Power Semiconductors for New Energies

September 2019

Alfredo Arno
Power Semiconductors for New Energies

- High Power Modules & Drivers
- Intelligent Power Modules SLIMM
- Si HV & LV
- SiC & GaN
New Energies World Scenario

Potential Saving

- Energy saving via improvements in conversion efficiency is the best way to reduce power consumption and, consequently, minimize energy waste.

- Transportation consumes More than 20% of world energy.
- By 2020 more than 30 billion Smart Things needing power will need power.
- Electric lighting uses 20% of global electricity.
- Industry consumes More than 50% of world energy.
- Electric motors use 60% of industry electricity.
Power Discrete in HEV EV

Key Elements in Electric Vehicle

DC-DC HV
- HV MOSFET DM2
- SiC MOSFET
- Modules
- TVS

Battery Management Systems (BMS)
- LV MOSFET
- Schottky
- TVS

DC-DC HV to 12V
- HV MOSFET DM2/DM6
- LV MOSFET
- TVS

Traction Inverter
- SiC MOSFET and IGBT
- Modules
- TVS

On-Board Charger (OBC)
- HV - SCR, Diodes, SiC Diodes & MOSFETs, M5/DM2/DM6
- LV – MOSFETs and Diodes
- Modules
- TVS

DC-DC HV to 48V
- HV MOSFET DM2/DM6
- LV MOSFET
- TVS
Automotive Discrete Products

Diodes, Thyristors & TVS

MOSFETs & IGBTs

Filters & Protection

New: SiC, FERD, Flat Packages & Modules

Safety
- Airbag
- Camera
- RADAR

Body & Convenience
- BCM & gateways
- Dashboard
- HVAC
- LED
- Roof & Seat Control

Door Zone
- Doors
- Mirror

Powertrain for HEV
- Bidirectional Aux Power Converter
- Electric Traction
- AC/DC (On Board Charger)
- Main Inverter
- Start-stop

Powertrain for ICE
- CNG/LPG engine control
- Direct Injection
- Transmission

Infotainment & Telematics
- Infotainment
- Sound system
- Telematics
- Vehicle-to Everything (V2X)

Chassis
- ABS and ESC
- Active suspension
- Electric power steering
- Electric park and brake

Discrete Products 20% content of Auto Electronics (60% of Auto Power Electronics)
## ACEPACK™ Modules

**Adaptable, Compact and Easier PACKage**

### Key features

- 100% controlled by ST for silicon (SiC, MOSFET, IGBT and Diodes)
- Compact design and cost-effective system approach for a plug & play system solution
- Configuration flexibility
- 2500Vrms electrical isolation

### Configurations

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

### Target Applications

- Bridge rectifier
- Half Bridge
- Boost
- ....

### Key features

- SMD assembly
- Top side cooling
- Low thermal resistance
- Reduced parasitic inductance and capacitance
- 2500Vrms electrical isolation

### Configurations

- Six-pack

### Key features

- Optimized for 200 kW inverters
- 1200V 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

### Configurations

- Six-pack
Features and Benefits

**ACEPACK™ 1 & 2**

**Adaptable**

- Press FIT and solder pins options, configuration flexibility
- Up to 1200V breakdown voltage
- Integrated screw clamps
- All power switches in a module including NTC
- Several current ratings available

**Compact**

- Several configurations (CIB, 6-pack ..) available and low stray inductance
- High reliability and robustness, miniaturized power side board occupation
- Simplified and stable screwing
- Compact design and cost-effective system approach

**Easier**

- Very high power density
2500Vrms electrical isolation

SMD assembly

Dice chips on Direct Bond Copper (DBC) substrate

Reduced parasitic inductance and capacitance

Suitable for several switching technologies

Several configurations available and low stray inductance

High reliability and robustness, miniaturized power side board occupation

Compact design and cost effective system approach

Very high power density

Ideal to realize a complete system

High level of modularity
ACEPACK™ Drive
Compact Solution for Traction Inverter

Very High Power Density with Direct Cooling for EV and HEV

Main Features & Benefits
- Large output power range >200 kW
- 750V - 1200V SiC MOSFET based switch
- Improved light load power losses for extended EV driving ranges
- Extremely low conduction losses
- Direct Cooled Copper Base Plate with pin fins
ACEPACK™ Drive Evaluation Kit

Very High Power Density with Direct Cooling for EV and HEV
Intelligent Power Module Portfolio

Wide Current Range Scalability

Complete Product Portfolio

- From 1A up to 35A
- Includes ST Driver IC, MOSFET, IGBT and Diode
- Assures package compactness and thermal performance
IPMs – SLLIMM™ Family
Small Low Loss Intelligent Molded Module

