pcim
ASIA SHANGHAI

Increased Power Density and Lifetime of Thin Automotive Inverter Chips through Cu-bonding

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Motivation

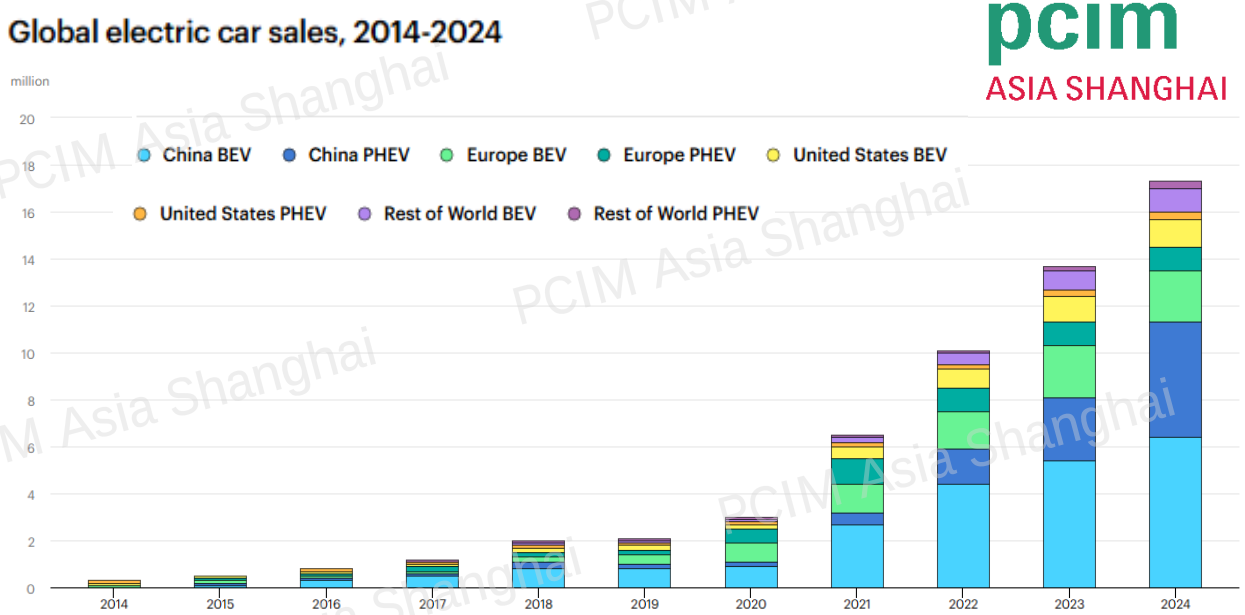
Battery electric vehicle market continues to grow and diversify in transport applications

Maximizing power densities requires:

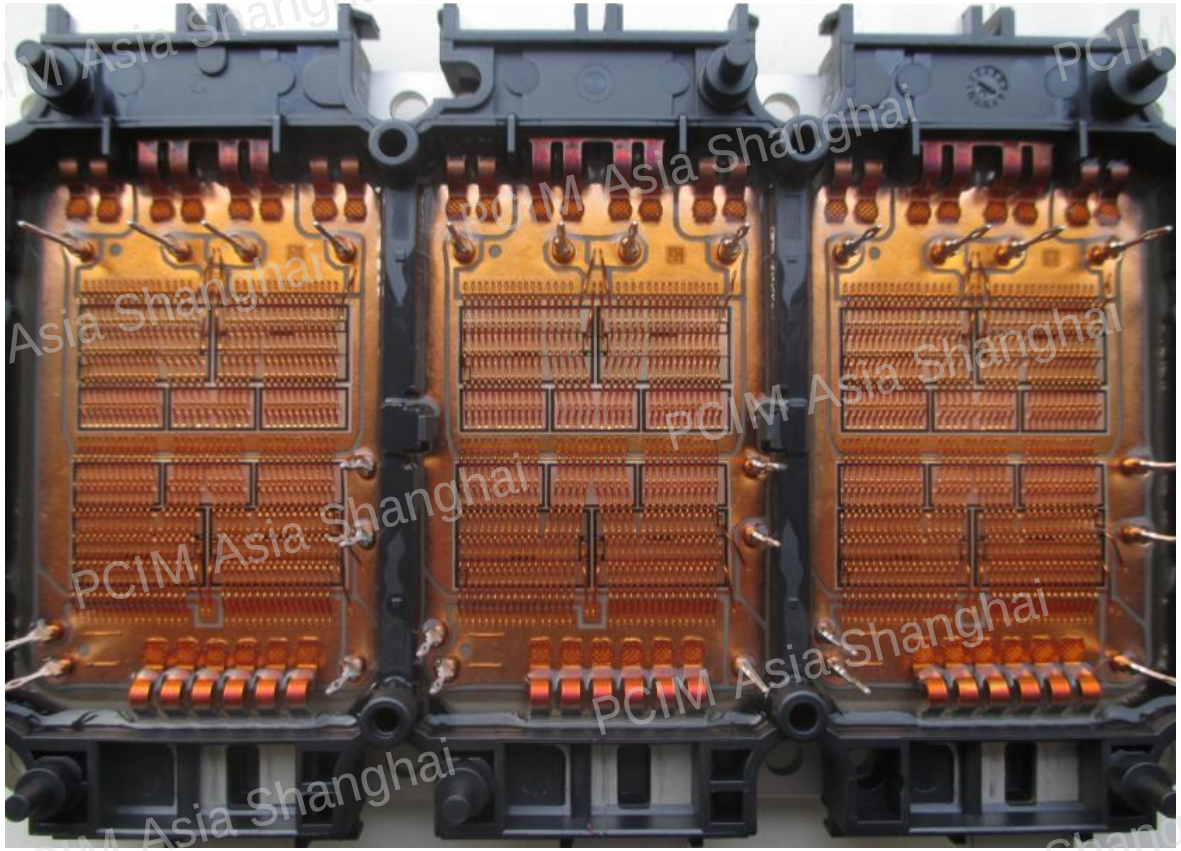
- **higher junction temperatures**
- and **longer lifetimes**

