Ultra-Compact and Light Weight Intelligent Power Semiconductor Module for Hybrid System

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2. Design of Aluminum heat sink

3. Development of high reliability solder material

4. Conclusions
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Required Performance of Power Module for HEV

Intelligent Power Module for Hybrid Electric Vehicles

Engine Room of HEV
- PCU
- Motors
- Engine & other

Power Module
- Gate driver
- VCU ECU
- Busbar
- Converter P/M
- Inverter P/M
- VCU P/M
- Heat sink

Requirements for power module
1. High Efficiency, 2. Downsizing, 3. Lightweight
High power density is required for automotive module

Direct liquid cooling with aluminum fin is key technologies for 3rd gen.
Subject of Conventional Power Module Structure

Direct liquid cooling module structure

Cross section

- Chip
- Solder
- Ceramic substrate
- Solder
- Heat-sink

Aluminum is
- Light weight
- Good corrosion resistance

Weight ratio

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (2nd gen.)</td>
<td>60%</td>
</tr>
<tr>
<td>Aluminum</td>
<td>40%</td>
</tr>
<tr>
<td>Heat-sink</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
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</tbody>
</table>

Aluminum heat sink can reduce module weight by 60%
Subjects of Aluminum heat sink structure

I. Low thermal conductivity

- Copper
- Alminum

CTE (ppm/K)

0 10 20 30

Substrate

Copper

Alminum

Thermal conductivity (W/m·K)

0 100 200 300 400

II. Large CTE mismatch

ΔCTE 1.4 times Higher

- Copper
- Alminum

CTE (ppm/K)

0 10 20 30

Temperature of semiconductor

Max Temp.

25°C UP

125°C Copper

150°C Aluminum

Reliability of joint layer

Thermal cycle at 1500cyc.

Copper heat sink

Aluminum heat sink

- Thermal design and high strength joint layer are needed
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I. Low thermal conductivity

- Copper: Higher
- Alminum: Lower

II. Large CTE mismatch

- ΔCTE: 1.4 times Higher
Subject for the design of aluminum heatsink

Simulation model (real product)

**Size**: 320x170 mm
**Inlet**: 60 °C
**Flow speed**: 10 l/min.
**Chip operation**: maximum

Temperature distribution of coolant

- **125 °C**
- **145 °C**
- **141 °C**

**ΔT=20 °C**
**ΔT=16 °C**

- Flow direction
- Flow direction

- Optimization is necessary to reduce temperature distribution
Optimization of flow distribution

Before Optimization

With this design, we have a almost the same performance with Aluminim heat sink as Copper heat sink.
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I. Low thermal conductivity

- Copper
- Alminum

Ⅰ. Low thermal conductivity

![Diagram showing low thermal conductivity comparison between Copper and Alminum](image)

II. Large CTE mismatch

- ∆CTE 1.4 times Higher

- Substrate
- Copper
- Alminum

![Diagram showing CTE mismatch comparison between Copper and Alminum](image)
Strengthening Mechanism of Solder Alloy

Aging condition
175 °C
1000 hours

Precipitation Strengthening

Solid Solution Strengthening

Combination Strengthening

Tensile strength (MPa)

-44%

-5%

-2%
Effect of Thermal Fatigue Characteristics of New Solder

Thermal cycle test -40~105°C

- Achieved 7 times longer lifetime against the general Sn-Ag Solder.
Product Summary of a Newly Developed IPM

Mass Production Model
320mm x 170mm

Gate Drive ICs (for protection functions)

Output power : 400kVA

Engine Room in hybrid Electric Vehicle

<table>
<thead>
<tr>
<th>Unit</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Module</td>
<td>14-in-1 unit of IGBT/FWD in total IGBT</td>
</tr>
<tr>
<td></td>
<td>Output power : 400 kVA (in total)</td>
</tr>
<tr>
<td>IGBT chip</td>
<td>Fuji Electric V-series (6th generation)</td>
</tr>
<tr>
<td></td>
<td>System voltage : 1200 V</td>
</tr>
<tr>
<td>Self Protection function</td>
<td>IPM status sensing (temperature, voltage and failure information) and self</td>
</tr>
<tr>
<td></td>
<td>protection by itself. Information communication with ECU.</td>
</tr>
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Conclusions

1. Design of Aluminum heat-sink
   - Developed a cooling structure that can be efficiently cooled

2. Development high reliability solder material
   - Reliability is 7 times longer compared with the Sn-Ag solder
   - Achieve a automotive quality used by Aluminum heat-sink

⇒ We achieved direct liquid cooling module
   - 30% volume, 60% weight reduction compared to products with conventional technologies
Thank you for your attention!

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Where Fuji Electric locates

Sagrada Familia in Barcelona
Where EVS held