- **SLLIMM nano series**
  - 600V IGBT
  - 500V MOSFET
  - 1 up to 3A
  - NDIP (TH)
  - NSDIP (SMD)
  - 12.45 x 29.15 x 3.10 mm

- **SLLIMM nano 2nd series**
  - 600V IGBT
  - 600V SJ-MOSFET
  - 3 up to 8A
  - N2DIP (TH)
  - 12.45 x 32.15 x 4.10 mm

- **SLLIMM 2nd series**
  - 600V IGBT
  - 600V SJ-MOSFET
  - 8 up to 35A
  - SDIP2F-26L
  - SDIP2B-26L
  - 24 x 38 x 3.5 mm

Power range:
- 20W
- 100W
- 500W
- 3000W
**SLLIMM™ 2nd Series**

**Product**

- **Switch type**: IGBT, SJ MOSFET
- **Voltage rating**: 600V
- **Current capability**:
  - IGBT: 8A, 10A, 15A
- **Package**: SDIP2F-26L, SDIP2B-26L

**Features**

- TFS IGBT and SJ MOSFET based technologies
- High current scalability
- Full molded and DBC package
- Thermal sensor and NTC thermistor option
- Comparator, UVLO, Shutdown function

**Benefits**

- Improved thermal performances
- Best $R_{th}$ value in the market
- Temperature monitoring
- Protection embedded inside the power module
- High efficiency at low load applications

**Application**

- Washing machines
- Refrigerators
- Air conditioners
- Sewing machines
- Pumps
- Compressor
- Servo motors
- Any inverter system up to 3kW

1.1 °C/W
SLLIMM™ Nano Series

Product

<table>
<thead>
<tr>
<th>Switch type</th>
<th>MOSFET</th>
<th>IGBT</th>
<th>MOSFET</th>
<th>IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage rating</td>
<td>500 V</td>
<td>600 V</td>
<td>500 V</td>
<td>600 V</td>
</tr>
<tr>
<td>Current capability</td>
<td>1A, 2A</td>
<td>3A</td>
<td>1A, 2A</td>
<td>3A</td>
</tr>
<tr>
<td>Package</td>
<td>NDIP (12.45x29.15)</td>
<td>NSDIP (12.45x29.15)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Features

- IGBT and MOSFET based technologies
- Optimized voltage drop in conduction
- Through-hole (TH) and SMD packages
- In line or zig-zag leads
- NTC thermistor option
- Comparator, UVLO, Interlocking function

Benefits

- High flexibility and robustness
- Improved efficiency and reliability
- Package compactness
- Temperature monitoring
- Protection embedded inside the power module

Application

- Small fans
- Roller shutters
- Dish washer
- Compressor
- Pumps
- Refrigerators
SLLIMM™ Nano 2nd series

**Product**

<table>
<thead>
<tr>
<th>Switch type</th>
<th>SJ-MOSFET</th>
<th>IGBT (planar, TFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage rating</td>
<td>600 V</td>
<td></td>
</tr>
<tr>
<td>Current capability</td>
<td>3A, 5A</td>
<td>3A, 5A, 8A</td>
</tr>
<tr>
<td>Package</td>
<td>N2DIP (12.45x29.15)</td>
<td></td>
</tr>
</tbody>
</table>

**Application**

- Small fans
- Roller shutters
- Dish washer
- Compressor
- Pumps
- Refrigerators
- Washing machines

**Features**

- TFS IGBT and SJ-MOSFET based technologies
- Optimized voltage drop in conduction
- In line or zig-zag leads w/wo stand-off option
- Slots for heatsink screw
- NTC thermistor option
- Comparator, UVLO, Interlocking function

**Benefits**

- High flexibility, robustness and improved efficiency
- Improved isolation voltage up to 1.5 kVrms/min
- Package compactness and thermal performances
- Temperature monitoring
- Protection embedded inside the power module
- High efficiency at low load applications
Power Semiconductors for New Energies

- SiC Schottky Rectifiers
- IGBTs
- gapDRIVE™
- SiC MOSFETs
- Silicon MOSFETs
Rectification On Board Charger

- Bridge and Bridgeless
  - AC/DC
  - DC-DC

SiC Diodes
- Bridge and Bridgeless
- Soft Start ICL
- Thyristors TVS
- Bridge Rectifiers
- SiC MOSFET
  - Si HV MOSFET (M5, DM6, DM2)
- Rapid Quiet Rectifiers
- Gate driver

