SiC power modules for your electric vehicle design

STMicroelectronics
STPOWER Silicon Carbide (SiC) MOSFET offers for electric vehicles

Why stronger demand for e-vehicles boosts the need for Silicon Carbide (SiC)

Silicon Carbide in vehicle applications

STPOWER Silicon Carbide
The enabling technology for automotive applications
Why stronger demand for electric vehicles boosts the need for SiC

Replacing silicon based IGBTs and Diodes by SiC solutions will result in

- Higher efficiency and extended vehicle range
- Smaller form cost and weight
- Less cooling effort and faster recharging
Electrification Boosted by Power Silicon & New Materials will Accelerate Growth of a Flattish Light Vehicles Market

Continuous and Consistent Growth of Electrified Light Vehicles - xEVs

Total xEV* [Mu]

- Total Electrified Vehicle **CAGR ‘19-’25** → **>28%**
- By **2025 Battery Electric Vehicles** will be **>25%** of Total Electrified Vehicles

Silicon Carbide allows Battery Electric Vehicles to go Beyond the Limits of Silicon

Replacing Silicon based IGBTs and Diodes in the **Traction Inverter** and **On-Board Charger** by **SiC MOSFETs** resulting in:
- Higher efficiency
- Smaller form cost & weight
- Less cooling effort
- Faster recharging
- Extended vehicle range

Today **>40% BEVs** are using **SiC**

*including Mild Hybrid, Full Hybrid, Plug-in Hybrid, Battery Electric Vehicle

**xEV source:** SA, IHS, ST Internal

**SiC source:** IHS, Feb 20, ST internal
Silicon Carbide Market Outlook

SiC power semiconductors by application

<table>
<thead>
<tr>
<th>Application</th>
<th>CAGR Y'18-'25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>52%</td>
</tr>
<tr>
<td>Industrial**</td>
<td>12%</td>
</tr>
<tr>
<td>Others*</td>
<td>13%</td>
</tr>
</tbody>
</table>

SiC power semiconductors by macro product family

<table>
<thead>
<tr>
<th>Segment</th>
<th>2019</th>
<th>2028</th>
<th>CAGR (19-28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction</td>
<td>983.7</td>
<td>4831.5</td>
<td>13.6%</td>
</tr>
<tr>
<td>Aerospace and Military</td>
<td></td>
<td></td>
<td>18.1%</td>
</tr>
<tr>
<td>PV inverters</td>
<td></td>
<td></td>
<td>17.0%</td>
</tr>
<tr>
<td>Industrial Motor Drives</td>
<td></td>
<td></td>
<td>10.0%</td>
</tr>
<tr>
<td>EV charging stations</td>
<td></td>
<td></td>
<td>430%</td>
</tr>
<tr>
<td>Commercial vehicles</td>
<td></td>
<td></td>
<td>70.4%</td>
</tr>
<tr>
<td>HEV/EV</td>
<td></td>
<td></td>
<td>46.5%</td>
</tr>
<tr>
<td>UPS</td>
<td></td>
<td></td>
<td>34.1%</td>
</tr>
<tr>
<td>Power supplies</td>
<td></td>
<td></td>
<td>17.5%</td>
</tr>
<tr>
<td>** Others**</td>
<td></td>
<td></td>
<td>21.0%</td>
</tr>
</tbody>
</table>

Source: IHS – SiC & GaN Power Semiconductor Report (May 2019), mid case. (SAM by segments including: SiC MOSFET + SiC Diodes + Hybrid modules + full SiC modules)

*Military and aerospace, traction, Other applications
**renewable energies applications included

Silicon Carbide Continuous Growth

[$ m] CAGR_{(19-28)} : 25.5%

CAGR_{(19-28)}

- Others: 13.6%
- Traction: 18.1%
- Aerospace and Military: 17.0%
- PV inverters: 10.0%
- Industrial Motor Drives: 430%
- EV charging stations: 70.4%
- Commercial vehicles: 46.5%
- HEV/EV: 34.1%
- UPS: 17.5%
- Power supplies: 21.0%

Silicon Carbide Continuous Growth

[x 5]

2019  | 2028  | CAGR_{(19-28)}

- Others: 13.6%
- Traction: 18.1%
- Aerospace and Military: 17.0%
- PV inverters: 10.0%
- Industrial Motor Drives: 430%
- EV charging stations: 70.4%
- Commercial vehicles: 46.5%
- HEV/EV: 34.1%
- UPS: 17.5%
- Power supplies: 21.0%
One key technology based on Wide Band Gap (WBG) semiconductors for multiple applications