High power density applications:

- commercial, construction, and agricultural vehicles (CAV) with high-power auxiliary drive units
- Smaller package form factors for e.g. autonomous driving in light-duty vehicles or standard passenger cars with integrated Si/SiC Fusion switches



Motivation



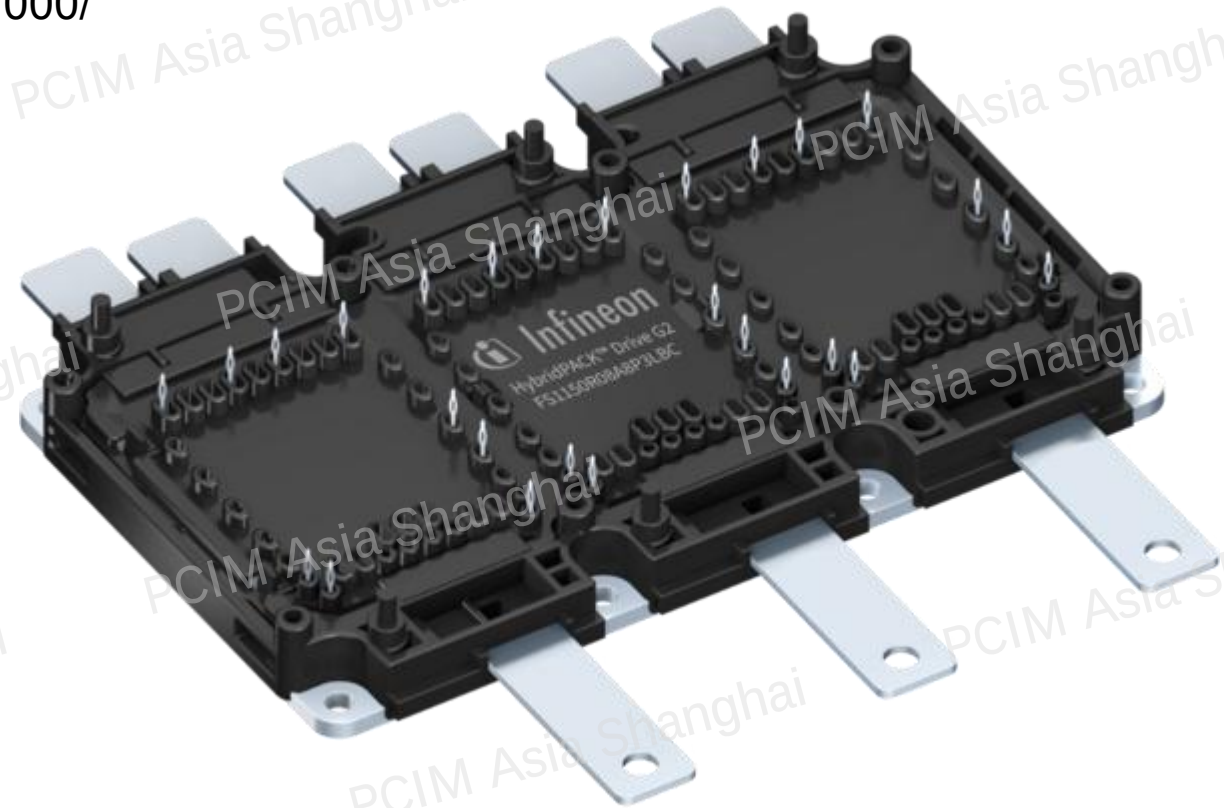
Infineon FS1300

Break-through in power cycling lifetime achieved:

- On thin automotive grade dies of thicknesses < 80 µm
- Key innovation:
  - Bonding process directly on die surface using copper wires
  - Dies terminated by nanometric Cu layer

The module

- Productive HybridPACK™ Drive G2 module FS1000/ FS1150
- Six-pack configuration for automotive inverter applications



The module

- Productive HybridPACK™ Drive G2 module FS1000/ FS1150
- Six-pack configuration for automotive inverter applications
- Equipped with the 750 V EDT3 IGBT/ Diode chip technology with
    - Standard aluminum frontside metallization and aluminum bond wires

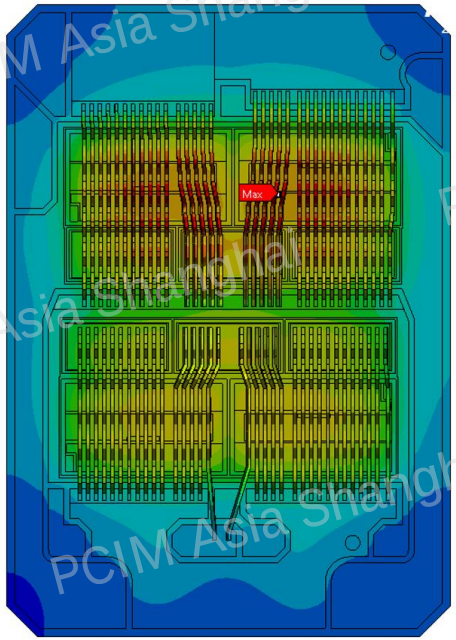
The module

- Productive HybridPACK™ Drive G2 module FS1000/ FS1150
- Six-pack configuration for automotive inverter applications
- Equipped with the 750 V EDT3 IGBT/ Diode chip technology with
  - Standard aluminum frontside metallization and aluminum bond wires
  - Copper frontside metallization and copper bond wires