Voltages:
- $V_{outDC}$
- $V_{bat} = [200\text{V}-80\text{V}]$

New technologies: 1, 8, 7, 6, 9
# High-Voltage Power MOSFET

## Superjunction Technology

### Breakdown Voltage

<table>
<thead>
<tr>
<th>Voltage Range</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>600V</td>
<td>M2, M6</td>
</tr>
<tr>
<td>650V</td>
<td>DM2, DM6</td>
</tr>
<tr>
<td>800V – 1700V</td>
<td>M5, DM2, DM6, K5</td>
</tr>
</tbody>
</table>

### MDmesh series

<table>
<thead>
<tr>
<th>Component</th>
<th>Focus Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>M2</td>
<td>Flyback, PFC/LLC resonant converter – Charger adapters, LED lighting</td>
</tr>
<tr>
<td>M6</td>
<td>Flyback, PFC/LLC high efficiency resonant converter – Charger adapters</td>
</tr>
<tr>
<td>DM2</td>
<td>Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS</td>
</tr>
<tr>
<td>DM6</td>
<td>Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS</td>
</tr>
<tr>
<td>M5</td>
<td>Hi-end-power PFC and hard switching topologies Solar, Server, Telecom SMPS</td>
</tr>
<tr>
<td>DM2</td>
<td>Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS</td>
</tr>
<tr>
<td>DM6</td>
<td>Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS</td>
</tr>
<tr>
<td>K5</td>
<td>Flyback topology LED driver, LED lighting, auxiliary SMPS</td>
</tr>
</tbody>
</table>

### Focus Applications

- Flyback, PFC/LLC resonant converter – Charger adapters, LED lighting
- Flyback, PFC/LLC high efficiency resonant converter – Charger adapters
- Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS
- Hi-end-power PFC and hard switching topologies Solar, Server, Telecom SMPS
- Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS
- Half/full bridge topologies, ZVS, LLC Solar, Server, Telecom SMPS
- Flyback topology LED driver, LED lighting, auxiliary SMPS
High-Voltage MOSFET Series

- **MDmesh™ M2**: Ron in package
  - 400V
  - 5Ω
  - 1.3Ω
  - 1.8Ω
  - 5Ω

- **MDmesh™ M5**: Ron in package
  - 550V
  - 380mΩ
  - 36mΩ
  - 100mΩ
  - 15mΩ

- **MDmesh™ M6**: Ron in package
  - 600V
  - 42mΩ
  - 1.8Ω
  - 1.55Ω
  - 1.3Ω

- **MDmesh™ DM2**: 480mΩ
- **MDmesh™ DM6**: 380mΩ
- **MDmesh™ K5**: 80mΩ
MDmesh™ Technology Overview
High-Voltage MOSFETs

**MDmesh™ M5 (550V ÷ 650V)**
Permits reduction of switching losses and targets higher power density
- Enabler for High-Power PFC

**MDmesh™ M2/DM2 (600V ÷ 700V)**
Optimized switching characteristics with very low turn-off switching losses, suitable for most high-frequency converters
- Enabler for FlyBack

**MDmesh™ M6/DM6 (600V ÷ 700V)**

**MDmesh™ K5 (800V ÷ 1700V)**
Allows operation over very-high voltage range
- Enablers for High Efficiency

**MDmesh™ M6/DM6 (600V ÷ 700V)**
Allows higher levels of efficiency (Platinum, Titanium) Due to its ideal performance – Saves Energy to achieve climate goals
- Enablers for Converters
MDmesh™ M6: New Super-Junction MOSFET Family

600V - 650V - 700V MDmesh™ M6: Advance in high-efficiency topologies

The ideal switch to boost efficiency

- **Latest** HV MOSFET (600V - 650V - 700V) series
- **Targeted** for ZVS & LLC Bridge topologies
- **Improved** Efficiency at light load conditions
MDmesh™ M6: Technology Features for Resonant Converters

- New diffusion process and the optimization of MDmesh™ M2
- Thermal SPICE model also available on web
- Optimized diffusion process to enhance resonant converter performance

<table>
<thead>
<tr>
<th>Optimized threshold voltage</th>
<th>Optimized Coss</th>
<th>Low gate charge</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

- Reduced switching losses
- Increase Power Efficiency at light load
- High-frequency operation
MDmesh™ M6: Advantages in Resonant Topologies

