■ A3 【パワーデバイスと実装（自動車系）】谷本講師

先端パワーエレクトロニクス技術体系講座
Advanced Course

～次世代SiCインバータ～

EV機電一体パワーモジュール

福島SiC応用技研株式会社（FSiC）
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Global Urgent Problems & Issues

- Exhaustion of fossil fuels
- Resource capture
- Exhaust gas pollution
- Nuclear fuel waste (Fukushima disaster!)
- Global warming (? Scientifically debatable)

- Energy saving
- Renewable energy creation

Power Conversion Systems

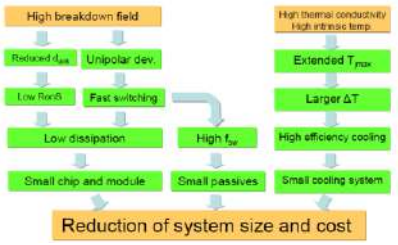
Requirements	Solution
Higher efficiency	SiC/GaN unipolar devices
Smaller size	+
Lighter weight	Higher current density
Air cooling	+
More robustness	Higher f_{SW} > 20 kHz
Lower cost	+
	Extended T_{jmax} > 200°C

Smaller size results in lower cost.

Major Properties of SiC

Physical Property	Si	4H-SiC
Band gap (eV)	1.12	3.26
Breakdown Field (MV/cm)	0.3	2.8
Electron mobility (cm/s)	1350	1000
Thermal conductivity (W/cmK)	1.5	4.9
Intrinsic temperature (K)	600	1400

Scenario of Size Reduction



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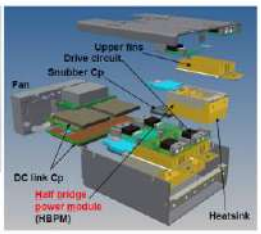
Inverter Comparison

SiC Inverter "NIJI"
(10 kW@50 kHz, 15 kW@20 kHz)

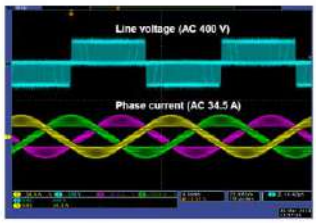
70 kW/L SiC Inverter

Input	600 V (DC)
Output	3φ ~400 V, 25 kW
Size	105 × 80 × 40 ≒ 350 mL
Power density	70 kW/L
Frequency	50 kHz



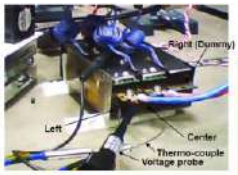
Assembly diagram

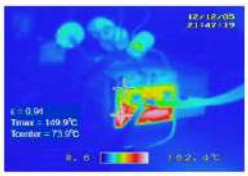
AC 50 Hz 20 kW Output Waveform



Power factor = 0.82, f_{sw} = 50 kHz

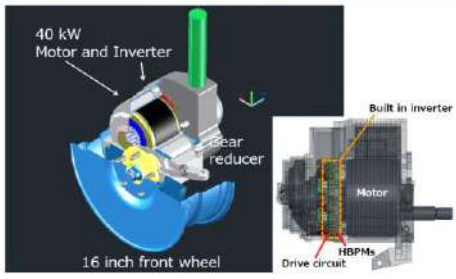
Continuous Output Test





Tc (fins) = 160℃
Tj = 180℃(Calc.)
Dissipation = 100 W/module

EV In-Wheel Motor



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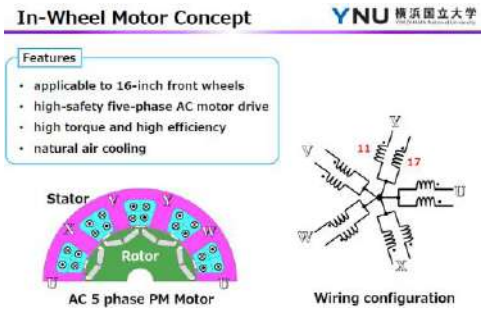