→ **Comparison** in terms of
- **junction temperature** and
- **lifetime**

Reduction of bond loop temperature

FS1150 aluminium



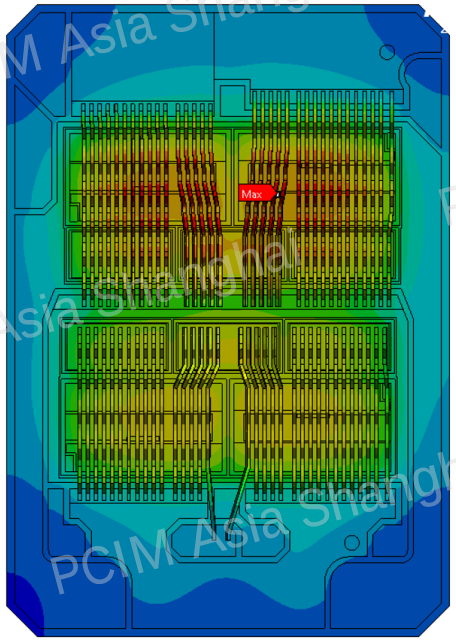
I_{ref}
$Power@175°C = P_{ref}$
$T_{bond}^{max} = T_{ref}$

Elevated current densities
→ Lead to overheating of bond wires
→ Which leads to degradation of the surrounding encapsulation gel

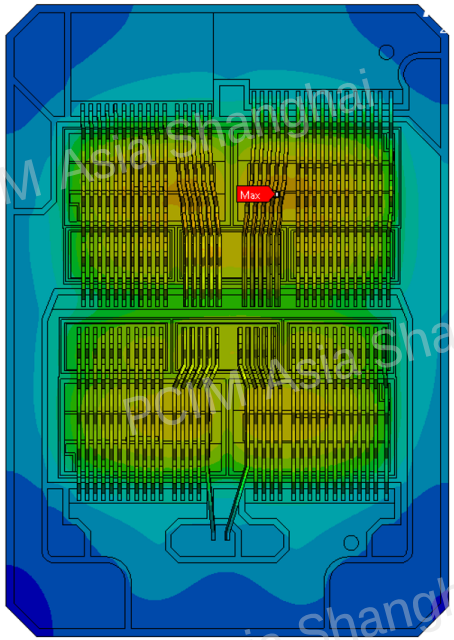
Simulated thermal states (chip losses calibrated to reach Tvj,max = 175°C for FS1150)

Reduction of bond loop temperature

FS1150 aluminium



FS1300 copper



I_{ref}	I_{ref}
$Power@175°C = P_{ref}$	P_{ref}
$T_{bond}^{max} = T_{ref}$	$T_{bond}^{max} = T_{ref} - 22.5°C$

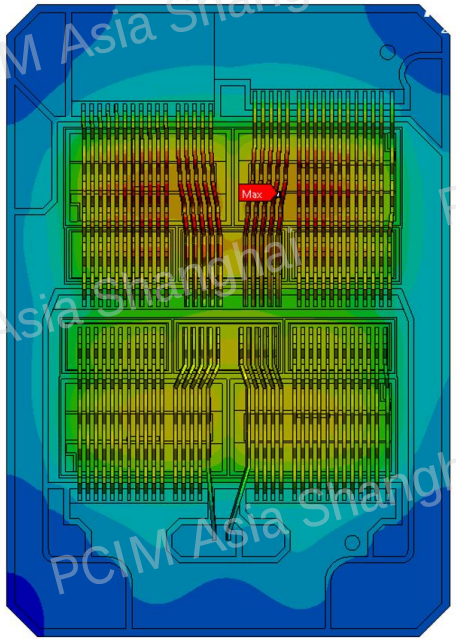
Elevated current densities
→ Lead to overheating of bond wires
→ Which leads to degradation of the surrounding encapsulation gel

Simulated thermal states (chip losses calibrated to reach Tvj,max = 175°C for FS1150)

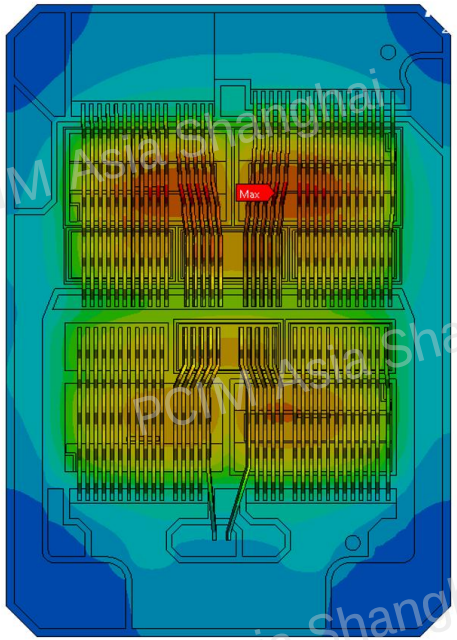
→**significant reduction in maximum bond temperature <u>exceeding 20 K</u>** for FS1300 compared to FS1150

Reduction of bond loop temperature

FS1150 aluminium



FS1300 copper



I_{ref}	$112\% \cdot I_{ref}$
$Power@175°C = P_{ref}$	$Power@185°C = 113\% \cdot P_{ref}$
$T_{bond}^{max} = T_{ref}$	$T_{bond}^{max} = T_{ref} - 5.8°C$

Elevated current densities
→ Lead to overheating of bond wires
→ Which leads to degradation of the surrounding encapsulation gel

Simulated thermal states for:

- the aluminum-based FS1150 at Tvj,max = 175°C
- the copper-based FS1300 at Tvj,max = 185°C and simultaneously increasing the operating current by 12%:

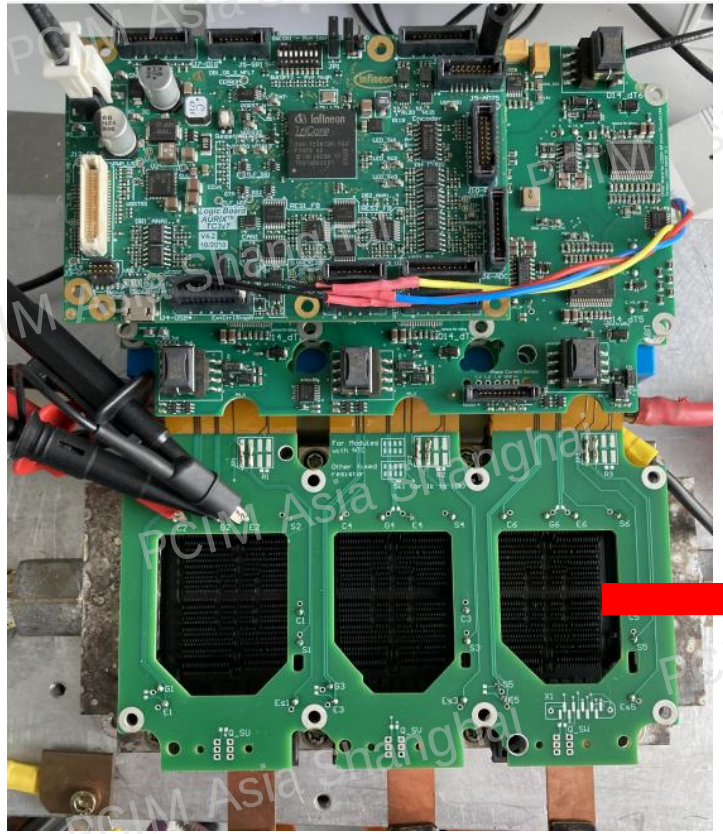
→**reduction in maximum bond temperature:**

- **<u>exceeding 5 K</u>** compared to the aluminum variant at 175°C

Finite Element Analysis (FEA) simulations are performed using ANSYS Mechanical. The temperature is represented by the same color scale for all three subfigures.

Reduction of bond loop temperature

Inverter setup for thermography measurements

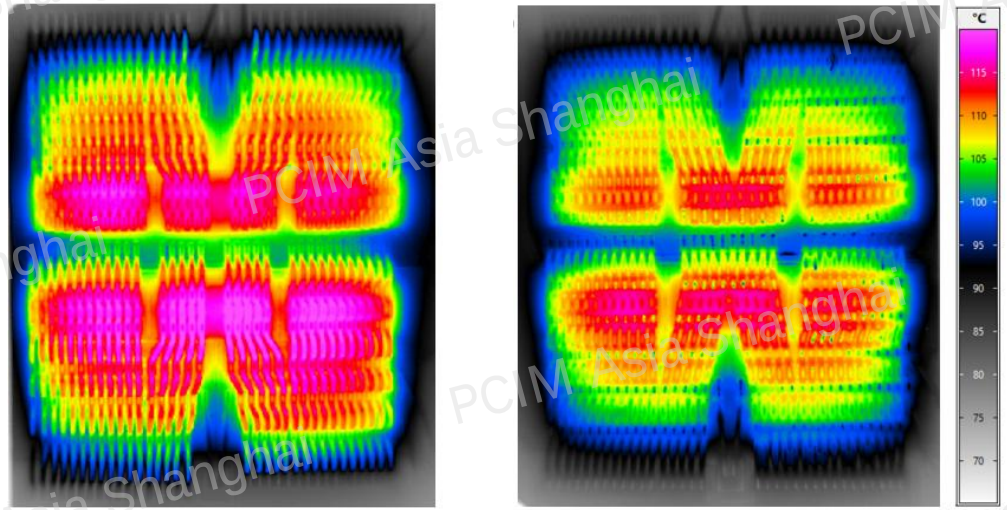


Thermography of module surface at inverter operation at same operational point:

- Identical hotspot areas for Al and Cu variants
- Cu variant has significantly lower absolute temperature especially in bond loop area
- Operation with inductive load shown below:

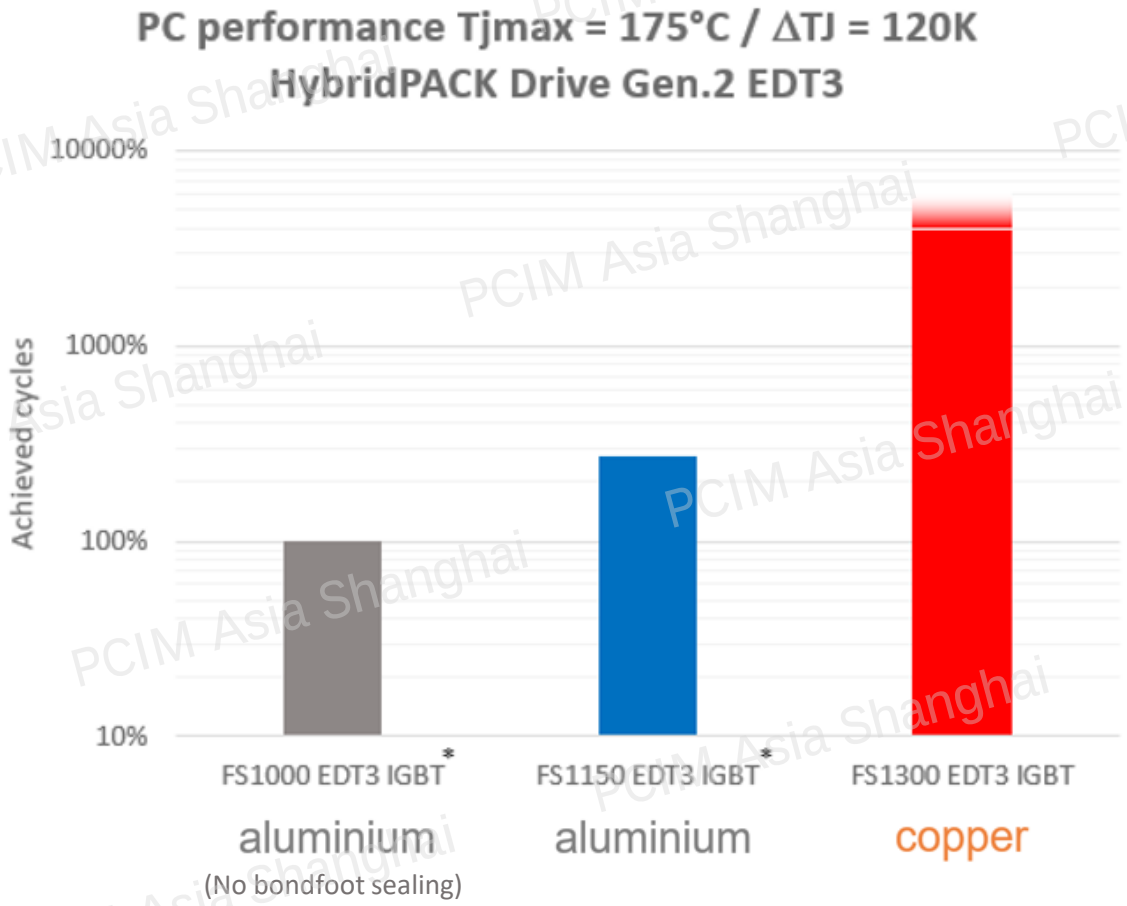
FS1150 aluminium

FS1300 copper



The temperature is represented by the same color scale for both figures.

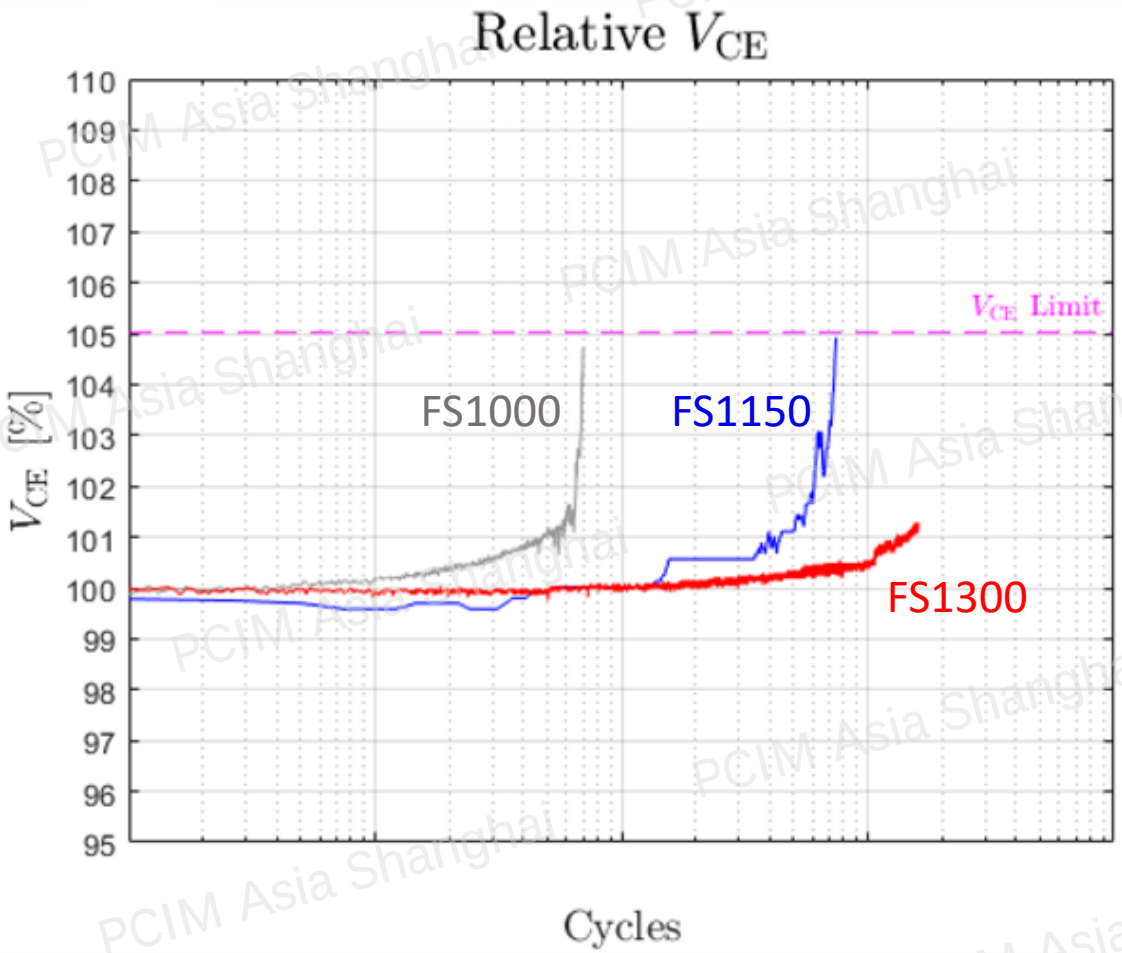
Increased power cycling and lifetime robustness



- Significant increase in lifetime test PCsec of Cu variant compared to Al variant
- EOL (end of life) for Cu variant was not reached (!)

