Presented at 3D-PEIM in Miami, January 3rd, 2023

Superior heat dissipation by low pressure Ag sinter joining & real time AI lifetime prediction for SiC power module

Katsuaki Suganuma, Zheng Zhang, Aiji Suetake, Chuantong Chen, and

Yasushi Sakurai, Yasuko Matsubara

SANKEN, Osaka University

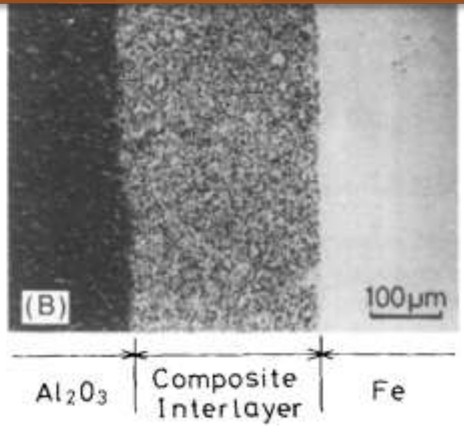
SANKEN
J-Innovation HUB

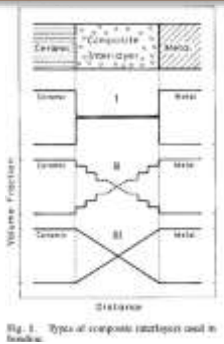
Outline

- ✓ Introduction
- ✓ Advanced power modules & reliability
- ✓ Ag sinter joining & heat management
- ✓ Substrate and Ni-P plating
- ✓ Thermal property measurement and management
- ✓ Reliability and lifetime prediction by AE sensing + AI
- ✓ Summary

Several contributions to ceramic/metal joining

Sinter Joining & Functionally Gradient



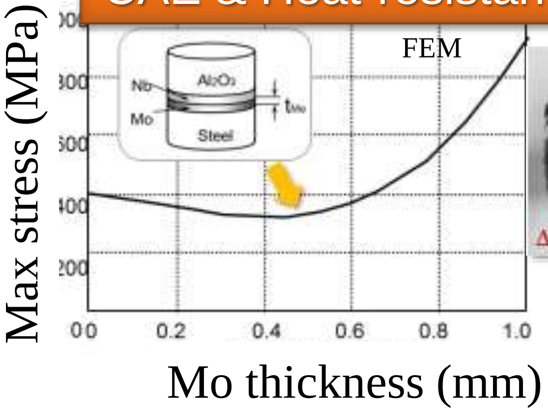


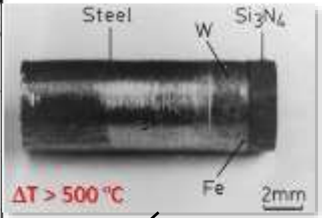
In 1983

K. Suganuma, et al; J. Amer. Ceram. Soc., 66 (1983), c117

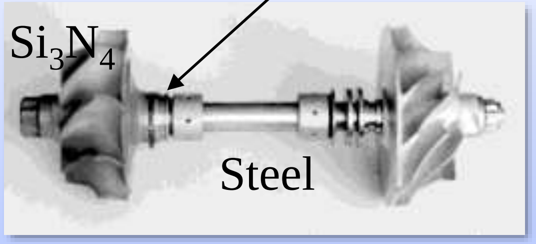
CAE & Heat-resistant Joining

In 1984





K.Suganuma et al, J. Nucl. Mater., 133&134 (1985), 773.