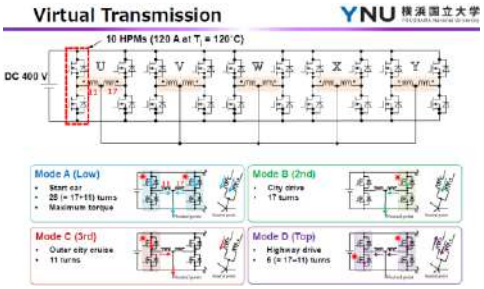

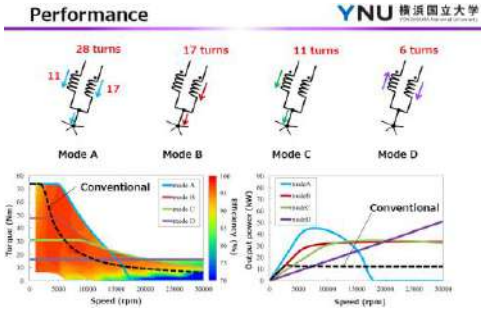

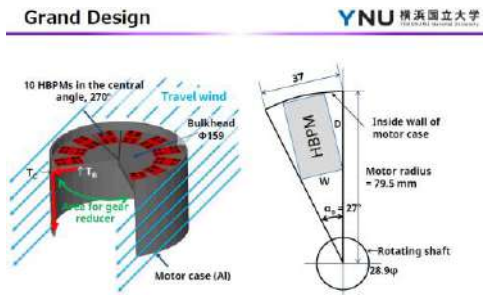

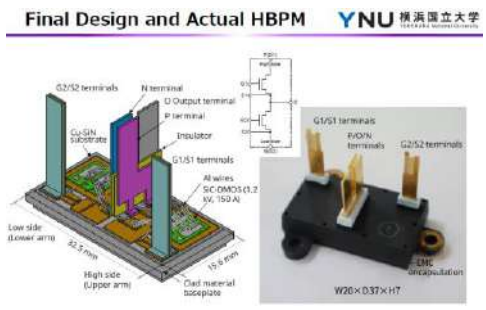

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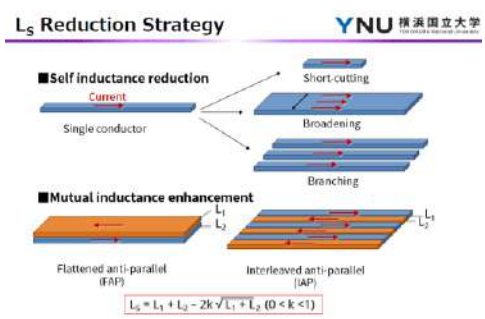