**Traction Inverter:** Converts DC Voltage into 3-phase AC at up to 200kW for the electric motor

**DC-DC Charger:** Converts High Voltage DC from High Voltage batteries

**On-Board Charger (OBC):** Converts AC from the Grid 95+265 V\textsubscript{ac} to a DC voltage required for battery charging 400÷800V
Wide Band Gap Technology Mapping

<table>
<thead>
<tr>
<th>Technology</th>
<th>Features</th>
<th>Preferred for (some example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si HV MOSFET</td>
<td>Medium-high power, high voltage, up to several kW, high frequency</td>
<td>SMPS, server and telecom, DC/DC, low power motor control, OBC, charging station, …</td>
</tr>
<tr>
<td>IGBT</td>
<td>Very high power, high voltage, medium frequency up to 50 kHz</td>
<td>HV motor control, H.A., UPS, welding, induction heating, main traction, …</td>
</tr>
<tr>
<td>SiC MOSFET</td>
<td>Very high power, high voltage, high frequency, high temperature ratings</td>
<td>High power DC/DC, UPS, charging station, main traction inverters, OBC, …</td>
</tr>
<tr>
<td>GaN Transistor</td>
<td>Very high frequency &gt; 80 kHz, medium-high power up to several kW</td>
<td>SMPS, Telecom Power, DC/DC, OBC, PV inverters, LiDAR, …</td>
</tr>
</tbody>
</table>

Operating frequency

System power level
• SiC MOSFETs, results in higher efficiency, smaller form factor, less complexity in cooling Vs. Si approach

• High power DC-DC converter for fast and reliable DC Charging reduces the charging time of HEVs and EVs
SiC technology for traction inverter

To enhance traction inverter efficiency

- High power inverter stage to drive the vehicle traction motor.

- Replacing silicon based IGBTs and diodes in the inverter stage by SiC MOSFETs, results in higher efficiency, smaller form factor, less cooling requirements, …

- Comprehensive ST portfolio of STPOWER SiC MOSFETs as bare die, package or module solution in 650 V as well as 1200 V technology.
SiC technology for HV DC-DC converter

To minimize conduction and switching losses

• High voltage DC-DC converter to **boost battery voltage up**, enabling operation of the traction motor within optimized voltage range.

• High voltage DC-DC converter for fast and reliable **DC Charging** in dual voltage domains reducing significantly the charging time of HEVs and EVs.

• **STPOWER** SiC MOSFET solutions from ST operate at **higher switching frequency** and at **higher temperature** enabling
  - minimized magnetic losses
  - a smaller, lighter cooling system
  - the highest power levels
SiC technology for on-board charger

To speed-up systems charging time

- **Charging the battery** of plug-in HEVs and EVs from the single-phase or 3-phase power grid.

- Different architectures and topologies in automotive are required to **support scalable solutions**.

- ST solutions enable **compact and efficient** designs
  - STPOWER SiC MOSFETs & SiC Diodes
  - STPOWER SJ MOSFETs, IGBTs, fast Diodes & SCRs
STPOWER Silicon Carbide
The enabling technology for automotive application

ST best-in-class SiC Technology

ST offers a broad range of SiC solutions: Discrete, Bare Dice, Module

ST continue capacity expansion to support market acceleration

ST invests on advanced package technologies with HiP247-4™ leads, HU3PAK™, STPAK™, ACEPACK™ SMIT
STPOWER SiC MOSFET families

Overview

The best high voltage and high frequency switch for high density applications

Gen1
1200V-1700V

The best option for $R_{ON}$ vs. $T_j$ behavior: highly suitable for motor drive applications

Gen2
650V, 1200V

The best $R_{ON}$ vs. $Q_g$ trade-off: highly suitable for a broad range of automotive and industrial applications

Gen3
650V, 750V, 900V, 1200V

An ultra-fast series with the best $R_{ON}$ vs. $Q_g$ trade off: highly suitable for very high frequency applications

SiC MOSFET: the true R-evolution for high voltage power switches
STPOWER Silicon Carbide
the enabling technology for automotive applications

### Silicon Carbide product portfolio

**AG 650V SiC MOSFETs: Gen 2 High Voltage Product Family in production**
- SCTx35N65xx
- SCTx100N65xx

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H²PAK-7</td>
<td></td>
</tr>
<tr>
<td>HiP247™</td>
<td></td>
</tr>
<tr>
<td>HiP247™ long leads</td>
<td></td>
</tr>
</tbody>
</table>