In 1986

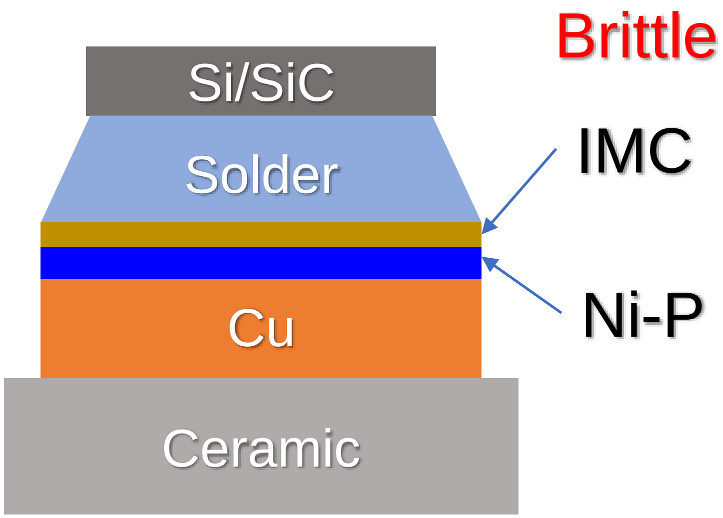
World first Al/AlN substrate manufactured by casting for HEV

In 1998

Towards Advanced "Tough" Semiconductors

- ✓ Autonomous driving/flying/robot subjects require unbreakable semiconductors
- ✓ Infrastructures such as datacenter/base station require the same toughness
- ✓ These semiconductors must be monitored on their status to maintain their safe operation and the potential failure should be reported before their life-time

Ideal interconnection

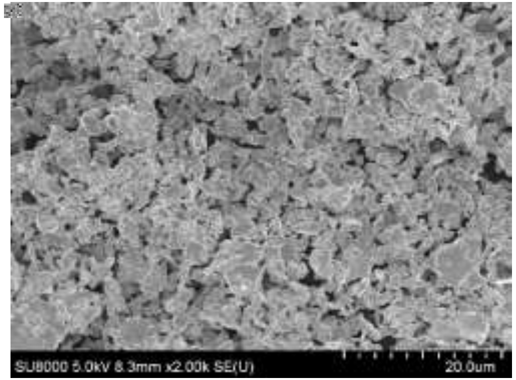


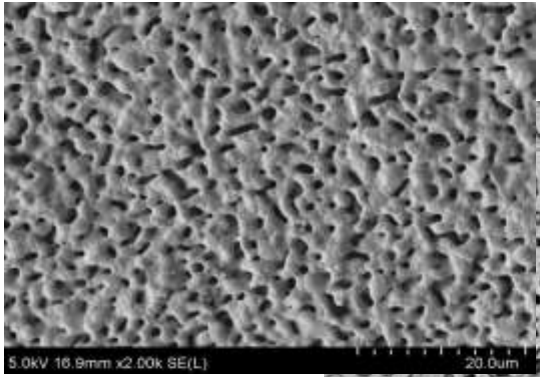
- ✓ In severe thermal cycles, IMC and Ni-P will be the origin of failure
- ✓ Brittleness of Ni-P plating should be improved
- ✓ IMC formation must be avoided
- ✓ Brittleness of ceramics must be improved

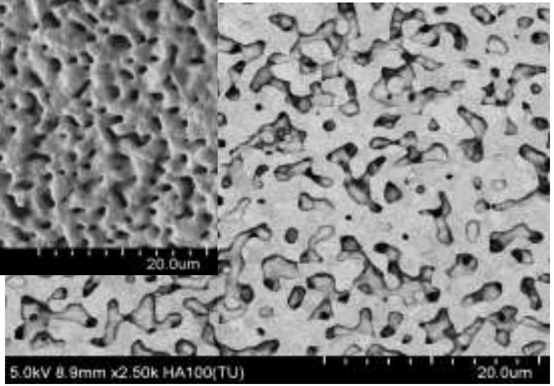
Choices of interconnection materials

	Solder	Conductive adhesive	Sinter joining	
			Nano Ag/Cu	Micron Ag/Cu
Electric conductivity	X	X	◎	◎
Thermal Conductivity	X	X	◎	◎
Strength	○	○	○	○
Heat resistance	X	△	◎	◎
IMC formation	X	○	○	○
Cost	○	△	X	△/○
Others	• Easy handling • ~250 °C	• ~150 °C	• High pressure • 200~250 °C	• No/Low pressure • 180~250 °C