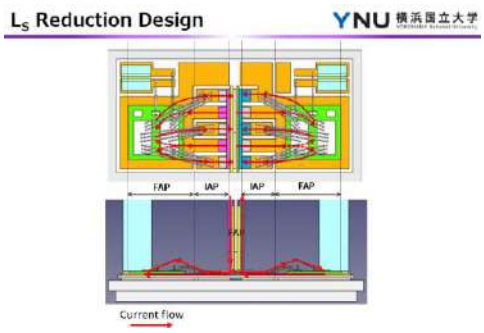

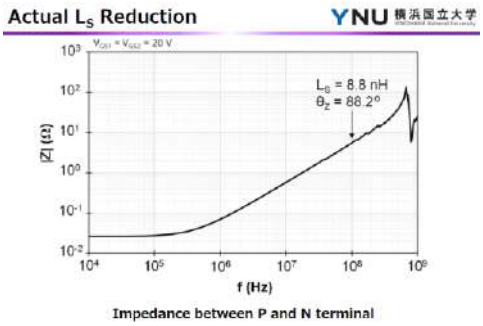

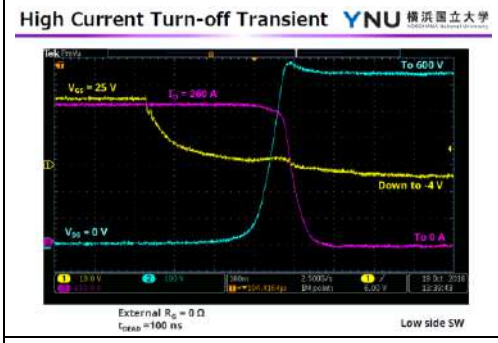

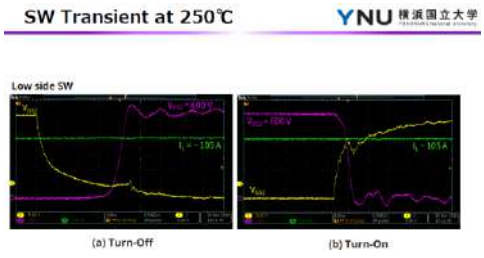

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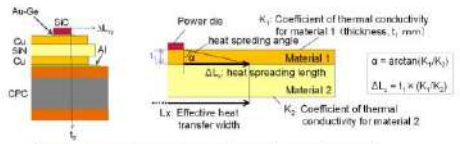
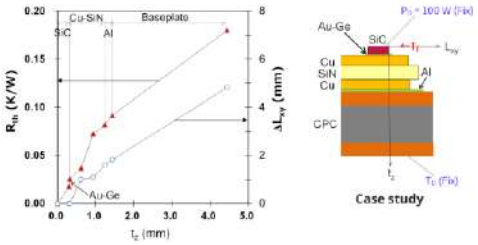
Heat Release Calculation



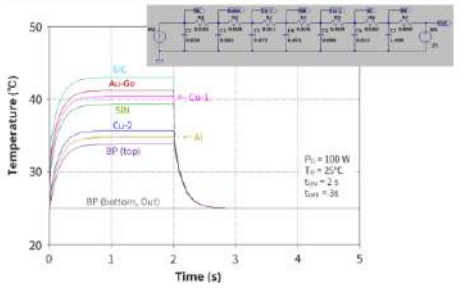
Component		TC	CTE	SH (C)	SG (α)	Thickness
Item	Material	K (W/mK)	(ppm/K)	(J/(g*K))	g/cm3	t (mm)
Power die	SiC	293	4.8-6.6	0.69	3.21	0.3
Die attach	AuGe	44	12	0.15	14.67	0.02
AMB Cu	Cu	401		0.38	8.93	0.3
SiN sub	SiN	120	6.5	0.65	3.26	0.32
AMB Cu	Cu	401		0.38	8.93	0.3
Sub attach	Al	237	24.3	0.27	2.70	0.2
Baseplate	CPC141	220	7.8	0.32	9.50	3

7.6W×7.6D

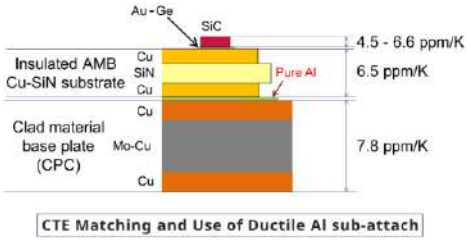
R_{th} and Heat Spreading



Thermal Response (LTspice Sim)

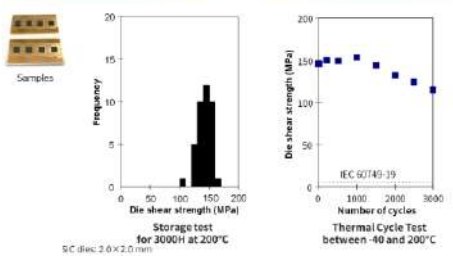


Thermal Stress Design



CTE Matching and Use of Ductile Al sub-attach

Die Attachment Reliability



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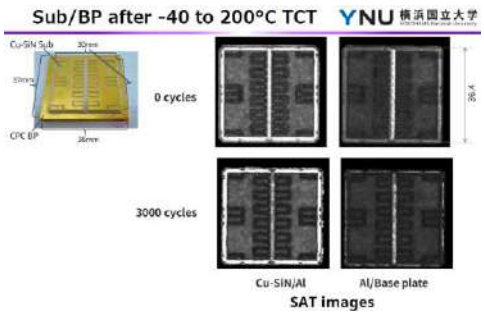

