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Investigation on direct liquid cooling design of power modules with flat baseplate for automotive application

Masahide Kamiya, Fuji Electric Co.,Ltd

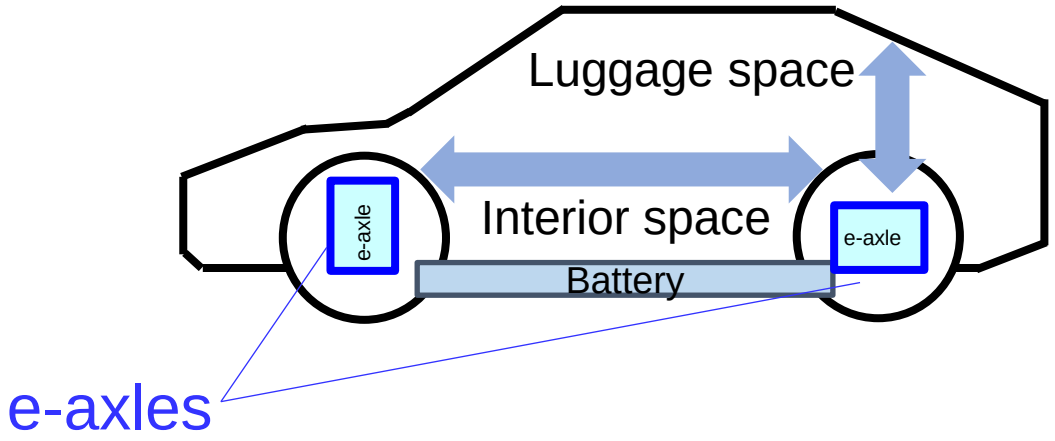
Contents

Future Trends of e-axles

To meet the rapidly developing EV market,
e-axle manufactures are now facing below problems.

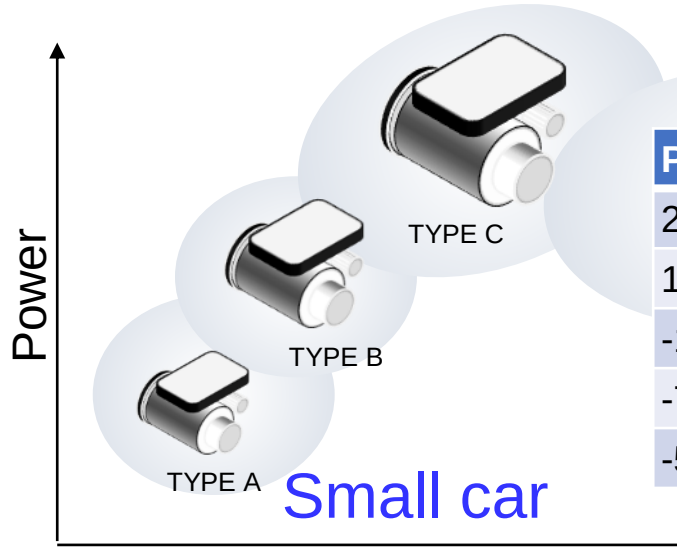
Performance

Expansion of interior and luggage space
⇒ Small and high power e-axles



Development

The development of e-axles for all segments
⇒ High development efficiency
⇒ Commonalizing components



Power range	Car class
200 kW-	E,F segment
150-200 kW	D,E segment
-100 kW	C segment
-75 kW	B segment
-50 kW	A segment

Fuji New Power Module Package M682

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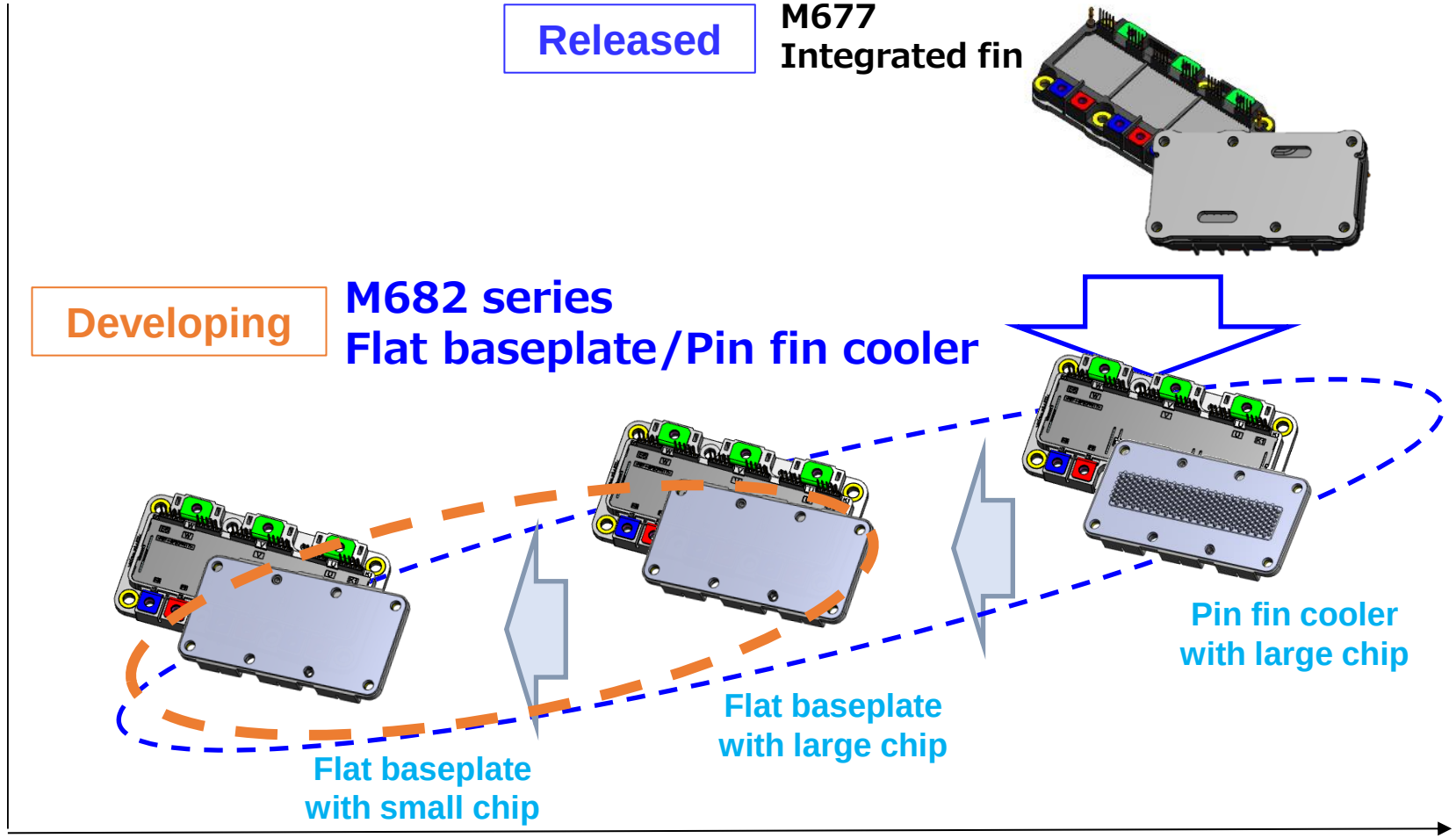
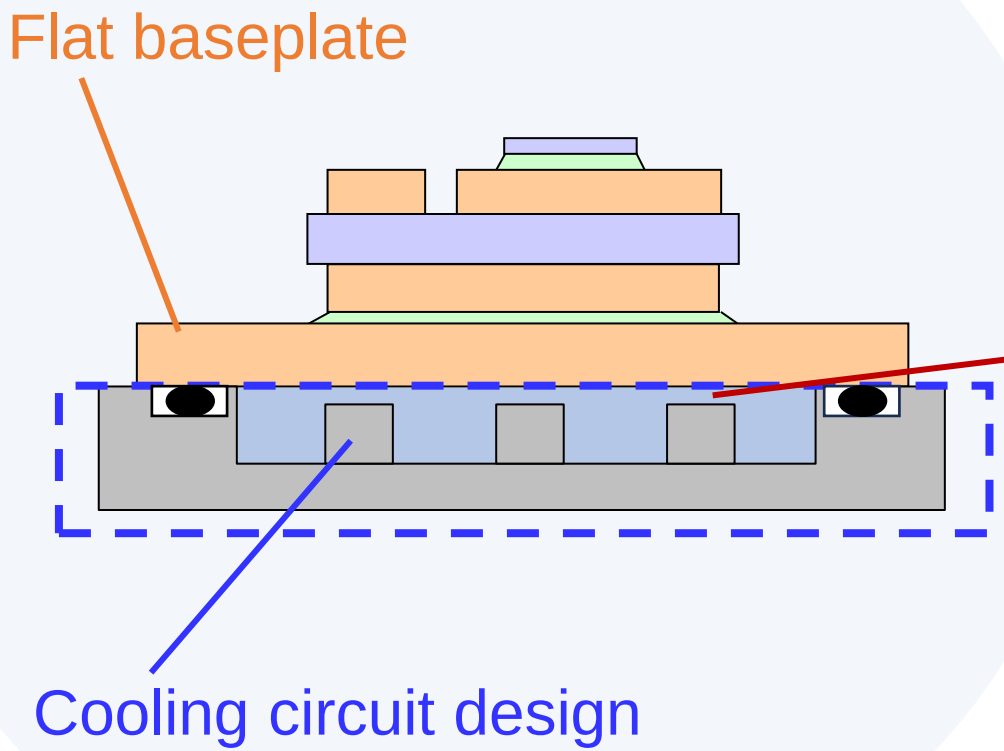
For commonalizing components, M682 is designed in the same package for 50-100kW inverters