**AG 1200V SiC MOSFETs: Gen 2 Very High Voltage High Product Family in production**
- SCTx40N120xx
- SCTx70N120xx
- SCTx100N120xx

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
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<tr>
<td>H²PAK-7</td>
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<td></td>
</tr>
<tr>
<td>HiP247™ long leads</td>
<td></td>
</tr>
</tbody>
</table>

### Main applications

- Traction Inverter
- Power DC-DC Converter

### Key benefits

- Smaller form factor with high power density
- Higher system efficiency at high frequency
- Reduced size/cost of passive components
- Low power losses at high temperatures
- Compact design and cost-effective system approach
- Simpler topologies
**STPOWER ACEPACK** module
Adaptable Compact Easier PACKage

**Option**

**A1 - A2 (*)**

- 100% controlled by ST for SiC, MOSFETs, IGBTs and Diodes
- Compact design and cost-effective system approach for a plug & play system solution
- Configuration flexibility
- 2500 $V_{RMS}$ electrical isolation

**SMIT (**)**

- 2500 $V_{RMS}$ electrical isolation
- SMD assembly
- Total footprint 32.7 x 22.5 mm
- Top side cooling
- Low thermal resistance

**DRIVE (**)**

- Optimized for 200 kW inverters
- SiC MOSFET based switch
- Improved light load power losses for extended EV driving ranges
- Extreme low conduction losses
- Short circuit ruggedness
- Direct cooled Cu base plate with pin fins

**Key features**

- CIB
- Six-pack
- Three level
- Boost interleaved
- ....

**Configurations**

- Bridge rectifier
- Half-bridge
- Single-boost
- ....

**Target Applications**

- On Board Charger
- DC-DC Converter
- Traction Inverter

(*) available (***) Engineering Samples available

* Is a registered and/or unregistered trademark of STMicroelectronics International NV or its affiliates in the EU and/or elsewhere
STPOWER SiC MOSFET product portfolio by application

Breakdown Voltage

- 650 V
- 750 V
- 1200 V
- 1700 V

Series

- Gen2
- Gen3
- Gen3
- Gen1
- Gen2
- Gen3
- Gen1

On-state resistance

- 18 mOhm to 55 mOhm
- 55 mOhm
- 11 mOhm
- 52 mOhm to 520 mOhm
- 25 mOhm to 75 mOhm
- 70 mOhm and 15 mOhm
- 1 Ohm and 65 mOhm

Focus Applications

- OBC & DC-DC
- Renewable energy
- Power Supply
- Industrial drives
- OBC & DC-DC
- Power Supply
- Solar
- DC-DC
- Renewable energy
- Photovoltaic
- HVAC
- Power supply
- OBC & DC-DC
- Inverter
- Street Lighting
- Charging stations
- Industrial drives
- Inverter
- DC-DC
- Power Supply
- DC-DC
- Power Supply
- Renewable energy
30+ years’ experience with STPOWER and Discrete

The success factor of fast growing EV market

<table>
<thead>
<tr>
<th>GaN HEMT</th>
<th>HV Si MOSFET: MDmesh</th>
<th>IGBT</th>
<th>ST commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>650 V and 100 V normally off solutions to boost efficiency and power density thanks to fast switching operation</td>
<td><strong>Super-Junction MultiDrain</strong></td>
<td><strong>High Power IGBT Trench Field-stop</strong></td>
<td><strong>Investing in new facilities to sustain Power Silicon growth</strong></td>
</tr>
<tr>
<td>OBC</td>
<td><strong>Higher Efficiency</strong></td>
<td><strong>Narrow MESA</strong></td>
<td><strong>Agrate Fab 300mm</strong></td>
</tr>
<tr>
<td>48V DC-DC</td>
<td><strong>Higher Voltage Range</strong></td>
<td><strong>Electric heater and aircon</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>More Power Density</strong></td>
<td><strong>OBC and DC-DC</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>OBC and DC-DC converter</strong></td>
<td><strong>PTC Heater, OBC, aircon</strong></td>
<td></td>
</tr>
<tr>
<td>Continue innovation on Power Package</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **2SPAK**
- **PowerFLAT 8x8 DSC**
- **STPAK**
- **TO-LL**
- **PowerFLAT 8x8 HV**
- **HU3PAK**
- **ACEPACK SMIT**
- **ACEPACK 1, 2**
- **ACEPACK DRIVE**
Thank you