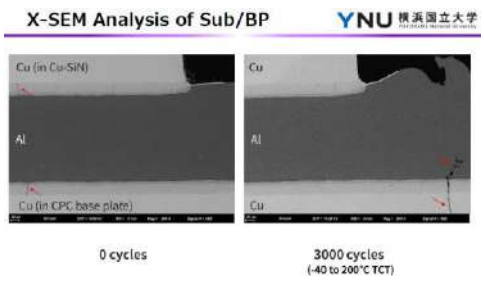

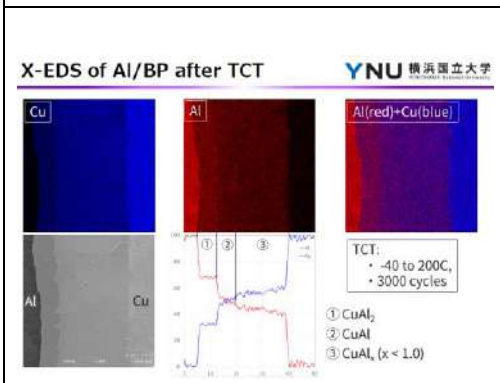

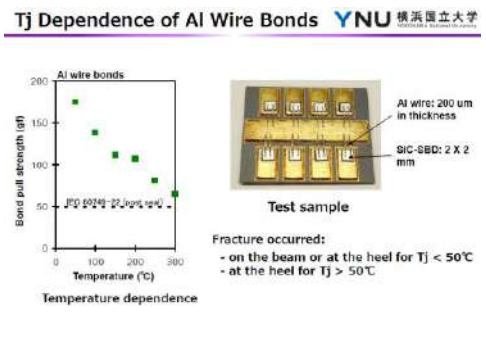

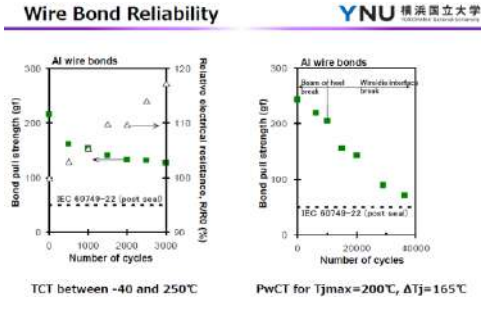

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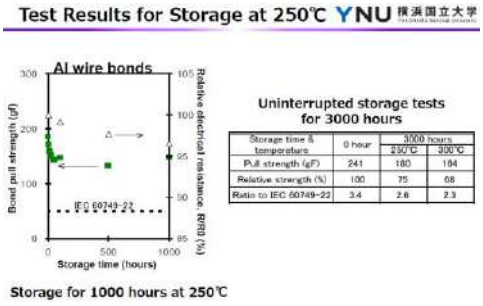
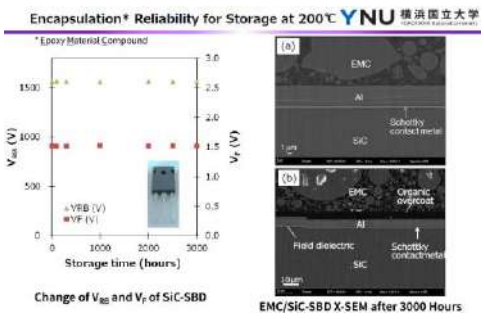
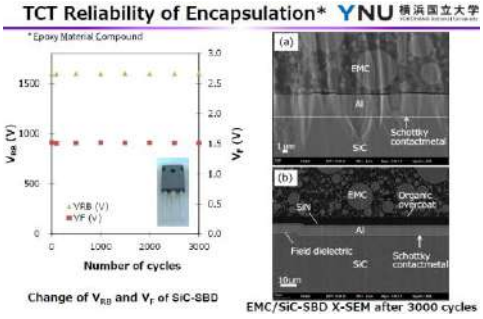
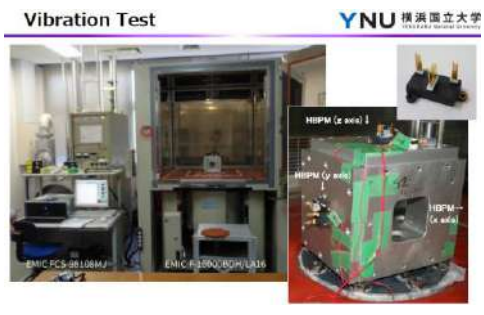
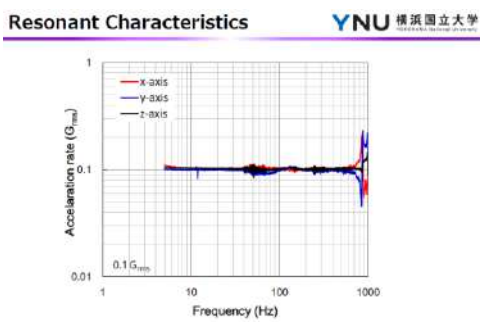