**System Power Efficiency**

- **Power Out (W)** vs. **Power Eff. (%)**
- **STF24N60M6** vs. **Competitor**

**STF24N60M6 Best Efficiency and Tcase Across Load**

- 69 °C
- 40 °C
- + 72%

Average of the Tcase values measured on two couples of the same p/n

**Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>STF24N60M6</th>
<th>C1</th>
</tr>
</thead>
<tbody>
<tr>
<td>* BV&lt;sub&gt;dd&lt;/sub&gt; min (V)</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td>* R&lt;sub&gt;DS(on)max&lt;/sub&gt; (mΩ)</td>
<td>190</td>
<td>180</td>
</tr>
<tr>
<td>* V&lt;sub&gt;GS(th) typ&lt;/sub&gt; (V)</td>
<td>4</td>
<td>3.5</td>
</tr>
</tbody>
</table>

* Datasheet values
MDmesh™ M6

600 to 700V MDmesh™ M6
High-voltage, SJ MOSFETs
To boost the efficiency

MDmesh™ M6 technology offers improved PFC and LLC efficiency especially at light load conditions for increased power density

PORTFOLIO available on your mobile

Promotion

More Efficiency

To explore the complete MDmesh™ M6 product portfolio, visit www.st.com or use our ST-MOSFET-Finder mobile app for Android and iOS
600V & 650V IGBTs Series
in Trench Gate Field Stop

Higher performances in home appliances as well as high frequency converter

- Best Trade-off Static-Dynamic Characteristics
- Max junction temperature of 175°C
- Tail-less switching off waveforms
- Very fast freewheeling diode for very low $E_{on}$

<table>
<thead>
<tr>
<th>Breakdown Voltage</th>
<th>600V</th>
<th>650V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>5 to 20 A</td>
<td>20 to 80 A</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>8 to 30 kHz</td>
<td>50 to 100 kHz</td>
</tr>
</tbody>
</table>

| IGBT series | H | V | M | HB | HB2 | IH |

<table>
<thead>
<tr>
<th>Focus Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home appliances (fans, pumps, washing machines and dryers)</td>
</tr>
<tr>
<td>Welding, high frequency converters, PFC, solar, UPS, charger</td>
</tr>
<tr>
<td>Industrial motor control, automotive traction inverter, GPI, Air-Con</td>
</tr>
<tr>
<td>High frequency converters, PFC, solar, UPS, charger, welding and induction heating</td>
</tr>
<tr>
<td>Induction heating and soft switching</td>
</tr>
</tbody>
</table>

* Enlargement in development
≥1200V IGBTs Series in Trench Gate Field Stop

For rugged, efficient and reliable industrial power drives and more

- Best trade-off Static-Dynamic Characteristics
- Max junction temperature ($T_{j \text{ max}}$) of 175°C
- From 2 up to 100 kHz
- Very fast freewheeling diode option

<table>
<thead>
<tr>
<th>Breakdown Voltage</th>
<th>1200V</th>
<th>1250V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>15 to 75 A</td>
<td>8 to 75 A</td>
</tr>
<tr>
<td></td>
<td>15 to 40 A</td>
<td>20 A, 30 A</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>Up to 8 kHz</td>
<td>2 to 20 kHz</td>
</tr>
<tr>
<td></td>
<td>20 to 100 kHz</td>
<td>16 to 60 kHz</td>
</tr>
</tbody>
</table>

IGBT series
- S
- M
- H
- IH

Focus Applications
- Industrial motor control, GPl, Air-Con
- PFC, welding, high frequency converters, solar, UPS, charger
- Induction heating, microwave and soft switching
STripFET™ F7
40-100V Power MOSFET Technology

Key Characteristics
- Among the best RDS(on) in the market
- Minimal RDS(on) x Qg (FoM)
- Low input capacitances
- Optimized Crss/Ciss capacitance ratio
- High avalanche ruggedness
- Low intrinsic diode recovery charge

Features
- Extremely Low Rds(on)
- Optimized body diode (low Qrr)
- Intrinsic capacitances (Optimal capacitance Crss/Ciss ratio)
- ST provides several package solutions, including PowerFLAT 5x6 and H²PAK

Benefits
- Low conduction losses
- Excellent switching performance (higher efficiency)
- No EMI issue
- A more complete solution provided to the customer

Application
- Power Tools
- Fork Lifts
- Electric Light Transportation
- TELECOM and SERVER
- SMPS
- Adapter/Battery Charger
- UPS
- Solar Inverter
- Lighting/Display

- Adapter/Battery Charger
- UPS
- Solar Inverter
- Lighting/Display
STripFET™ F8
30-150V Power MOSFET for High End > 500KHz

