F8 [150V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET H8 [30V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET H8 [25V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET F7 [120V]
- Low on-state resistance
- High current capability
- Extremely low Rth
- High quality & reliability

STripFET F8 [100V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET H8 [30V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET F8 [80V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET F6/F7 [80V]
- Low on-state resistance
- High current capability
- Extremely low thermal resistance
- Reduced EMI for motor control

STripFET F7 [120V]
- Low on-state resistance
- High current capability
- Extremely low Rth
- High quality & reliability

STripFET F7 [100V]
- Low on-state resistance
- High current capability
- Extremely low Rth
- High quality & reliability

STripFET F8 [100V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET F8 [40-45V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET F8 [100V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability

STripFET H8 [25V]
- Very low on-state resistance
- Extremely low FoM
- High quality & reliability