Sintering of Ag flake pastes







Ag + solvent
250 ºC-60 min
No pressure
In air

Typical properties of sintered Ag paste

Density (g/cm^3)	Porosity (%)	Thermal conductivity (W/m·K)
6.20	40.9	150 ~ 200

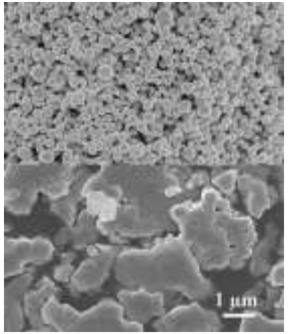
- ✓ Handling easiness
- ✓ Low temperature & low/no pressure
- ✓ Air atmosphere
- ✓ High performance
- ✓ Large area bonding
- ✓ Affordability

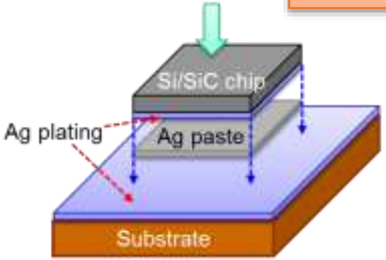
SANKEN

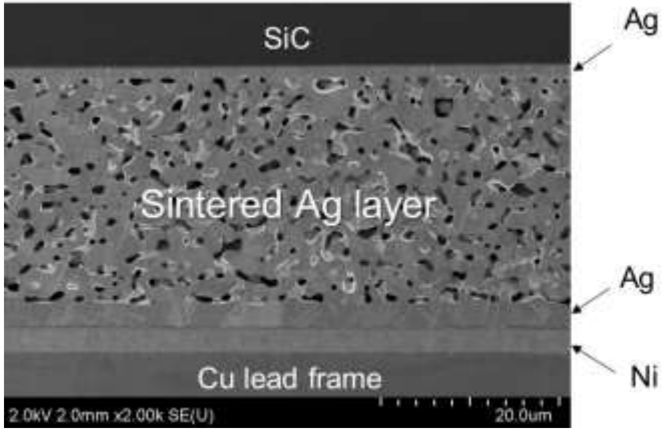