Applications

- Power Tools
- Fork Lifts
- Electric Light Transportation
- Telecom and Servers

- SMPS
- Adapter/Battery Charger
- UPS
- Solar Inverter
- Lighting/Display

Features

- Lower $R_{DS(on)} \times \text{Area} \ (-40\% \ Vs. \ F7)$
- Extremely Low $Q_g/Q_{gd}$
- $Q_{rr}$ & Soft switching F7 like
- Extremely low thermal resistance

Benefits

- Reduced conduction power losses
- Reduced switching losses and passive sizes
- Reduced noise immunity
- Improved current capability and power dissipation
- Low EMI & turn on losses
- Extended package offer to enhance silicon performance
650V-1200V G2 SiC Rectifiers for EV

SiC 650V G2 and 1200V Technology: using JBS (Junction-Barrier Schottky)

- Soft switching behavior
- Low forward conduction losses
- Low switching losses
- High forward surge capability
- High power integration

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

Graph: Bipolar behavior vs. Schottky behavior
650V-1200V G2 SiC

Superior performances vs competition

**SUPERIOR FORWARD SURGE CAPABILITY**
More efficient clamping effect vs. best Competitor

**SMALLER TEMPERATURE SWING**
Better clamping effect and lower $V_F$ reduces the $T_{junc}$ during transient phases in the application.

1000W PFC start-up Pspice simulation
90V, 70kHz, $C_{out} = 600\mu F$, $L = 270\mu H$, $T_c = 125^\circ C$
650V SiC Diode Portfolio

Extend Package Portfolio with Flat Package

- **Low VF**
  - 40A: STPSC40065C
  - 20A: STPSC20065
  - 16A: STPSC12065
  - 10A: STPSC10065
  - 8A: STPSC8065

- **High Surge Capability**
  - 20A: STPSC20H065C
  - 12A: STPSC12H065C
  - 10A: STPSC10H065
  - 8A: STPSC8H065C
  - 6A: STPSC6H065
  - 4A: STPSC4H065

- **PowerFLAT™ 8x8 HV**

- Package Options: TO247, TO-220, TO-220I, D²PAK, DPAK

650V
AG Thyristors for EV Charging

Features

<table>
<thead>
<tr>
<th>Features</th>
<th>TN5050H</th>
<th>TN3050H</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DRM} / V_{RRM}$</td>
<td>1,200V</td>
<td>1,400V</td>
</tr>
<tr>
<td>Max $T_J$</td>
<td>-40°C to +150°C</td>
<td></td>
</tr>
<tr>
<td>$V_{DSM} / V_{RSM}$</td>
<td>1300V</td>
<td>1400V</td>
</tr>
<tr>
<td>$I_{TRMS} (T_C=125°C)$</td>
<td>80A</td>
<td>30A</td>
</tr>
<tr>
<td>$I_{TSM} (10ms,25°C)$</td>
<td>580A</td>
<td>300A</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></td>
</tr>
</tbody>
</table>

Design Value

- AEC-Q101 PPAP Available on request
- High switching life expectancy
- Enable systems to resist 6kV surge
- High speed power up / line drop recovery

A smart way to turn on your system
ST Fast Rectifier for EV Charging

ST Rectifiers for Input Bridge & Output Resonant

STBR: Lower $V_F$ / Lower drop

STRQ: $Q_{RR}$ better by factor of 2 and Soft switching
## Existing Isolation Technologies

### Isolation Technologies

<table>
<thead>
<tr>
<th>Polymeric/Ceramic Isolation</th>
<th>Thick Oxide Isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolation: film of <strong>polymer</strong> (or other dielectric such as DAF, glass). Custom assembly process required.</td>
<td>Isolation: <strong>Silicon Oxide</strong> 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

Galvanically Isolated Gate Driver technology

- Automotive (Hybrid/Electric Vehicles)
  - Motor Control
  - DC/DC Converters
  - Battery Chargers
- Industrial
  - 600/1200V 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, protection and diagnostics.

- **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.

Main Applications

- Industrial Drive
- EV / HEV
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)
  5A 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 36V
  Negative Gate drive ability (-10V)
# 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 Partial discharge &lt; 5 pC</td>
<td>1500</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td></td>
<td>$V_{PR}$</td>
<td>Method b, 100% Production test $V_{PR} = V_{IORM} \times 1.875$, $t_m = 1$ s Partial discharge &lt; 5 pC</td>
<td>2400</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2815</td>
<td>$V_{PEAK}$</td>
</tr>
<tr>
<td>Input to Output test voltage</td>
<td></td>
<td></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>$\Omega$</td>
</tr>
<tr>
<td>Isolation Withstand Voltage</td>
<td>$V_{ISO}$</td>
<td>1 min. (type test)</td>
<td>2500$3536</td>
<td>$V_{rms}\ \text{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}\ \text{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>
650V & 1200V SiC MOSFETs
The real boost for efficient designs