Investigation of power modules with flat baseplate for automotive application



Overview of the Presentation



□ Cooling circuit design

The trade-off between R_{th}(j-w) and pressure loss

□ Reliability

Corrosion

Internal pressure durability

□ Output performance

Current enhancement result

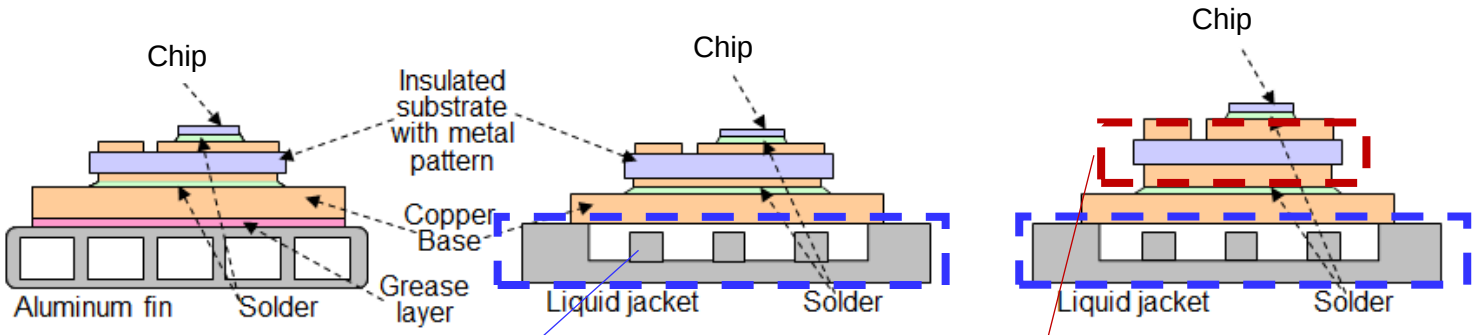
Contents

Power Module Structure and Thermal Resistance

By applying the direct cooling structure and Si_3N_4 insulating substrate, 48% reduction in thermal resistance is achieved.

