Transfer Molded IGBT for Hybrid Vehicle with Improved Cycling Durability

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Presentation Outline:

(1) T-PM module package
   - Transfer Molded Package
   - TCIL (Thermally Conductive Insulating Layer)
   - DLB (Direct Lead Bonding)

(2) T-PM module features
   - Current Sensing
   - Temperature Sensing

(3) T-PM reliability
   - Thermal cycling reliability
   - Power cycling reliability

(4) T-PM Inverter system design
   - Line-Up
   - System layout
   - Parallel operation

(5) Direct Liquid Cooled version
Introducing the **T-PM**
(Transfer-Molded) **Power Module**

**Main Features:**
- Dual Module – Half bridge configuration
- Compact, Rugged, Transfer molded package
- High thermal conductivity for efficient heat transfer
- Low loss CSTBT chip technology

“**Known Good**” Building block for high reliability inverters
Transfer Molded Package of T-PM

- The transfer molded package is mechanically robust and low cost. The package design is based on technology developed for “White Goods” consumer applications starting in 1997.
- Transfer molded packaging in the form of the T-PM has been used in inverters for electric and hybrid electric vehicles since 2003.
- Today there are more than one million T-PM modules on the road.
Chips are bonded to a heat spreader/lead frame using lead (Pb) free solder.

- A Thermally Conductive electrically Insulating Layer (TCIL) is attached to the bottom surface of the heat spreader.
- The heat spreader provides reduced thermal impedance.
- Direct Lead Bonding (DLB) provides reduced inductance and resistance.
By adopting a built in heat spreader the transient thermal impedance ($Z_{th(j-c)}$) of the T-PM is reduced to 65% of a conventional module in the $t=0.1s$ range.

The $Z_{th}$ reduction reduces $T_j$ ripple which helps to increase the power cycling life of the device.
DLB (Direct Lead Bond) compared to conventional wire bond structure

- The top surface (emitter/cathode) connection is made by directly soldering a copper tab to the chip’s surface.
- Increased bonding area of DLB provides reduced emitter contact resistance.
- DLB improves current uniformity in the semiconductor chips.
- Hot spots found at the bonding points in a conventional design are eliminated by DLB.
DLB Package inductance compared to conventional wire bond structure

- DLB module internal inductance reduced to 57% of wire bonded module
DLB package resistance compared to conventional wire bond structure

- DLB module internal lead resistance is reduced to 50% of a wire bonded module
**Main Features:**

- Dual Module – Half Bridge Configuration
- Advanced low loss CSTBT chips
- On-Chip temperature sensor
- Emitter current mirror for over current protection

![T-PM Schematic Diagram](image)
IGBT Chip with Current and Temperature Sensors

Main Features:

- Temperature sensing is accomplished by measuring the Vf of a string of diodes fabricated on the surface of the chip.
- Tj=175°C maximum rating.
- Low loss CSTBT chip technology.
- Current mirror provides a low level output proportional to the main emitter current.

On-Chip sensing features allow development of more robust protection.
Accurate On-Chip temperature sensing is accomplished by measuring the $V_f$ of a string of diodes fabricated on the chip’s surface. This type of temperature sensing is faster responding and more accurate than conventional techniques that use NTC sensors mounted somewhere near the chip.
- Current mirror emitter is provided for short circuit protection.
- The output of the current mirror depends on temperature and the value of the burden resistor. With Rs=100ohm the output is approximately 1/40,000th of the main current at Tj=125°C.
- Short circuit current can be interrupted before dangerous desaturation occurs.
- No need for high voltage components (desaturation detection diode) in the gate drive circuit.
Short circuit current is interrupted before desaturation occurs.
Fault energy is reduced by more than two orders of magnitude.
Reduced stress on the IGBT minimizes the risk of failure.
T-PM Gate drive and protection implemented using a low voltage ASIC

- Short circuit, over temperature and under voltage lock-out included on ASIC.
- Off-state gate current sink (a.k.a. Miller Clamp) eliminates need for negative gate bias.
- Soft shut-down provided for short circuit protection.
Reduction of solder joint stress by optimized over mold