K.Suganuma, F3D, Osaka University

Micron particle/film Ag joining

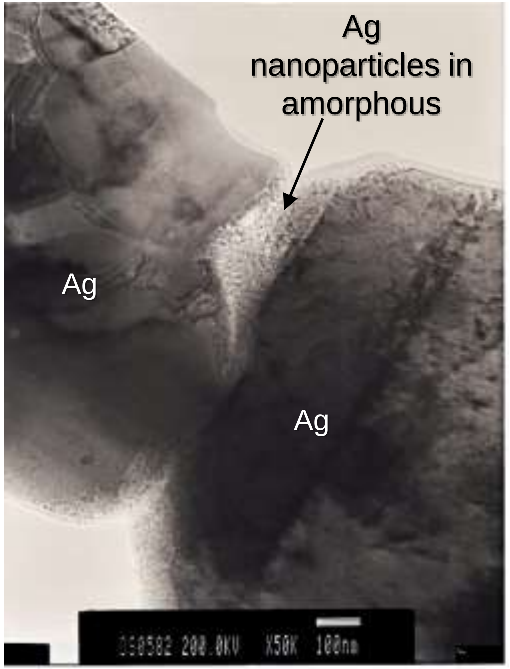
at 180-250 °C, 0~0.4 MPa, in air

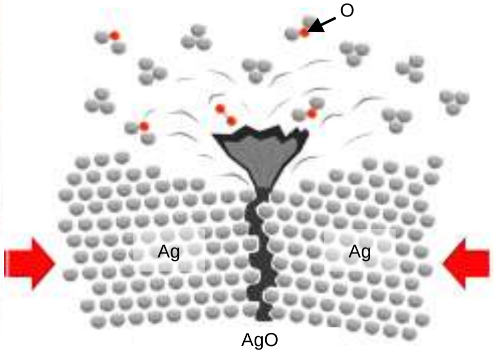






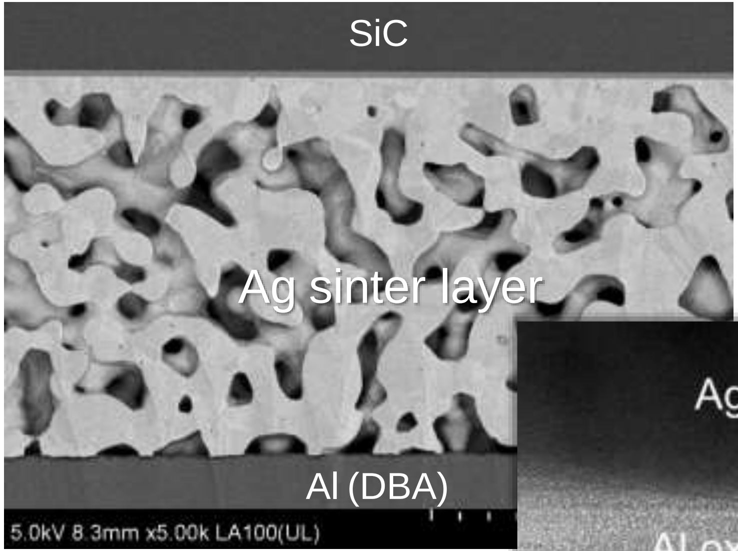
Suganuma et al. , Microelectronics Reliability **52** *(2012) 375.*

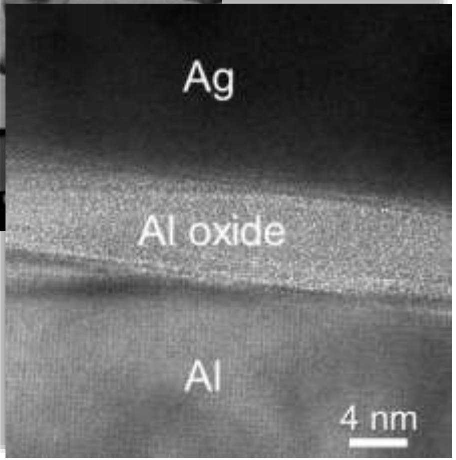


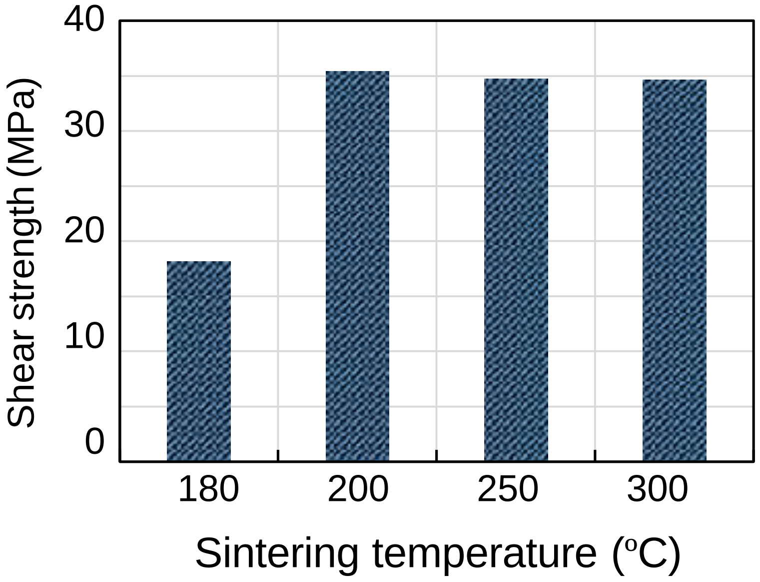


S.-K. Lin et al, Scientific Report, 6(2016), 34769.