Conventional

M682 flat baseplate



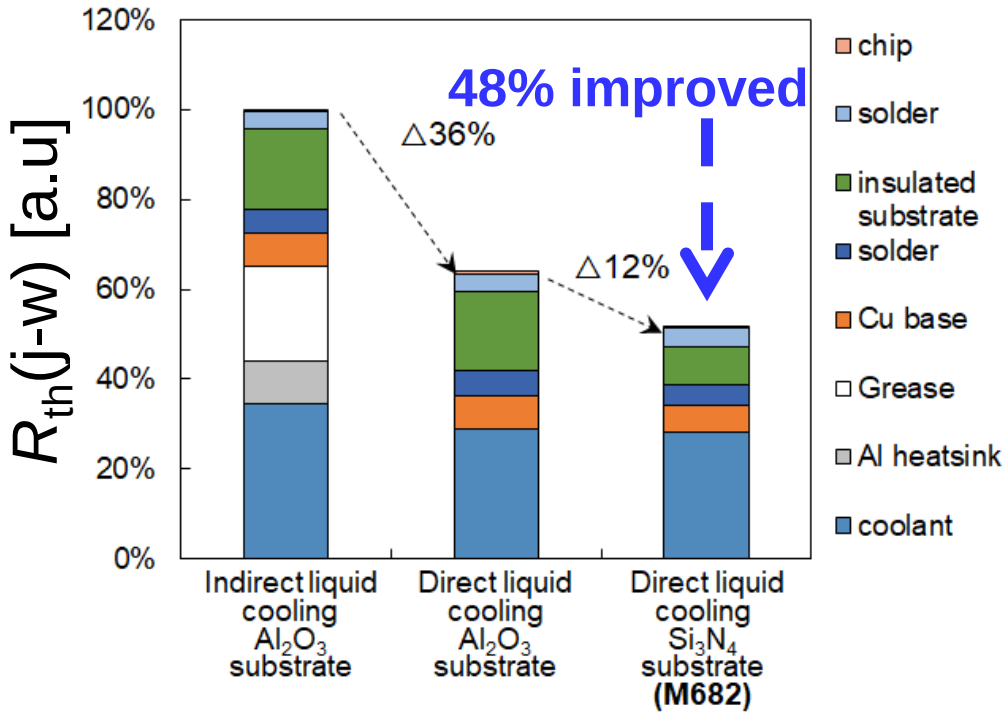
Indirect Cooling Al_2O_3 substrate

Direct Cooling Al_2O_3 substrate

Direct Cooling Si_3N_4 substrate

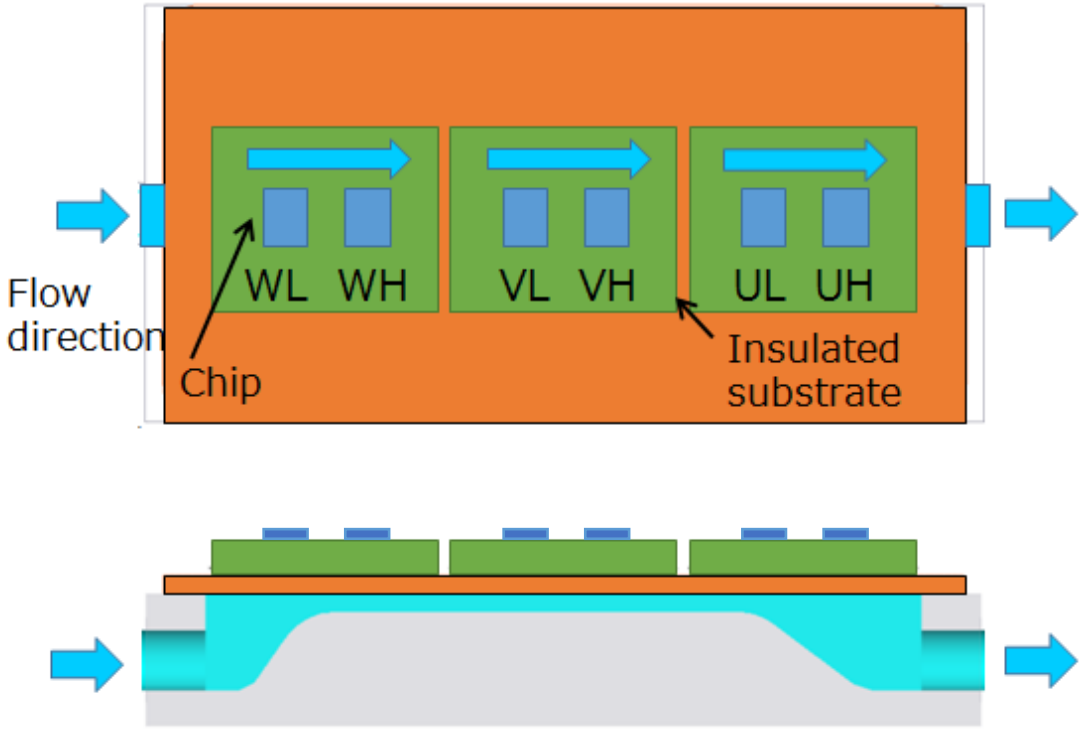
Direct liquid cooling jacket with ribs

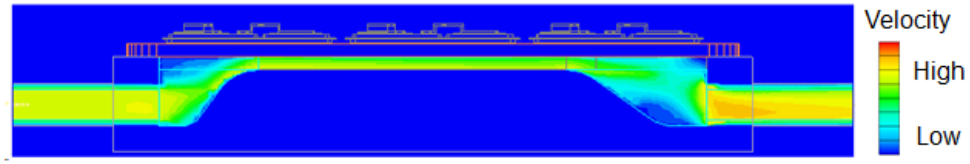
Si_3N_4 insulated substrate



Simulation of Coolant Flow in Liquid Cooling Jacket

In the no rib jacket model, the coolant flows uniformly.



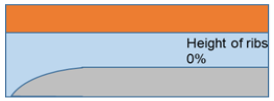
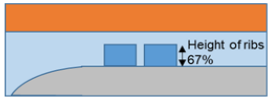
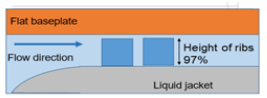
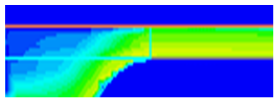
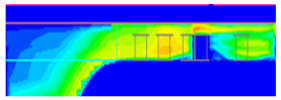
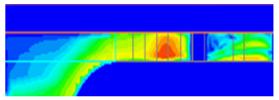


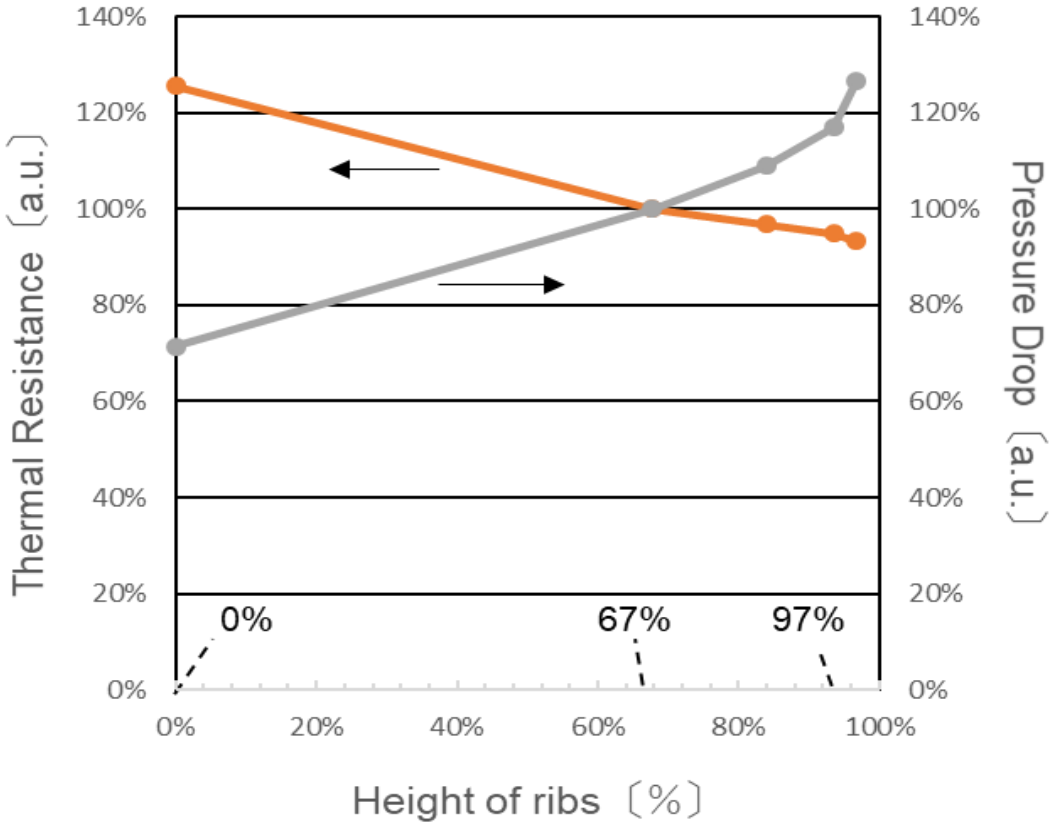
Coolant velocity
No rib model

A rib shape to enhance the coolant velocity is important.

Simulation of Coolant Flow in Liquid Cooling Jacket

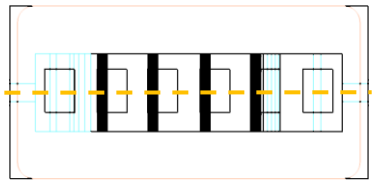
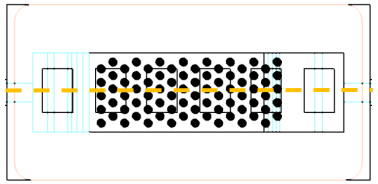
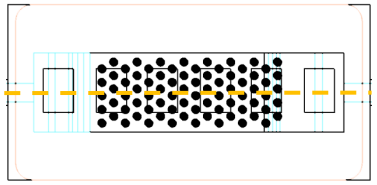
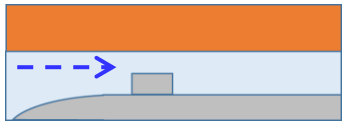
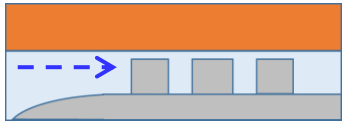
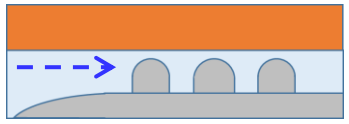
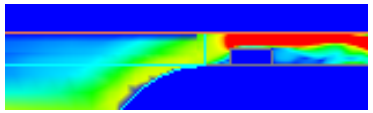
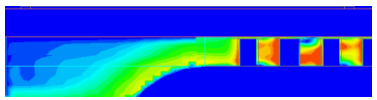
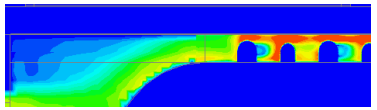
By adding ribs, the flow velocity near the base plate increases.