Lower Losses, High Efficiency, Reduced Footprint: Breakthrough in High-Voltage Converters

- Leading to new technology platform with awesome Figure Of Merit
- Very low on-state resistance
- 200°C Max junction temperature
- Very fast and robust intrinsic body diode
- Industrial and Automotive Grade qualified
- Outstanding system efficiency and reduced cooling requirements

Applications

- Traction inverters
- On board chargers
- DC-DC converters
- SMPS

- Auxiliary power supplies
- UPS
- Solar
- Welding
MOSFET $R_{DS(on)}$ Figure of Merit at $T_J=150^\circ$C

![Graph showing MOSFET performance]
$R_{DS(on)}$ Variation with Temperature

1200V SiC MOSFET

ST is the only supplier to guarantee max Tj as high as 200°C in plastic package
Silicon Carbide allows Power Devices to go beyond the limits of Silicon...

Why Silicon Carbide?
It’s all about the Bandgap

- Smaller Size
- Lower Energy Losses
- Higher Voltages
- Higher Speeds
- Higher Operating Temperatures

...and makes high-voltage power-applications smarter
Challenges for Silicon Carbide

Technical
- Defectivity
- Reliability

Manufacturing
- Triangle SFS
- Buried SFS
- PIT = MP
- Reliability

Capacity

April 1998
1st contract on SiC with CNR-IMETEM (Dr. V. Raineri)

May 2002
Schottky Diode Demonstrator (CNR line)

December 2005
Schottky Diode Mat 20

February 2003
ETC Epitaxial reactor prototype installed in ST

October 2007
1st Gen Diode Start Production

May 2004
Schottky Diode Demonstrator (ST line)

March 2009
Power MOSFET 3” Demonstrator

November 2003
First ST internal product request

May 2004
Power MOSFET 3” Demonstrator

June 1996
Collaboration with Physics Dept. (Prof. G. Foti)

May 2004
Schottky Diode Demonstrator (ST line)

December 2005
Schottky Diode Mat 20

October 2007
1st Gen Diode Start Production

May 2012
2nd Gen Diode Start Production

June 2003
2” ST line

June 2006
3” ST line

June 2011
4” ST line

June 2014
3rd Gen 3 Diode Start Production

June 2014
3rd Gen 3 Diode Start Production

June 2017
2nd Gen MOSFET AG 6” Start Production

June 2016
6” ST line

ST Silicon Carbide
20-Year History

Pioneers...
...to mass production
SiC MOSFET Facts at Glance

Front-end Evolution

1st Gen
Planar
In Production

2nd Gen
Planar

3rd Gen
Planar
Sampling 2019
Production 2020

4th Gen
Trench
Prototypes 2020

Continuous Shrinkage
$[R_{on} \times \text{cm}^2]$ - x4 shrink

SiC adoption faster than expected

x2 shrink

x3 shrink

x4 shrink

2017
2018
2019

Units shipped per year

650 V to 1200 V MOSFETs and DIODEs

Discrete Packages

Bare Dice Strategic offer for Key Players

SiC Module focus for Largest Market

SiC Module

In Production

Ramp-up by H1‘19

ACEPACK™

STPAK™

ACEPACK™ 1

ACEPACK™ 2

ACEPACK™ DRIVE

Production 2020

ACEPACK™ SMIT

Production 2020

HU3PAK™
Advantages of SiC in Traction Inverters

Drive Train Electrification: Enabled by SiC Technology

<table>
<thead>
<tr>
<th></th>
<th>Silicon IGBT + Diode</th>
<th>SiC MOSFET</th>
<th>Traction Inverter - End User Value Proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die area for 100A nominal current [mm²]</td>
<td>150</td>
<td>30</td>
<td>Power Semiconductors size: Up to 70% smaller</td>
</tr>
<tr>
<td>Max Junction temperature [°C]</td>
<td>175</td>
<td>200</td>
<td>Cooling System: Up to 70% smaller</td>
</tr>
<tr>
<td>Normalized switching energy</td>
<td>8</td>
<td>1</td>
<td>Passive Components: Up to 80% smaller (**)</td>
</tr>
<tr>
<td>Normalized Power Loss(*) (Typical Mission profile)</td>
<td>7</td>
<td>1</td>
<td>Up to 10% Mileage Extension</td>
</tr>
<tr>
<td>Average junction temperature at nominal power [°C] (*)</td>
<td>100</td>
<td>80</td>
<td>Extended life in use</td>
</tr>
</tbody>
</table>