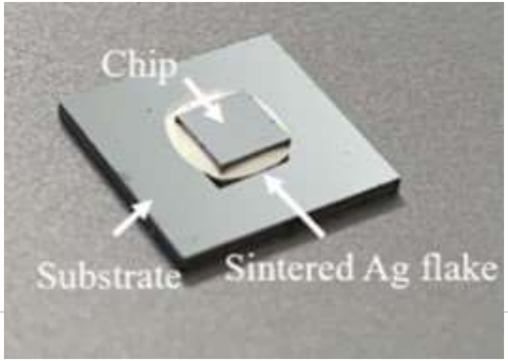
Direct bonding without metallization

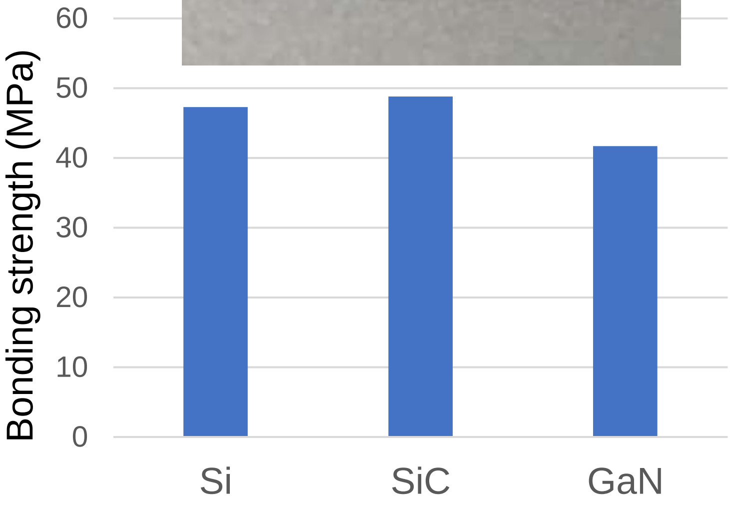


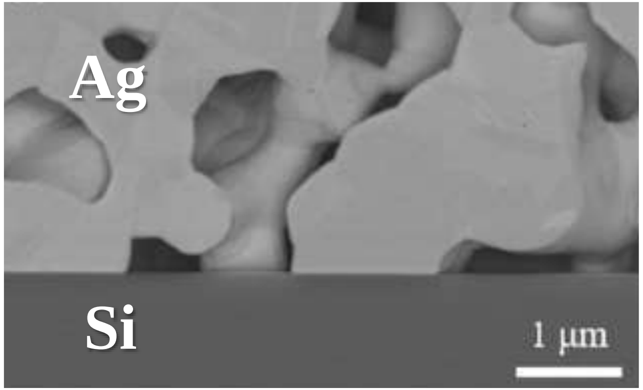


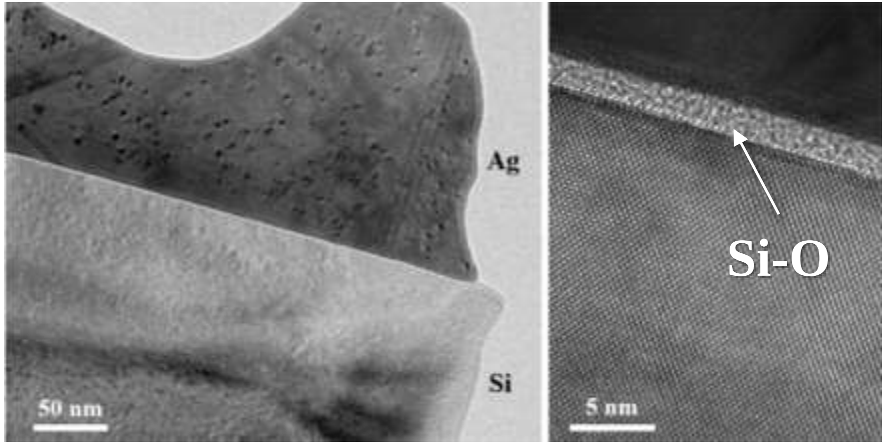


Direct bonding without metallization on Si/SiC/GaN



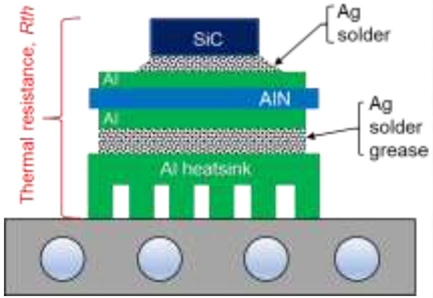