Storage time & temperature	0 hour	3000 hours 250℃	3000 hours 300℃
Pull strength (gF)	241	180	194
Relative strength (%)	100	75	68
Ratio to IEC 60749-22	3.4	2.6	2.3









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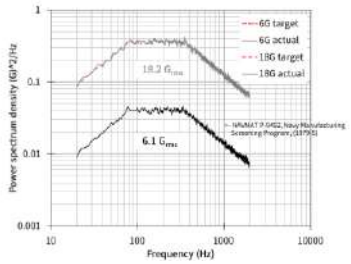
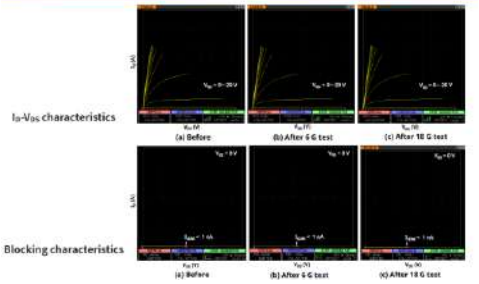
Power Spectrum Density



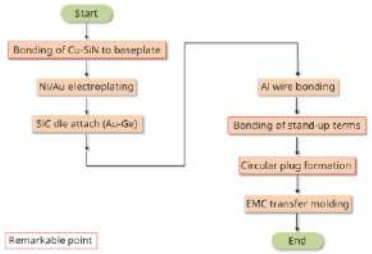
Random Vibration Test Results



Yield Rate

Property	6 G_{rms} Test (30H)		18 G_{rms} Test (30H)	
	Arm	Leg	Arm	Leg
Output	0/6	0/3	0/6	0/3
Blocking	0/6	0/3	0/6	0/3
Total	0/6	0/3	0/6	0/3

Assembly Flow Design



Comparison* with Market Products

Issues	Market Products**	Our module	Innovative Factor
Total Volume V (cc)	100	5	1/20
Thermal Resistance Rth_jb (K/W)	0.16	0.18	comparable
Parasitic Inductance Lp* (nH)	15	8.8	1/2
Junction temperature Tjmax (°C)	150	200 (250***)	50°C higher, More than 200°C
Thermal Excursion ΔTj (°C)	190	240 (260***)	50°C greater

*1.2 kV 120 A class HBPM, **Combination of best values, ***Short range in time.

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Practical 5-Phase Inverter

EV IWM equipped with Inverter

Summary

Extremely compact full SiC HBPMs built in a real EV IWM have been designed, prototyped and characterized.

The prototyped HBPMs are extremely compact in size and capable of withstanding junction temperatures up to nearly 200°C and steadily switching 260 A at DC 600 V.

They have better CTE matching and low thermal resistance, resulting in superior reliabilities.

An assembly process of the HBPM encapsulated with thermoset EMC has been proposed and finally completed.

Acknowledgement

This work was supported in part by the Strategic Innovation Promotion Program (SIP) directed by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

The authors gratefully thank Prof. Kan Akatsu (Shibaura Institute of Technology), Dr. Masaki Nakano and Dr. Yoshinori Murakami (Nissan Motor, Japan) for the design and fruitful discussions with regard to the IWM described here.

Thank you for your kind attention.