1200V

(*) 210kWpeak, 350Arms peak, 200Arms continuous Traction Inverter, 750V bus, f<sub>PWM</sub>=10kHz, T<sub>fluid</sub> = 60°C

(**) applicable to High Power DC to DC converter when present
Si IGBT vs. SiC MOSFET – 1200V

Silicon Solution: IGBT + Diode
4x100 mm² + 4x50 mm²

5x smaller semiconductor area

SiC MOSFET gen 3
Solution: 6x20 mm²

Higher efficiency for extra mileage

Vbus = 750V, 200kW peak!!

DC-link voltage: 750V, Switching frequency: 10 kHz, Tfluid = 65°C, mi=0.5

From 3.5 to 10% higher efficiency

Si IGBT

SiC MOSFET

Lower temperature for higher reliability

350A rms peak – 210kW, 200A rms nominal, DC-link voltage: 750V, Switching frequency: 10 kHz, Tfluid = 65°C

250 miles

250 miles

Higher efficiency for extra mileage
SiC MOSFET System Benefits – 1200V
Reducing PCU size

- 200A\text{rms} continuous
- DC-link voltage: 750V\text{dc}
- Switching frequency: 10 kHz
- T_{fluid} = 65°C

Up to 70% smaller PCU
# Advantages of SiC in Traction Inverters

## Drive Train Electrification: Enabled by SiC Technology

<table>
<thead>
<tr>
<th>Metric</th>
<th>Silicon IGBT + Diode</th>
<th>SiC MOSFET</th>
<th>Traction Inverter - End User Value Proposition</th>
</tr>
</thead>
</table>
| Die area for 100A nominal current [mm²] | 100 | 26 | **Power Semiconductors size:**
| Max Junction temperature [°C] | 175 | 200 | **Up to 60% smaller**
| Normalized switching energy | 6 | 1 | **Cooling System:**
| Normalized Power Loss(*) (Typical Mission profile) | 4 | 1 | **Up to 50% smaller**
| Average junction temperature at nominal power [°C] (*) | 100 | 90 | **Passive Components:**
| | | | **Up to 60% smaller (**)**
| | | | **Up to 6% Mileage Extension**
| | | | **Extended life in use**

---

(*) 170kWpeak, 525Arms peak, 300Arms continuous Traction Inverter, 400V bus, \( f_{\text{PWM}} = 10 \text{kHz} \), \( T_{\text{fluid}} = 65°C \)

(**) applicable to DC to DC converter when present

750V
Si IGBT vs. SiC MOSFET – 750V

Silicon Solution: IGBT+ Diode
3x100 mm² + 3x50 mm²

~4x smaller semiconductor area

SiC MOSFET gen 3
Solution: 6x20 mm²

Vbus = 400V 160kW peak !!

DC-link voltage: 400Vdc, Switching frequency: 10 kHz, Tfluid = 65°C, mi=0-5

Higher efficiency for extra mileage

Si IGBT

SiC MOSFET

Lower temperature for higher reliability

525Am trium peak – 170kW, 300Arm nominal, DC-link voltage: 400Vdc, Switching frequency: 10 kHz, Tfluid = 65°C

From 2 to 4% higher efficiency

300Arms

Efficiency at 10kHz @ % load
SiC MOSFET System Benefits – 750V
Reducing PCU size

- 300A_{rms} continuous
- DC-link voltage: 400V_{dc}
- Switching frequency: 10 kHz
- T_{fluid} = 65°C

2x smaller cooling system

750V IGBT based solution

Power module size: 20%
Cooling system size: 50%
DC link: 15%
PCB: 15%

With 750V SiC

Up to 50% smaller PCU
## Case Study 11kW, 3-Phase OBC

### SiC Advantages in On-Board Battery Chargers

<table>
<thead>
<tr>
<th></th>
<th>Silicon IGBT + Diode</th>
<th>SiC MOSFET + Diode</th>
<th>OBC - End User Value Proposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses [W]</td>
<td>300</td>
<td>216</td>
<td>Reduce heatsink size</td>
</tr>
<tr>
<td>Switching Frequency [kHz]</td>
<td>25</td>
<td>100/150</td>
<td>Reduce passive component size</td>
</tr>
<tr>
<td>Volume* [cm³]</td>
<td>4593</td>
<td>1986</td>
<td>Reduce congestion and decrease car weight</td>
</tr>
<tr>
<td>Weight* [g]</td>
<td>7708</td>
<td>3074</td>
<td></td>
</tr>
<tr>
<td>Efficiency** [%]</td>
<td>96.9</td>
<td>97.7</td>
<td>Higher Efficiency</td>
</tr>
</tbody>
</table>