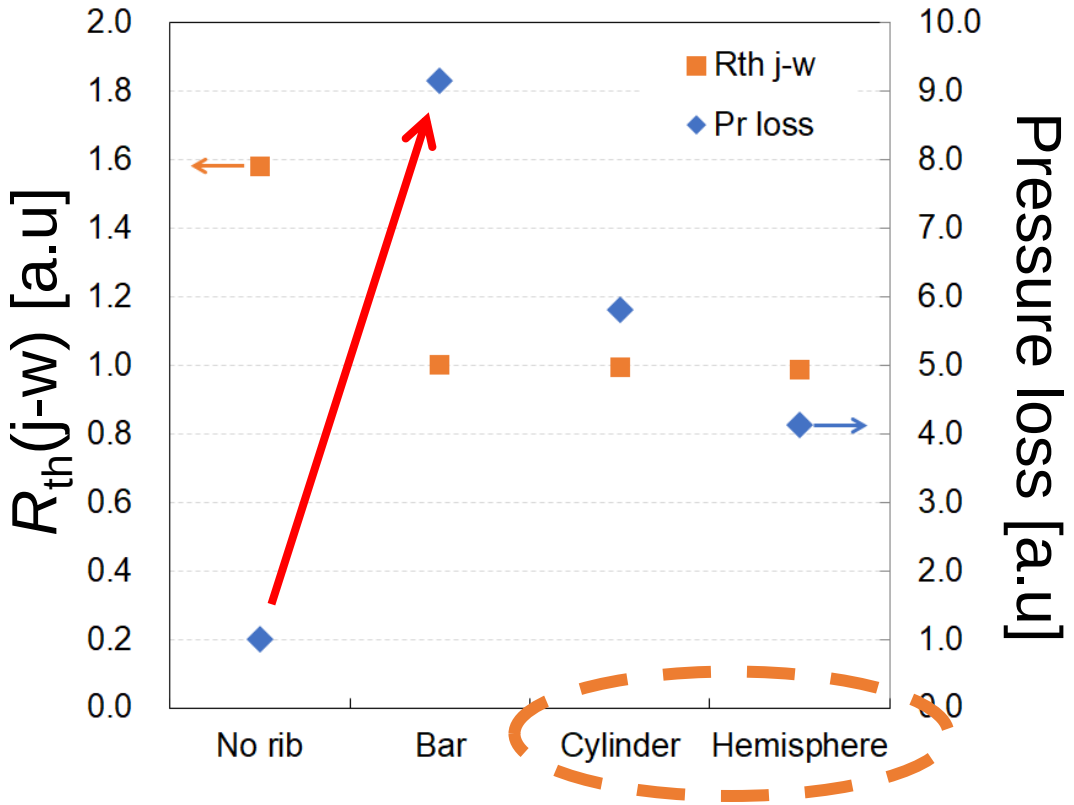
Height of ribs	0%	67%	97%
Cross Section			
Velocity			



Simulation of Coolant Flow in Liquid Cooling Jacket

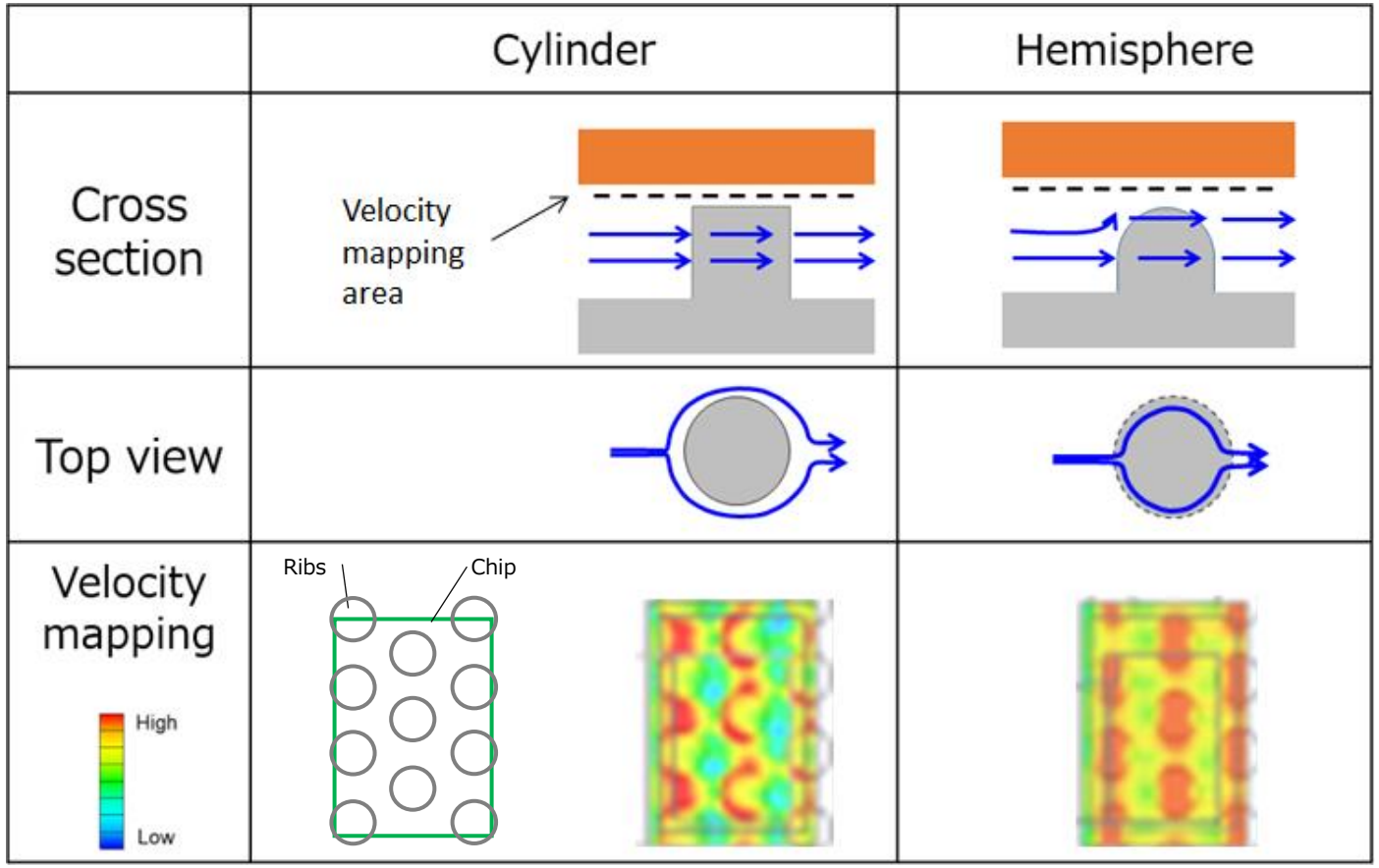
A bar ribs that covers the flow path significantly increases pressure loss.

Ribs	Bar	Cylinder	Hemisphere
Lay out			
Cross Section			
Velocity			



Simulation of Coolant Flow in Liquid Cooling Jacket

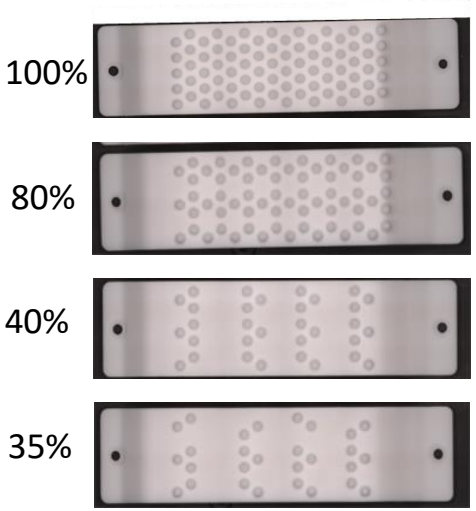
Hemispherical ribs improve the average velocity beneath the baseplate.



Good !

Analysis of Coolant Flow in Liquid Cooling Jacket

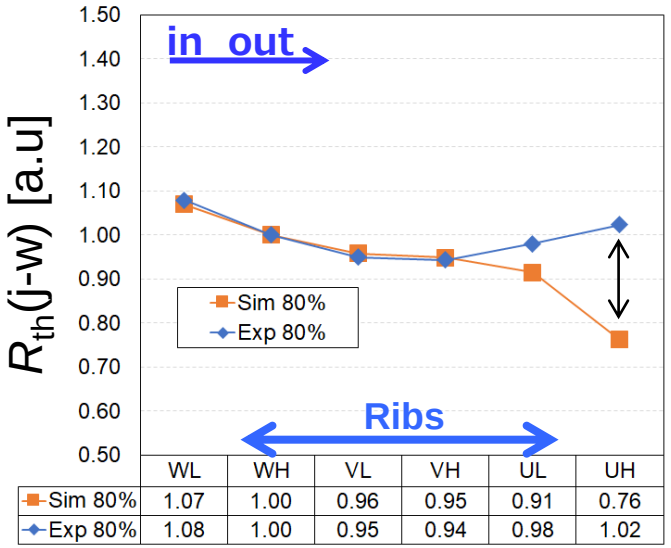
The distribution of thermal resistance measurement matched the simulation result.