Module cooling:
directly cooled copper PinFin baseplate with:
FS1000: DSC - Direct Copper Bonding, Al_2O_x ceramics
FS1150: AMB - Aluminum Metallization Bonding, Si_3N_4 ceramics
FS1300: AMB - Aluminum Metallization Bonding, Si_3N_4 ceramics
and sintering technology as backside interconnection used

Increased power cycling and lifetime robustness



AQG324 qualification guideline allows a maximum of 5% Vce increase during PCsec test

Aluminum variant (FS1000/ FS1150):

- Vce increase is the primary factor limiting their lifetime

→ Bond lift-off is the dominant failure mode

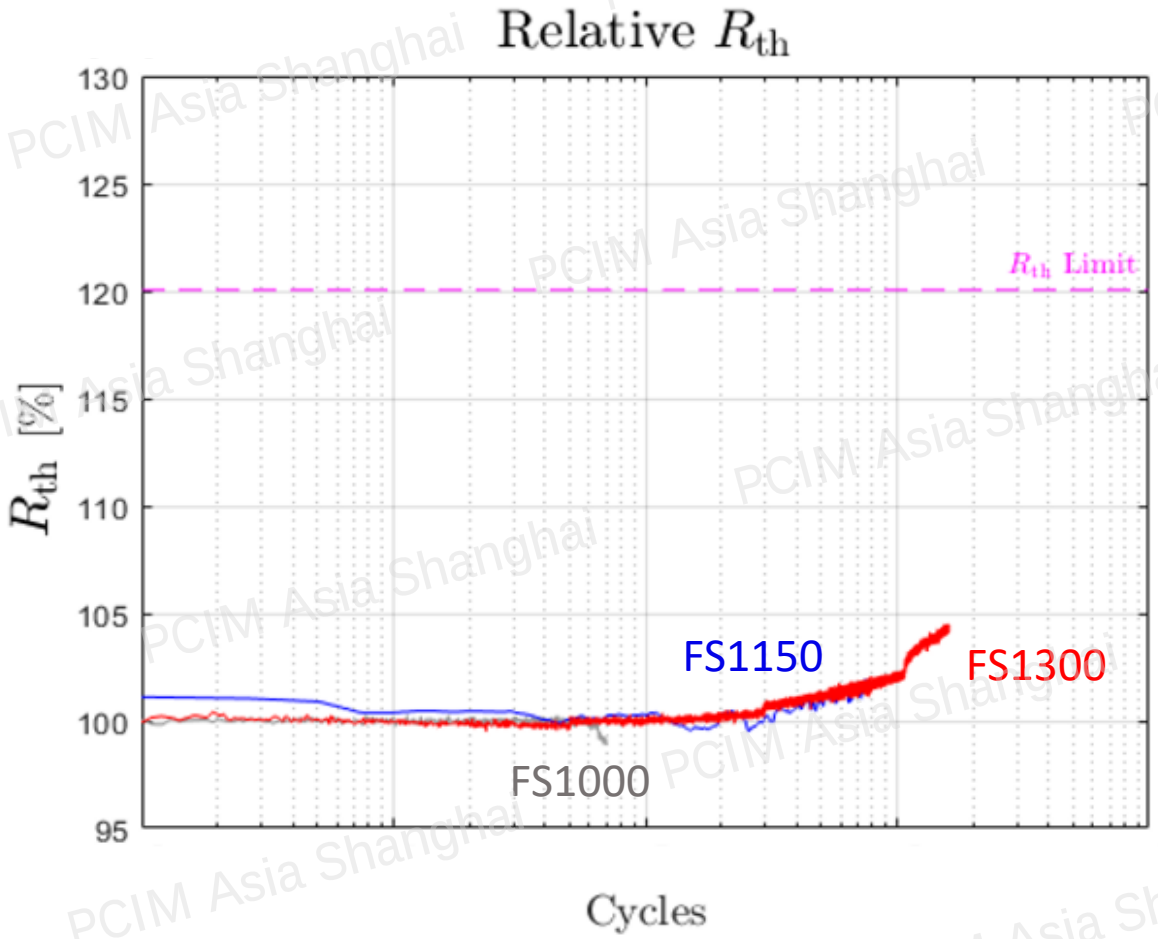
Copper variant (FS1300):

- remains well below the +5% Vce limitation threshold, even though undergoing approximately 15 times more cycles

→ Substantial margin for further operation

1 exemplary switch shown per module type

Increased power cycling and lifetime robustness



- Stable Rth monitoring values (until the Vce limits are reached): no observable degradation of the thermal path
- FS1300 exhibits a gradual increase in Rth, although it remains well below the maximum allowed value of 20% as defined in the AQG324 qualification guideline