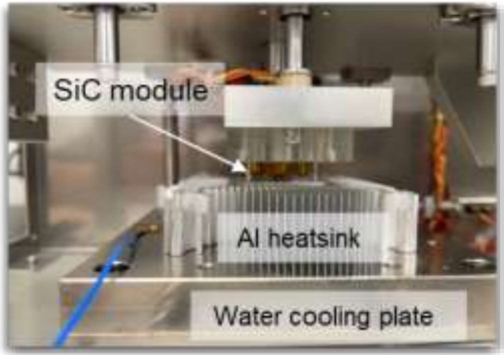


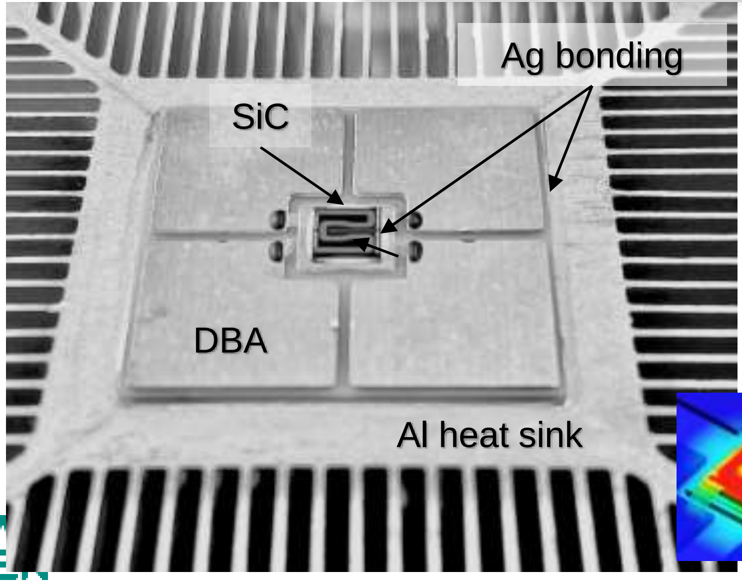


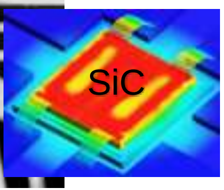
Z. Zhang et al, Scripta Mater 198(2021), 113833.

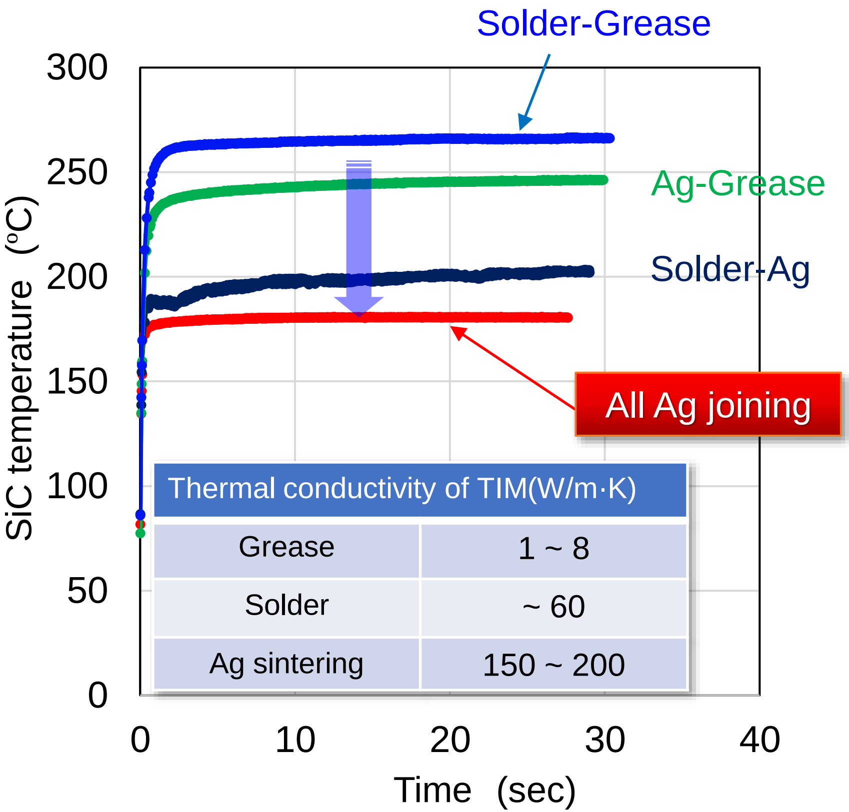
Cooling performance of Ag sinter joining