3 D printed pattern

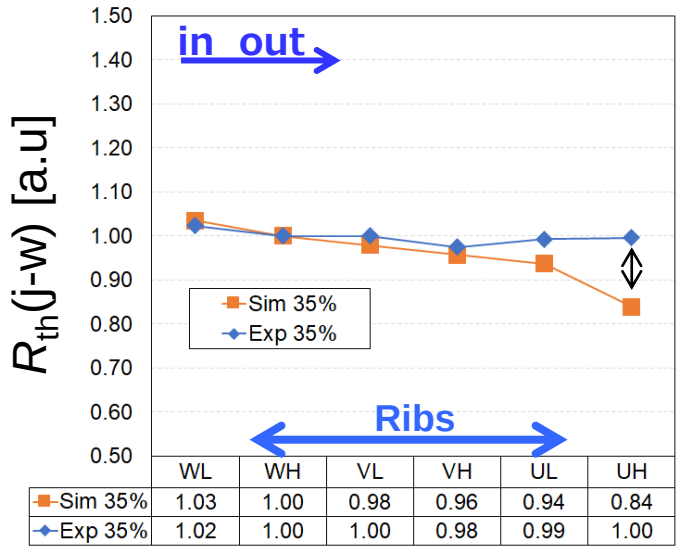
Liquid cooling jacket

Installed 3D model parts in water jacket



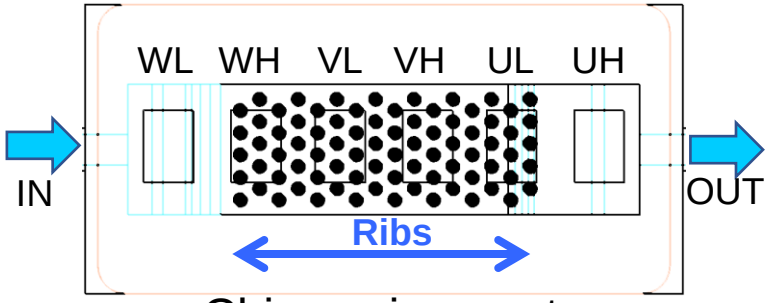
	WL	WH	VL	VH	UL	UH
Sim 80%	1.07	1.00	0.96	0.95	0.91	0.76
Exp 80%	1.08	1.00	0.95	0.94	0.98	1.02

Ribs of Area 80%

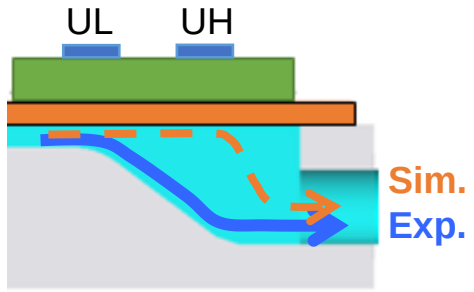


	WL	WH	VL	VH	UL	UH
Sim 35%	1.03	1.00	0.98	0.96	0.94	0.84
Exp 35%	1.02	1.00	1.00	0.98	0.99	1.00