*including heatsink, passive components, switches, filters
**only due to semi-conductor components

60% weight, volume reduction
Main Features & Benefits

- Multi sintering solution for better performance and higher reliability
- AEC-Q101 qualified, $T_j (\text{max}) = 175 ^\circ \text{C}$
- 650V / 1200V Voltage rated
- Suitable for silicon IGBT and SiC Power MOSFET technologies
- Compact and modular design approach
- High power density
- Improved thermal performance due to direct sintering to the bottom of the heatsink
- Sense pin for enhanced control
• **Current Suppliers**
  
  • **4 Suppliers** already qualified and in full production
  
  • LTA already finalized with a key supplier:

  Cree and STMicroelectronics Announce Multi-Year Silicon Carbide Wafer Supply Agreement

  Agreement to boost commercial expansion of SiC in automotive and industrial applications

  DURHAM, N.C. and GENEVA /07 Jan 2019

  Cree, Inc. (Nasdaq: CREE) announces that it signed a multi-year agreement to produce and supply its Wolfspeed® silicon carbide (SiC) wafers to STMicroelectronics (NYSE: STM), a global semiconductor leader serving customers across the spectrum of electronics applications. The agreement governs the supply of a quarter billion dollars of Cree’s advanced 150mm silicon carbide bare and epitaxial wafers to STMicroelectronics during this period of extraordinary growth and demand for silicon carbide power devices.

  “ST is the only semiconductor company with automotive-grade silicon carbide in mass production today, and we want to press forward to grow our SiC business both in terms of volume and breadth of applications served, targeting leadership in a market estimated at more than $3B in 2025,” said Jean-Marc Chery, president and CEO of STMicroelectronics. “This agreement with Cree will improve our flexibility, sustain our ambition and plans, and contribute to boosting the pervasion of SiC in automotive and industrial applications.

• **Long term Plan (Toward a full Vertically Integration)**
  
  • A strategic partnership with a new Supplier has just been closed (beg 2019):

  STMicroelectronics to Acquire Majority Stake in Silicon Carbide Wafer Manufacturer Norstel AB

  Acquisition will extend ST’s silicon carbide ecosystem and strengthen ST’s flexibility to serve fast growing automotive and industrial applications

  Geneva, Switzerland / 06 Feb 2019

  STMicroelectronics (NYSE: STM), a global semiconductor leader serving customers across the spectrum of electronics applications, today announced it has signed an agreement to acquire a majority stake in Swedish silicon carbide (SiC) wafer manufacturer Norstel AB (“Norstel”). After closing, ST will control the entire supply chain for a portion of its SiC devices at a time of constrained global capacity and positions itself for a significant growth opportunity. ST will acquire 55% of Norstel’s share capital, with an option to acquire the remaining 45% subject to certain conditions, which, if exercised, will result in total consideration of $137.5 million, funded with available cash.
SiC Technology Summary

6” wafer production and EPI process step in-house in ST

AEC-Q101 Automotive Grade

MOSFET and Diode products available and significantly growing for 1200V and 650V

Bare Die, Discrete Package and Module offer

Standard product offer and customized solutions

• **Battery Electric Vehicles** are disrupting the automotive market

• **SiC Technology** enables an optimized total cost of ownership model, for both automotive (traction Inverters on-board chargers) as well as Industrial (Solar, UPS, energy storage) domains

• **Introducing** the new material in **Automotive** is challenging but our experience shows it’s manageable

• **Ramp up** of SiC Technology in STMicroelectronics is much faster than market expectation
**Gallium Nitride (GaN): a new member of ST's Wide Band-Gap family**

Enables increased power density, higher frequency operation and improved efficiency

First product under development: **SGT120R65ALD***

**Product Features**
- **RDS(on)** = 120 mΩ @10 A
- **BVdss** > 650 V

**Key Benefits**
- Main breakthrough for High-Voltage Power conversion
- Compact Design
- Smaller form factor and increased Power density

**Conventional adaptor based on Silicon switch***

**Adaptor based on GaN switch**

**Package section**

**Top Side Cooling**

**Kelvin pin for optimized Gate Driving**

**PowerFLAT™ 8x8**

*Under Development*

*Super Junction power MOSFET*
Brand new finders, to allow an easier and faster recollect of the most important information about any power transistor in ST’s portfolio.