Thermal conductivity of TIM(W/m·K)	
Grease	1 ~ 8
Solder	~ 60
Ag sintering	150 ~ 200

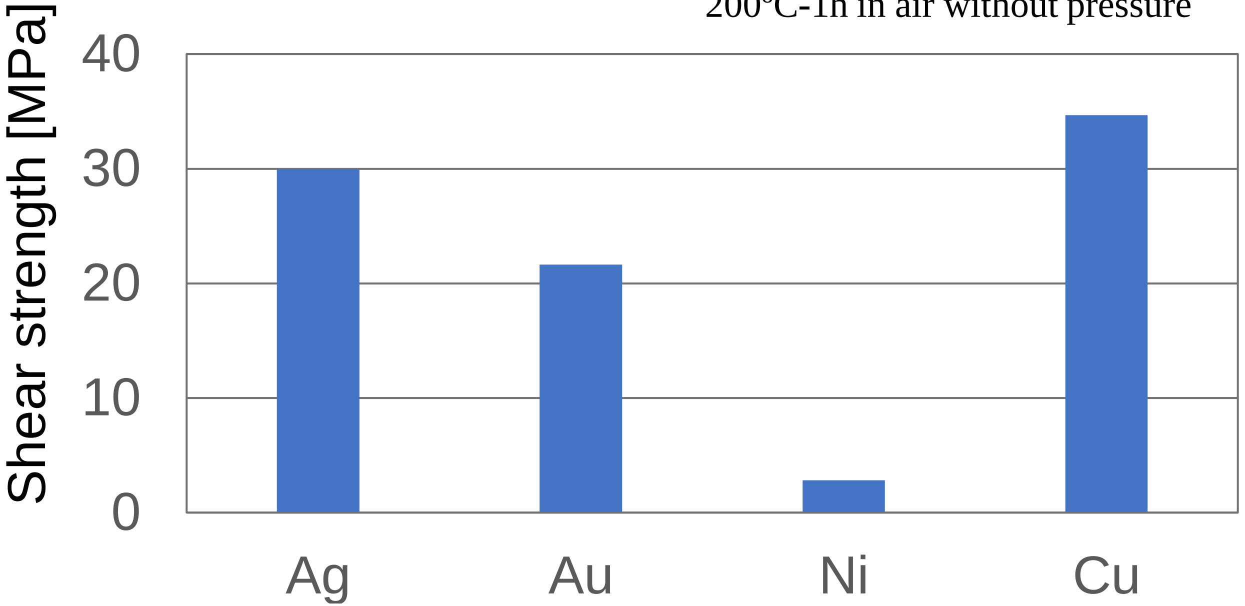
K.Suganuma, F3D, Osaka University

Outline

- ✓ Introduction
- ✓ Advanced power modules & reliability
- ✓ Ag sinter joining & heat management
- ✓ Substrate and Ni-P plating
- ✓ Thermal property measurement and management
- ✓ Reliability and lifetime prediction by AE sensing + AI
- ✓ Summary