1 exemplary switch shown per module type

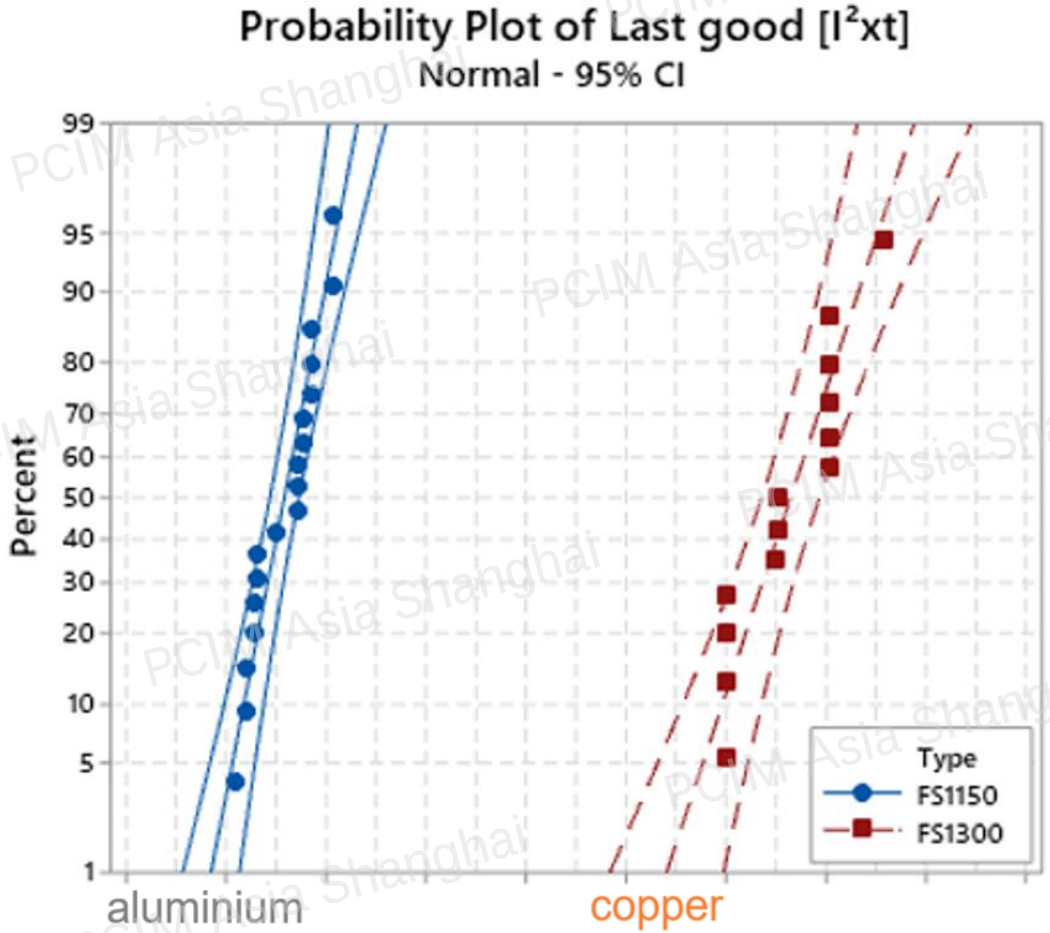
Increased power cycling and lifetime robustness

Ultrasonic microscopy image after PCsec

- Degradation of the solder between the AMB and baseplate underneath the IGBT areas was observed
  - although the Rth limits for the FS1300 were not reached
- Degradation of system solder layer between the copper ceramic on the backside and the baseplate
  - However, no delamination of the chip from the sinter layer or the copper from the ceramic was detected, demonstrating the high quality of the chip connection

Mechanically polished cross-section:

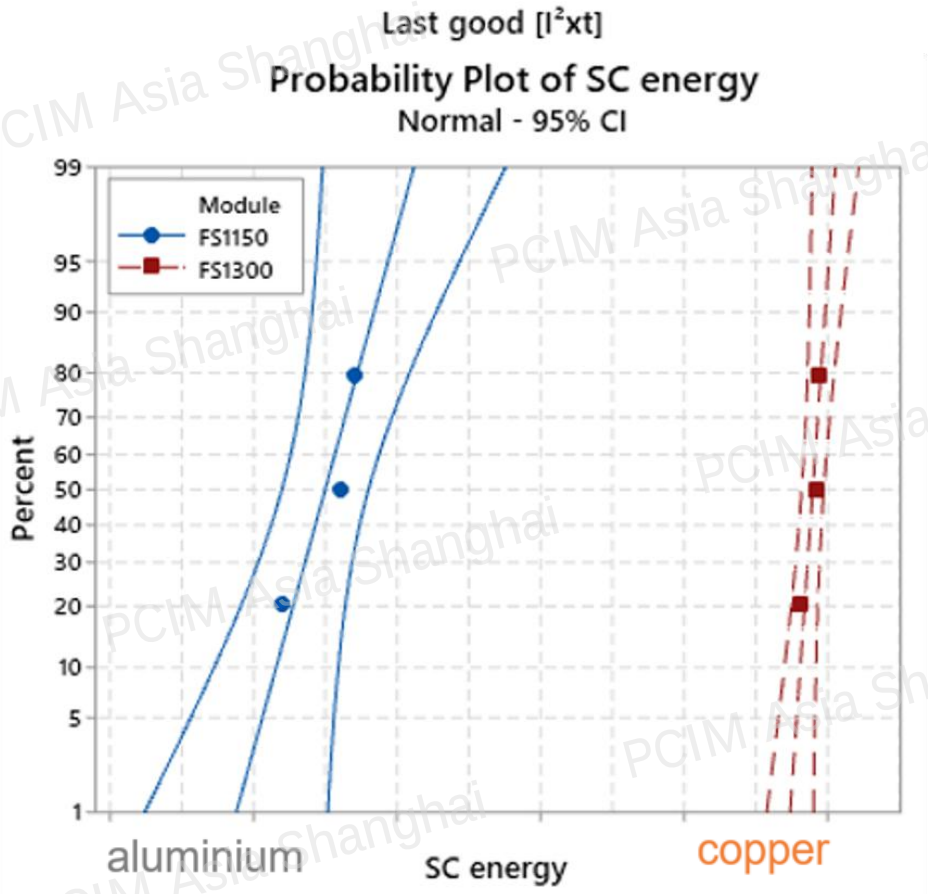
Improvement of I^2t diode robustness



- Notable 50% increase in I^2t value by employing copper metallization → significant enhancement of the power module's robustness
- → This breakthrough presents a promising opportunity for future developments to reduce costs by shrinking the active area, particularly in applications where I^2t is the dominant requirement

- last good value shown where the chips survive the I^2t half sine pulse with 10 ms duration
- same diode technology and bond layout used for both variants