Ribs of Area 35%



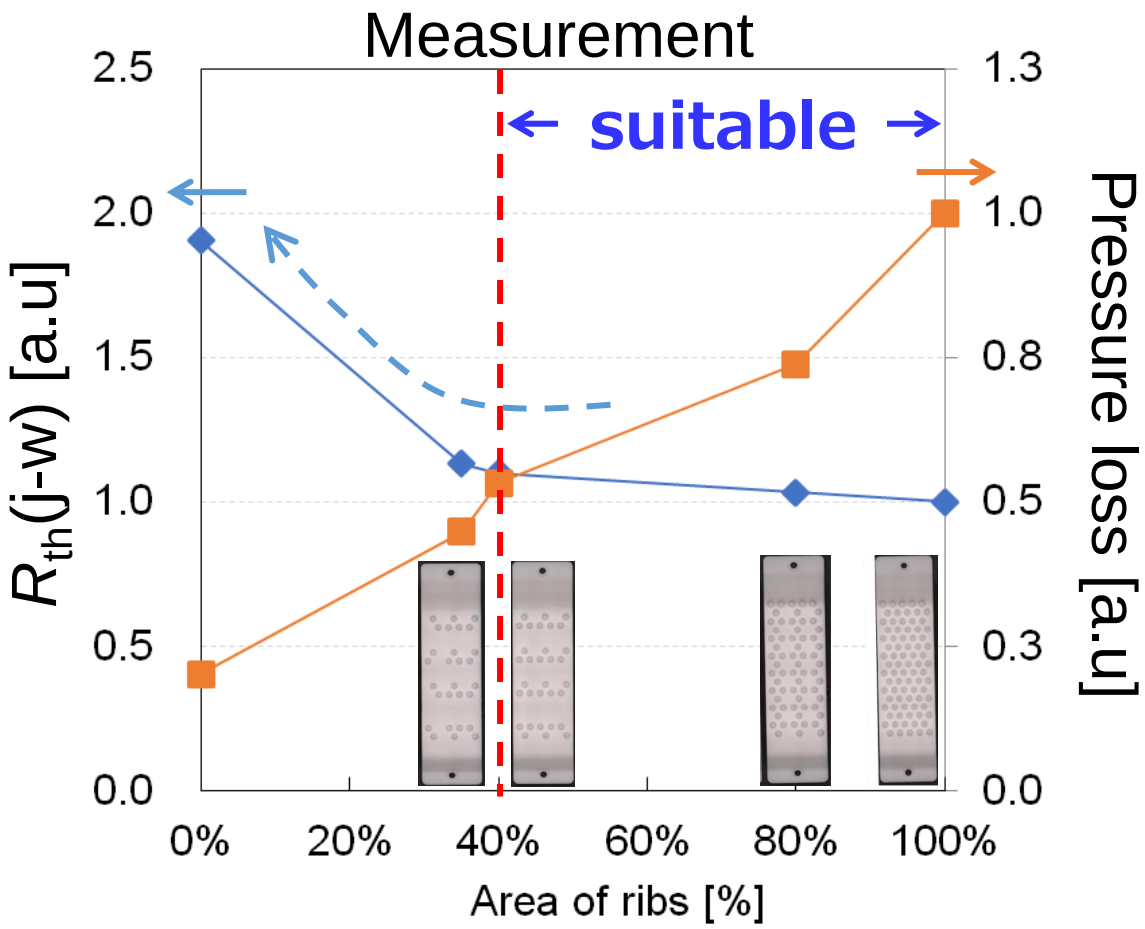
Chip assignment

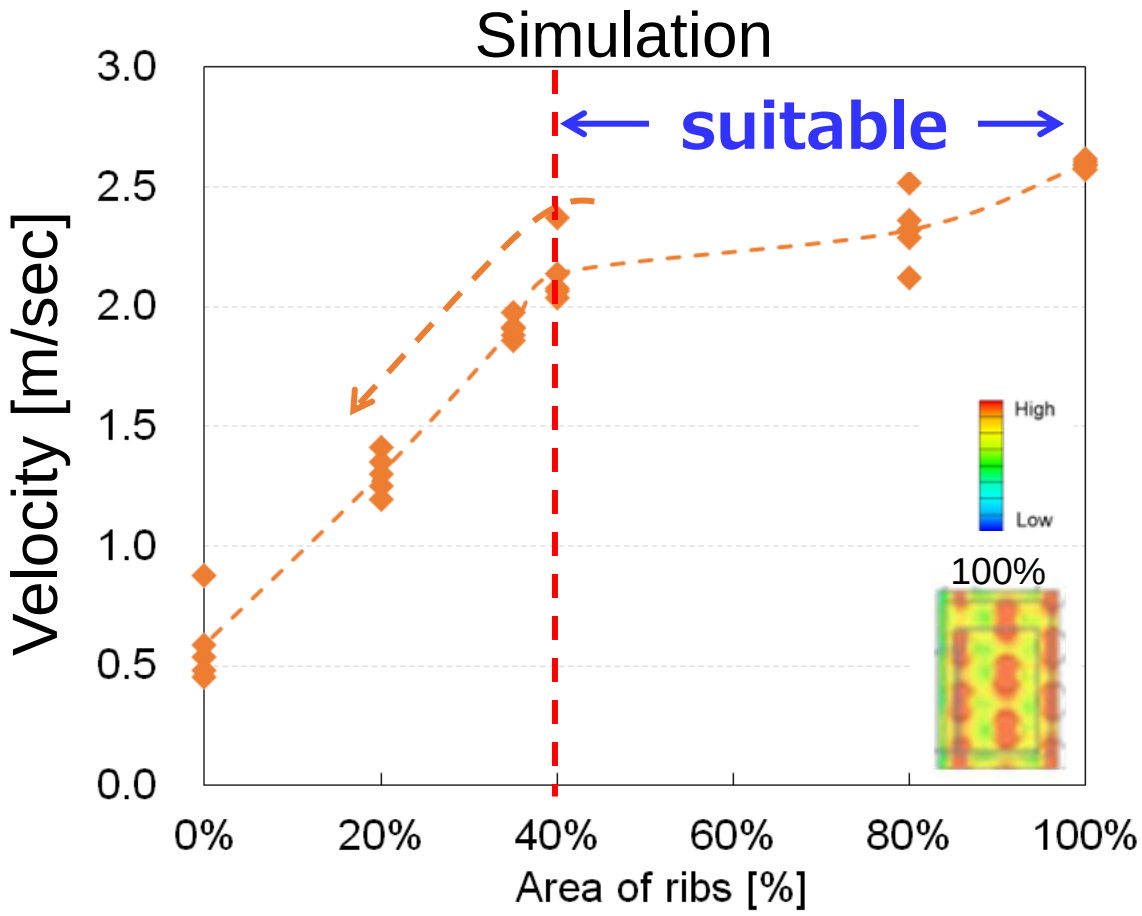


Coolant flow

Analysis of Coolant Flow in Liquid Cooling Jacket

The trade-off between R_{th}(j-w) and pressure loss can be controlled by the coolant velocity determined by the area of ribs.



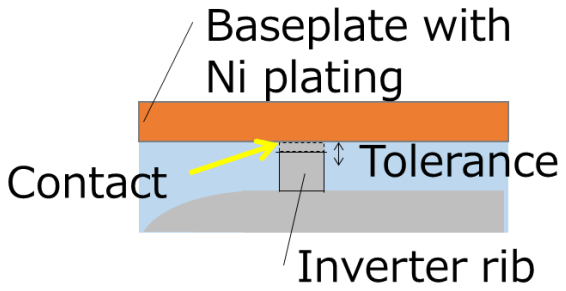


Contents

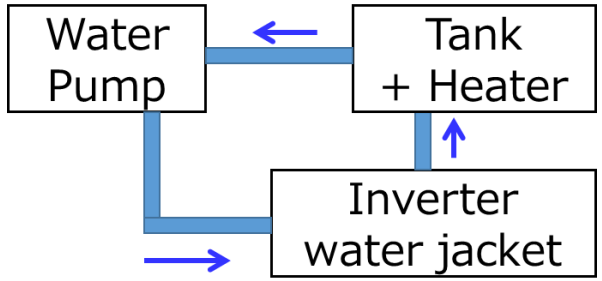
Reliability Test - Corrosion Test

Assuming the worst tolerance conditions, the test was conducted with the ribs and cooler initially in contact. No corrosion is detected.

Experiment setup



Cross section



Schematic Diagram

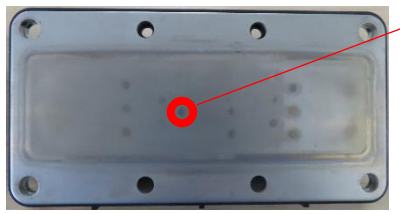
Material
- Flat baseplate: Cu
- Plating : Ni
- Inverter ribs: ADC12(Al)

Test Condition

Corrosion test		
Test water	OY water : LLC 50% = 1: 1	
OY water	CL^-	195ppm
	SO_4^{2-}	60ppm
	Cu^{2+}	1ppm
	Fe^{3+}	30ppm
LLC 50%	Long Life Coolant 50%	
Temperature	65℃	
Flow rate	12L/min	
Test time	1000hr	

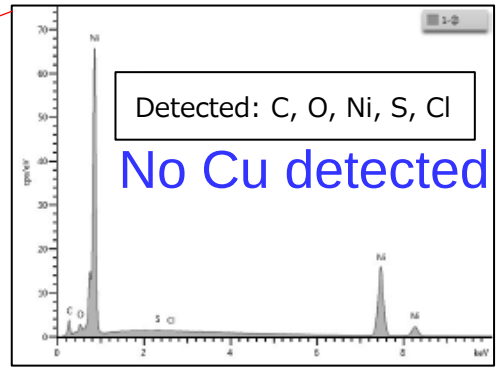
Result

Rib

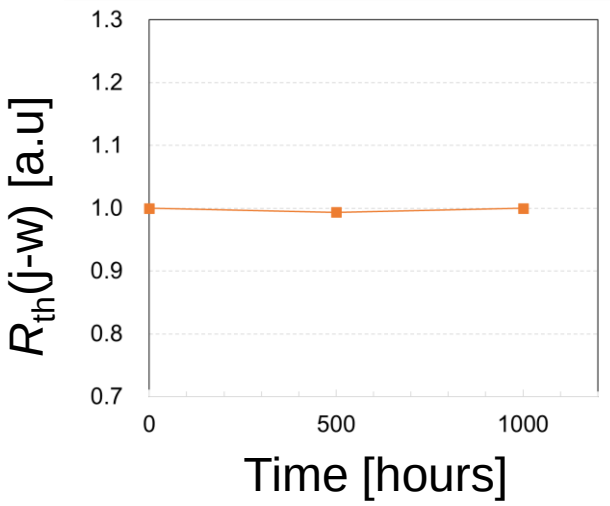


Baseplate

Photograph after test



EDX result
on baseplate

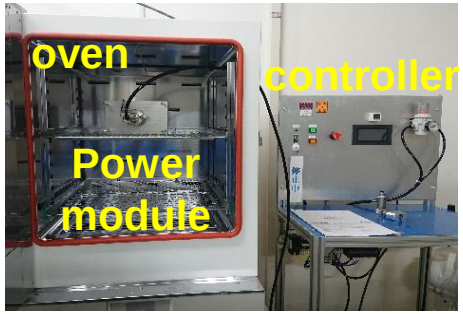


Thermal resistance
Not changed

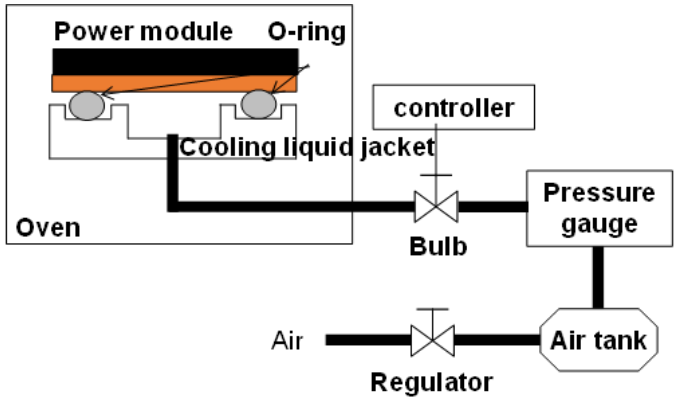
Reliability Test – Intermittent Pressure Test

An intermittent pressure test was conducted.
The solder has enough durability.