- CTE of resin is close to CTE of copper
- Chip is stretched by expansion of the resin
- Strain on solder is reduced

Optimized over mold and lead-frame design reduces the strain on the solder to about 25% of conventional construction.
Dimpled heat spreader improves solder durability

Dimples on heat spreader

Before test

After 2048 -40~125°C heat cycles

After more than 2000 cycles at delta T=165°C no crack was found in the solder: Extremely durable solder joint!
Result of thermal cycling test

Rth(j-c) does not deteriorate

T-PM High-Reliability

<table>
<thead>
<tr>
<th>T/C (Δ Tc=-40⇌125°C)</th>
<th>J-Series T-PM</th>
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</thead>
<tbody>
<tr>
<td>30 times or more than industrial Module</td>
<td></td>
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Chip surface thermal gradient reduction with DLB construction

(A) Chip temperature distribution of W/B structure

(B) Chip temperature distribution of DLB structure

The extremely large soldered contact area of the DLB results in a uniform chip surface temperature distribution and lower thermal resistance.
Power Cycling Reliability of DLB Construction

EOL Criterion:
*1 Solder joint area reduction more than 50% (Still no deterioration in characteristics).
*2 Bond wire lifted (open circuit)
T-PM Assembly Example

- Compact transfer molded package allows development of compact inverters.
- Known good building block can be used in single, three phase or fully regenerative configurations.
- T-PM can be paralleled for higher current applications.
Liquid cooled power assembly example

Control board

T-PM

Cooling plate
Liquid cooled intelligent power assembly
## T-PM Module Line-Up

<table>
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<tr>
<th>Voltage (V)</th>
<th>300A</th>
<th>600A</th>
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<tbody>
<tr>
<td>600V</td>
<td>CT300DJH060</td>
<td>CT600DJH060</td>
</tr>
<tr>
<td>1200V</td>
<td>CT300DJH120</td>
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</table>

All modules are in the same 56mm x 64mm x 7.5mm package
Parallel Connection of T-PM Module

T-PM modules can be paralleled for higher current applications.
New J1-Series T-PM

Features:

- 20% size reduction – compact 6-in-1 package
- 40% reduction in thermal impedance – integrated pin fin for direct cooling
- Lower losses – 6th generation CSTBT™
- Higher bus voltage operation – new 900V chip rating
New J-1 Series T-PM Lineup

<table>
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<tr>
<th>Rating</th>
<th>300A</th>
<th>400A</th>
<th>600A</th>
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<tbody>
<tr>
<td>650V</td>
<td>CT300CJ1A060</td>
<td></td>
<td>CT600CJ1A060</td>
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<tr>
<td>900V</td>
<td></td>
<td>CT400CJ1A090</td>
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<tr>
<td>1200V</td>
<td>CT300CJ1A120</td>
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T-PM Target Market

#1: OEM Passenger Vehicle
- Power electronics for HEV / EV
  - DC/AC inverter
  - DC/DC boost
- Automotive OEM or Tier 1 supplier

#2: Truck / Bus

#3: Alternative Passenger Vehicle
Evaluation Hardware

T-PM Evaluation PCB

T-PM Capacitor Board
Automotive T-PM Modules

J-Series T-PM
2-in-1

J1-Series T-PM
6-in-1

High Reliability
Attractive Cost – Quality – Performance
High Functionality
Conclusions:

(1) T-PM module package advantages
- Low cost, Rugged, Transfer molded package
- Excellent thermal performance using TCIL with integrated heat spreader.
- Low inductance and resistance using DLB

(2) T-PM module features
- Current mirror for effective over current protection
- Fast and accurate On-Chip temperature sensing
- Low loss full gate CSTBT chips $T_j(\text{max})=175^\circ\text{C}$

(3) T-PM reliability
- Excellent thermal cycling reliability by transfer molded construction
- Increased power cycling durability using DLB

(4) T-PM Inverter system design
- Flexible known good building block concept
- Allows compact, light weight inverter design
- Parallel operation possible

(5) New Direct Liquid Cooled version
Questions?