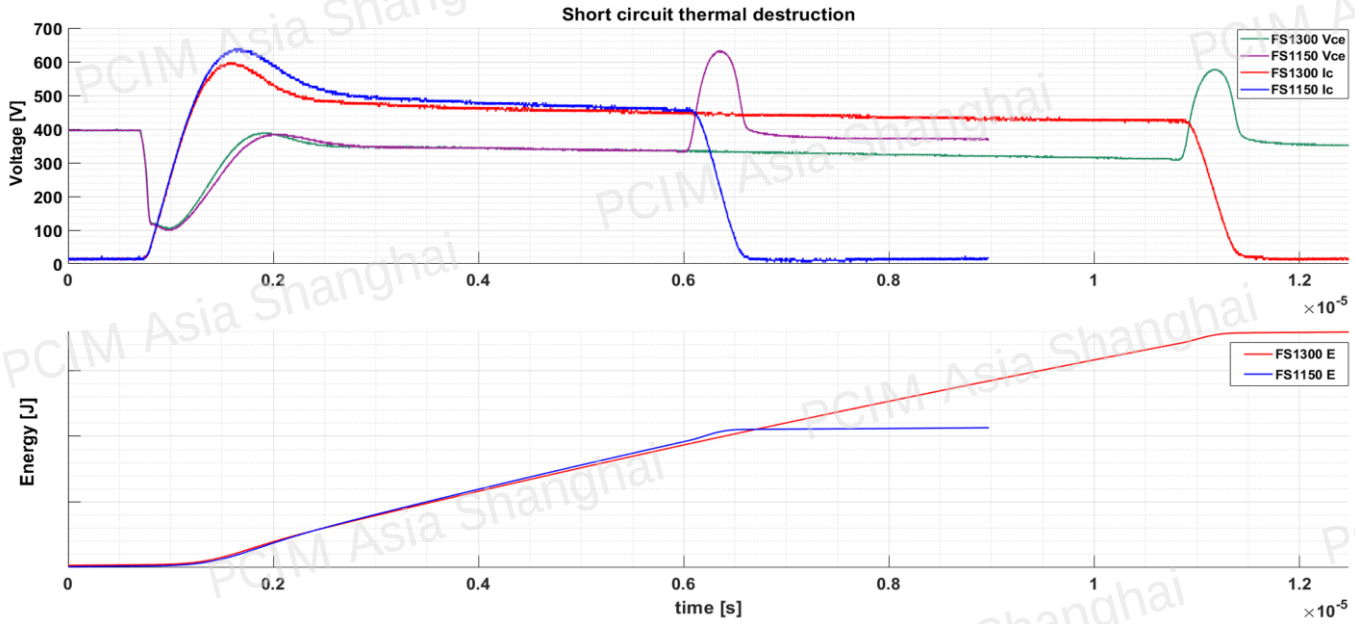
Improvement of IGBT thermal short circuit robustness



Last good tested value before thermal runaway shown:

- Cumulative short-circuit energy before thermal destruction significantly increased by 59% for FS1300 compared to FS1150

Improvement of IGBT thermal short circuit robustness



Last short circuit curves before thermal destruction.
Shown at Vge = 15 V and Tvj = 175°C with cumulative energies.

Short circuit time shown:

Significant increase for FS1300 compared to FS1150 due to:

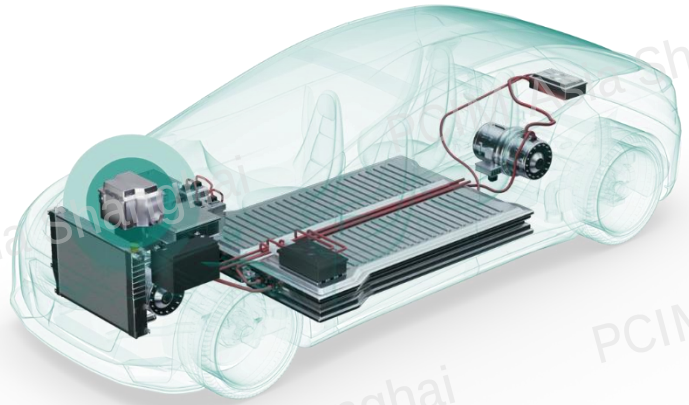
- enhanced thermal capacity on the topside of the chip
- increased homogeneity of both current and thermal distribution on the chip

→ achieved by using a more conductive copper metal stack, which effectively reduces thermal hotspots and promotes more uniform heat dissipation

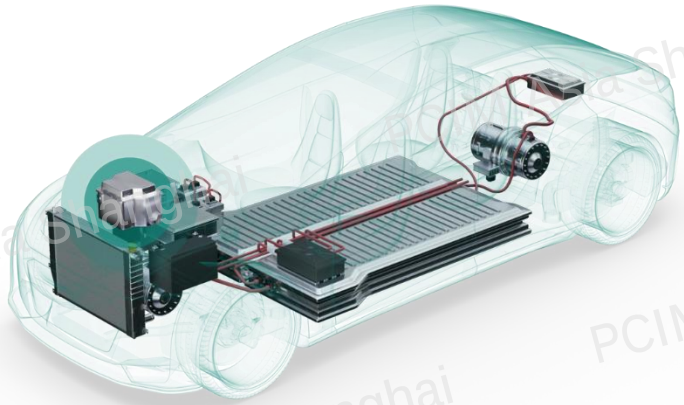
Summary and Outlook

- Copper frontside metallization and copper bonding lead to decreased maximum bond loop temperature, enabling increased maximum junction temperatures and thereby increased maximum current densities.
- Significantly prolonged lifetime in PCsec measurements were demonstrated.
- Furthermore, increased capability of I^2t robustness of the diode and short-circuit robustness of the IGBT were shown.
- These technology advancements enable operation beyond junction temperatures of 175°C.
- Ultimately, our estimates indicate that the copper-based concept allows minimum **12% increase in power rating**.
- Therefore, copper frontside metallization and copper bonding are promising solutions to meet future demands in electromobility for increased overall performance, enabling cost reduction by using smaller package sizes for the same power rating.

Thank you for your attention!



Are there any questions?



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