Experiment setup



Test set up



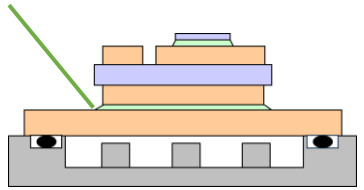
Schematic Diagram

Test Condition

Intermittent pressure test	
Pressure	300kPa by Air

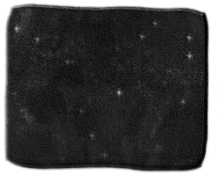
Result

Solder layer

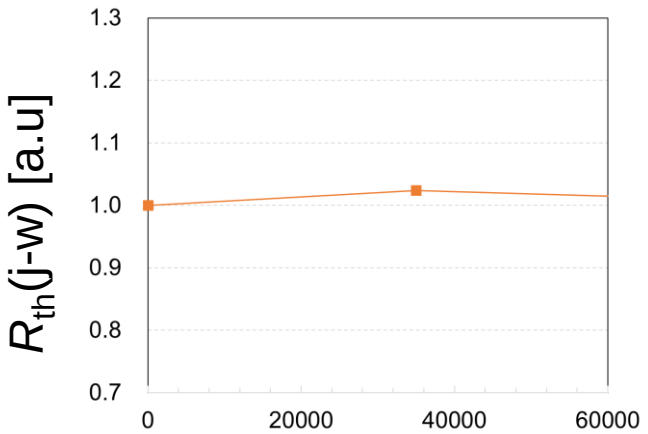


Cross section

SAT image in the solder layer

	Initial	After the test
Scanning Acoustic Tomograph		

Not changed



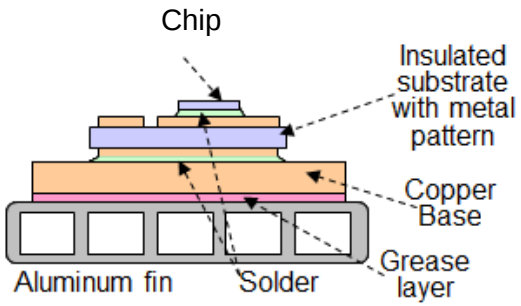
Thermal resistance
Not changed

Contents

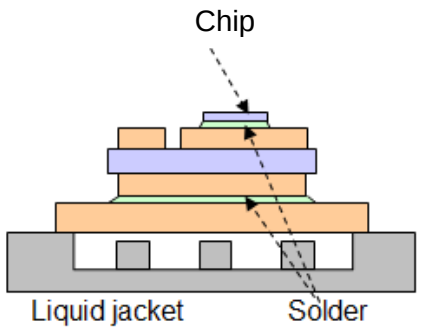
Output Power of M682 with a flat baseplate

The output current is enhanced by 1.5 times in M682 structure compared to the conventional indirect cooling power module.

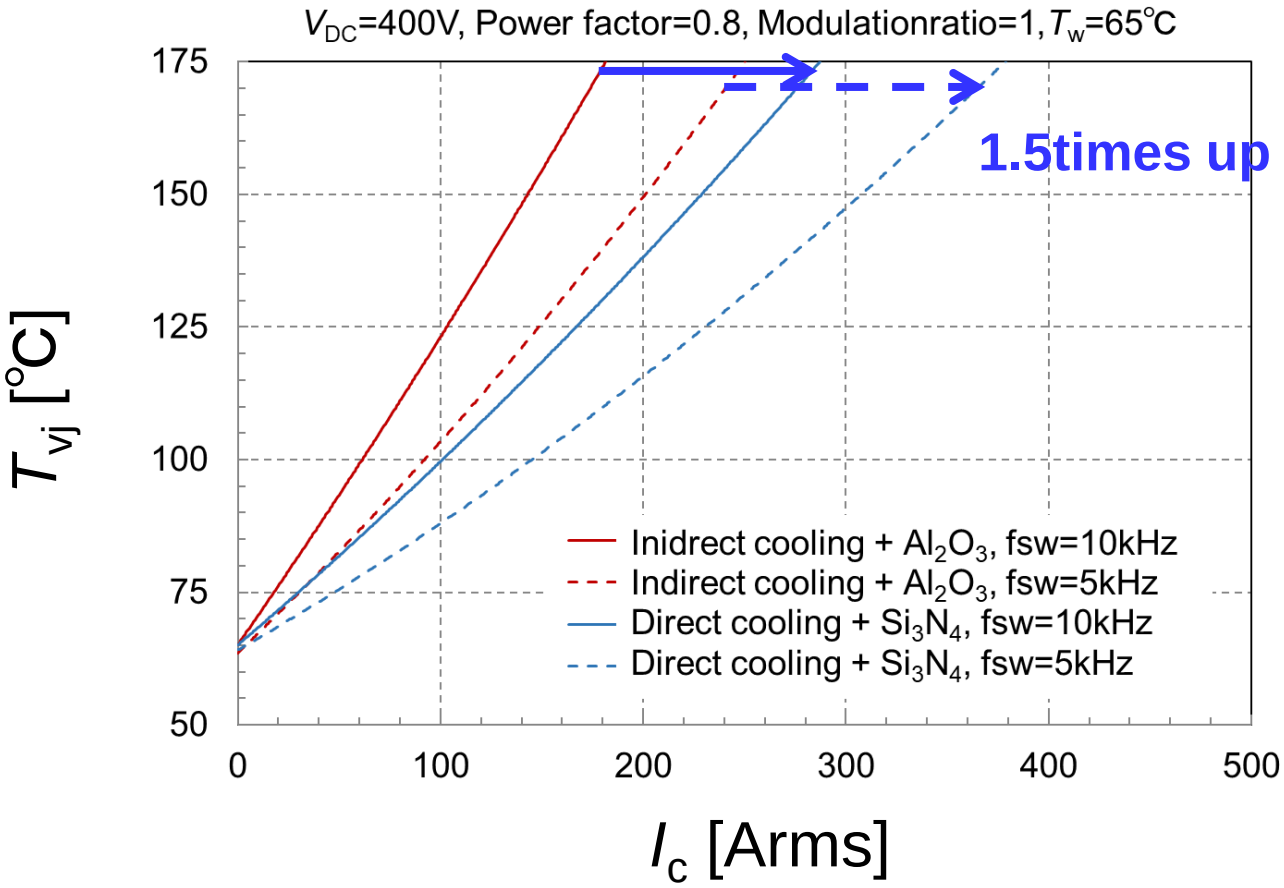
Conventional ----------> M682 flat baseplate



Indirect Cooling
Al_2O_3 substrate



Direct Cooling
Si_3N_4 substrate



Contents

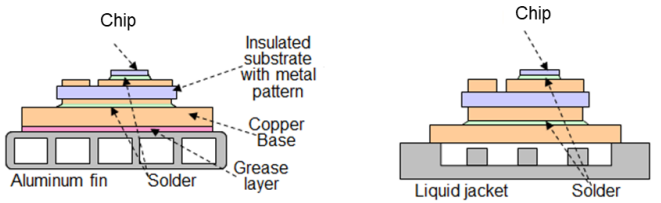
Conclusion

The power module with flat baseplate for automotive application is presented.

Cooling technology

The trade-off between R_{th}(j-w) and Pressure loss can be controlled by the area of ribs.

48% reduction of R_{th}(j-w)

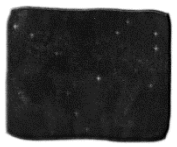


Conventional → M682 flat baseplate

Reliability test

No corrosion is detected.

An intermittent pressure test : The solder has enough durability.

	Initial	After the test
Scanning Acoustic Tomograph		

Output power performance

The output current is enhanced about 1.5 times

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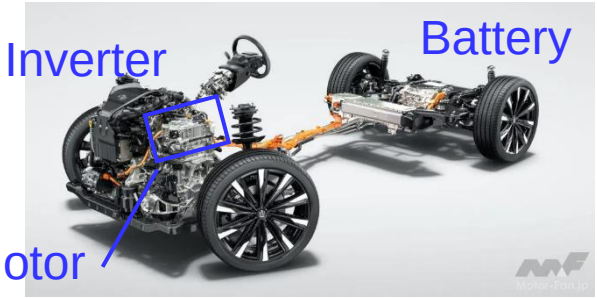
Thank you for the attention!

