STMicroelectronics SiC Module

Tesla Model 3 Inverter

Power Semiconductor report by Elena Barbarini

June 2018 – version 1
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Executive Summary

Pushed by aggressive legislation, CO2 reduction is one of the key challenges in the 21st century. The best solution currently available to the automotive industry is the electrification of vehicles, with different levels of electrification depending on the strategies of different car manufacturers. 780,000 battery electric vehicles were shipped in 2017, a number expected to grow to almost 2.8M by 2022. Standard inverter power modules integrate silicon IGBTs, but in electric vehicles the available space in the engine compartment is often so limited that it is difficult to accommodate a power control unit (PCU). Thus, it is necessary that the PCU, which controls electric vehicles’ traction motors, has a higher power density and therefore is smaller. Thanks to higher thermal and electrical performance, SiC is the new competitor to silicon at high voltages. Nevertheless, high power densities need high thermal dissipation and thus new packages are needed to improve device performance. To achieve these targets, manufacturers have developed different solutions, such as limiting wire bonding or using overmolded structures to efficiently cool the power semiconductor chips.

Tesla is the first high-class car manufacturer to integrate a full SiC power module, in its Model 3. Thanks to its collaboration with STMicroelectronics the Tesla inverter is composed of 24 1-in-1 power modules assembled on a pin-fin heatsink.

The module contains two SiC MOSFETs with an innovative die attach solution and connected directly on the terminals with copper clips and thermally dissipated by copper baseplates.

The SiC MOSFET is manufactured with the latest STMicroelectronics technology design, which allows reduction of conduction losses and switching losses. Based on a complete teardown analysis, the report also provides an estimation of the production cost of the SiC MOSFET and package.

Moreover, the report includes a technical and cost comparison with the Mitsubishi J-Series TP-M power module. It highlights the differences in design of the packaging and the material solutions adopted by the two companies.
POWER MODULE Die LEVEL: different integration

2-in-1 power module

4-in-1 power module

6-in-1 power module

Company Profile & Supply Chain
Physical Analysis
Manufacturing Process Flow
Cost Analysis
Selling Price Analysis
Comparison
Feedback
About System Plus

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Power Module Issues

In Si modules, mismatching CTE (coefficient of thermal expansion) makes layers detach from one another.

With the introduction of SiC this problem is much more highlighted; in fact the main problem of SiC is thermal dissipation because of material density; thus an adapted package and system integration is needed.
ST SiC products

- ST’s 650 V and 1200 V silicon carbide (SiC) MOSFETs feature very low RDS(on)*area combined with excellent switching performance, translating into more efficient and compact systems. Compared with silicon MOSFETs, SiC MOSFETs exhibit low on-state resistance*area even at high temperatures and excellent switching performances versus the best-in-class IGBTs in all temperature ranges, simplifying the thermal design of power electronic systems.

<table>
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<th>Part Number</th>
<th>VDSS</th>
<th>Drain Current (Dc) (A)</th>
<th>P&lt;sub&gt;TOT&lt;/sub&gt; (W)</th>
<th>Package</th>
<th>RDS(on) (Ω) (@VGS=20V)</th>
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<td>12</td>
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<td>100</td>
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<td>HiP247 IN LINE</td>
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</tbody>
</table>

★ Similar to analysed device
Heatsink

Overview / Introduction

Company Profile & Supply Chain

Physical Analysis
- Synthesis
- Package
- Die design
- Die Cross-Section

Manufacturing Process Flow

Cost Analysis

Selling Price Analysis

Comparison

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Al heatsink

Package Cross section
MOSFET die dimensions

- Die dimensions: 
  xxxx mm^2 (xxxxmm x xxxxmm)
- There is no marking on the die.
Die cross section

- Substrate thickness: xxxx µm

![Die cross section - Optical View](image)
Die cross section

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Die cross section – SEM View

Die cross section – SEM View

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Die cross section
Description of the Wafer Fabrication Units - MOSFET

In our calculation, we simulate a production unit using 100mm wafers.

MOSFET wafer fab unit:

Name: STMicro CTM 100mm wafer
Wafer diameter: 100mm (4-inch)
Capacity: 30,000 wafers / month
Year of start: 1980
Most advanced process: Power device
Products: Discrete/Power - Mainly power products; Diodes & MOSFET
Location: Catania, Italy
MOSFET Process Flow (1/4)

- **Epitaxy**
  - N- Drift region Epitaxy
  - SiC Substrate N+

- **Implantation**
  - SiO2 deposition
  - Pattern SiO2
  - P+ well implantation

- **Implantation**
  - SiO2 deposition
  - Pattern SiO2
  - N+ source implantation

*Drawing not to Scale*
MOSFET Process Flow (3/4)

Gate isolation

- Oxide: deposition and pattern

Silicide

- Nickel deposition and pattern
- Silicidation

Metal contact

- Ti and Aluminum deposition and pattern
MOSFET Front-End Cost

The front-end cost ranges from $xxx to $xxx according to years.

The main part of the wafer cost in 2018 is due to the xxx (xxx%).
The MOSFET die cost ranges from $xxxx to $xxxx according to years.

The Front-end manufacturing represents xxxx of the component cost in 2018.

Probe test, dicing and scrap account for xxxx of the component cost.
Final Module Cost

The module cost ranges from $xxx to $xxxx according to years.

The SiC MOSFET dies manufacturing represents xxx% of the component cost.

The packaging represents xx% of the component cost.

Final test and yield losses account for x% of the component cost.
Estimated Manufacturer Price

The module manufacturing cost ranges from $xxx to $xxx according to years.

By taking into account a gross margin of 39% for ST (2017 results), the module manufacturer price is estimated to range from $xxxx to $xxxxx according to years.
Related Reports

REVERSE COSTING ANALYSES - SYSTEM PLUS CONSULTING

Power Semiconductors & Compound
- Infineon FS600R07A2E3 HybridPACK2 100KW 3-phase
- Infineon EconoPACK4™ 1200V IGBT4 Module
- Semikron SKiM306GD12E4
- ROHM 1200V Trench SiC MOSFET
- Infineon CooliR²Die™ Power Module
- Toyota Prius Power Modules

MARKET AND TECHNOLOGY REPORTS - YOLE DÉVELOPPEMENT

Power Electronics & Compound Semiconductors
- Power Electronics for EV/HEV 2018
- Power Module Packaging: Material Market and Technology Trends 2017
- Power SiC 2017: Materials, Devices, Modules, and Applications
Business Models Fields of Expertise

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  (>130 analyses per year)
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  (>40 reports per year)
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