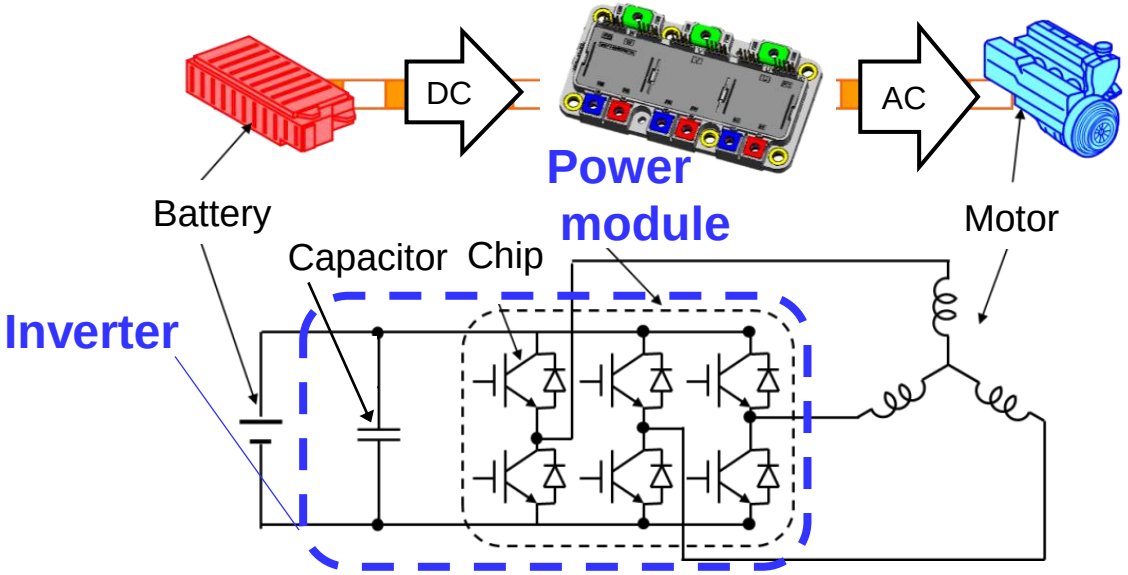
Masahide　Kamiya, Fuji Electric Co.,Ltd
I‘m pleased to answer your questions.
kamiya-masahide@fujielectric.com

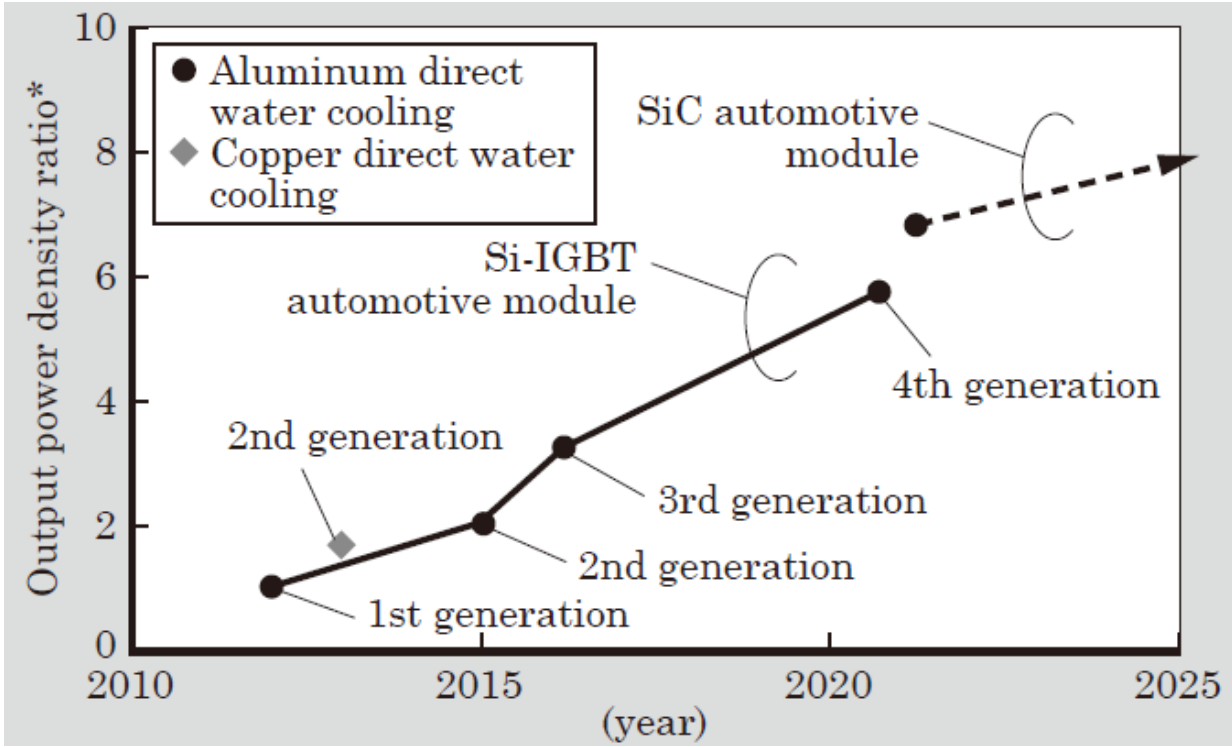
High Power Density Challenge

For small and high-power density of e-axles, the power modules are required to be downsized.



https://motor-fan.jp/mf/article/69827/20220715_01_31/





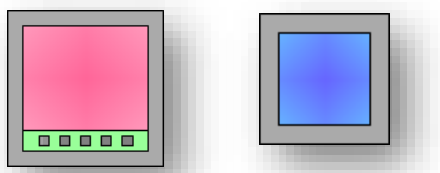
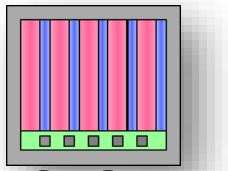
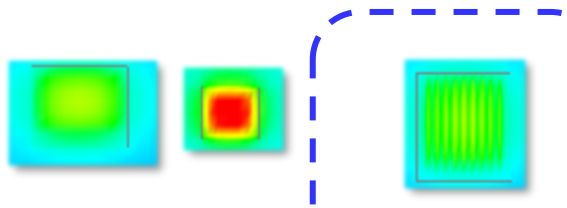
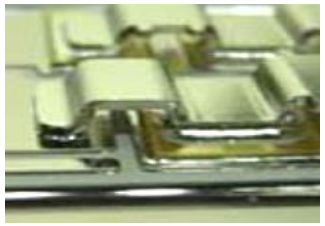
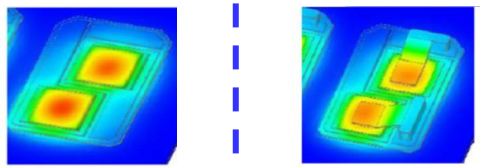
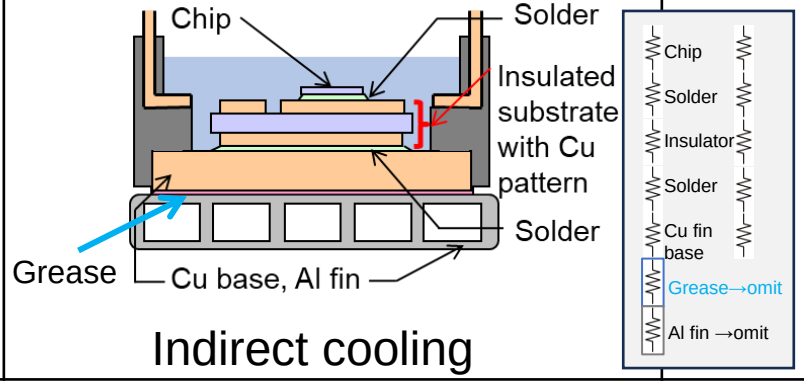
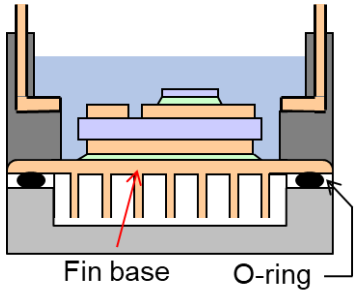
Fuji's trend of the power density of power module

Cooling Technology for Ultra-Compact RC-IGBT Modules for eEVs
Fuji Electric Review Vol.67-No.4,2021

(*) maximum output power(kVA) / module volume (L)

Technologies for Downsizing of Power Modules

For heat averaging, spreading and reduction of structural resistance, chip, connection and cooling technology are innovated.

	Conventional	Improved idea	Thermal contour
Chip			
Chip Connection	 Wire bonding	 Lead frame	
Cooling	 Indirect cooling	 Direct cooling