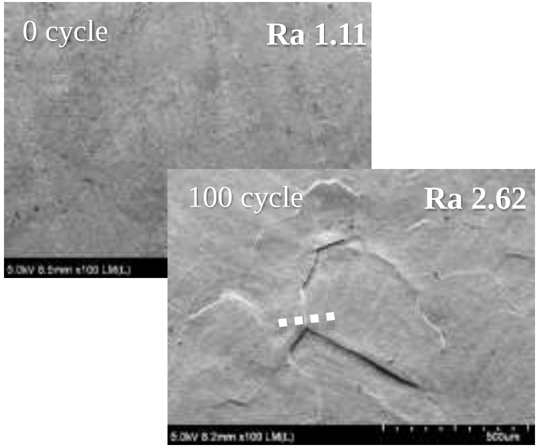
Bonding on various surfaces: Ag, Au, Ni, and Cu

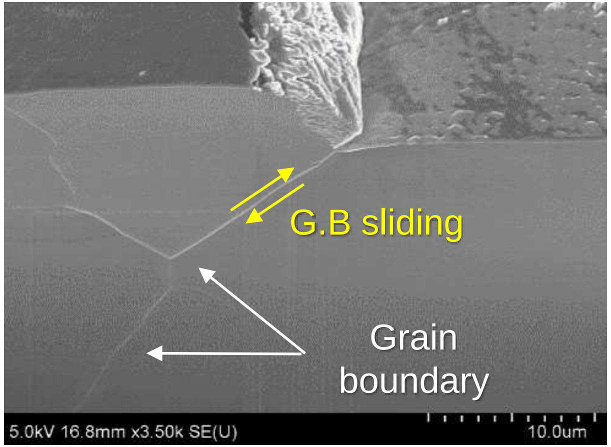
Chip: Cu 4mmx 4mm/Substrate : Cu
200°C-1h in air without pressure



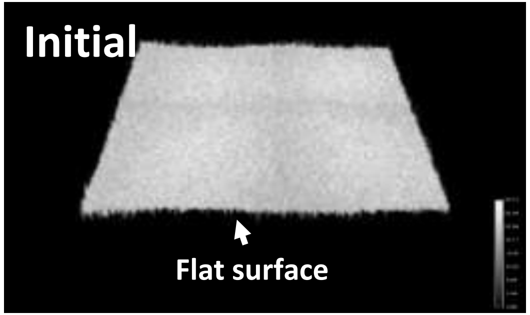
Metal surface deformation of substrate causes serious degradation

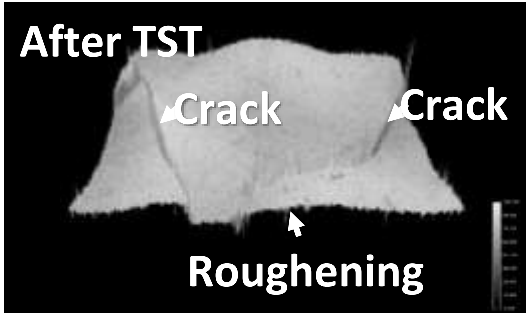
Thermal stress causes severe deformation of metal layer on ceramic substrate resulting in Ni-P plating cracking

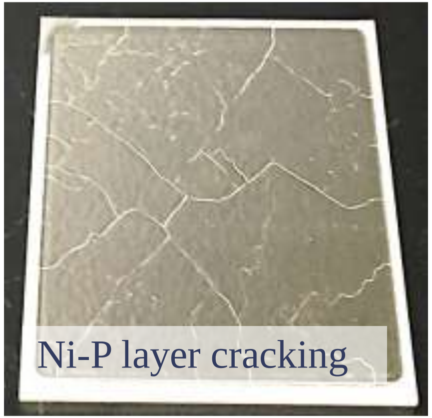




Plated Ni-P surface

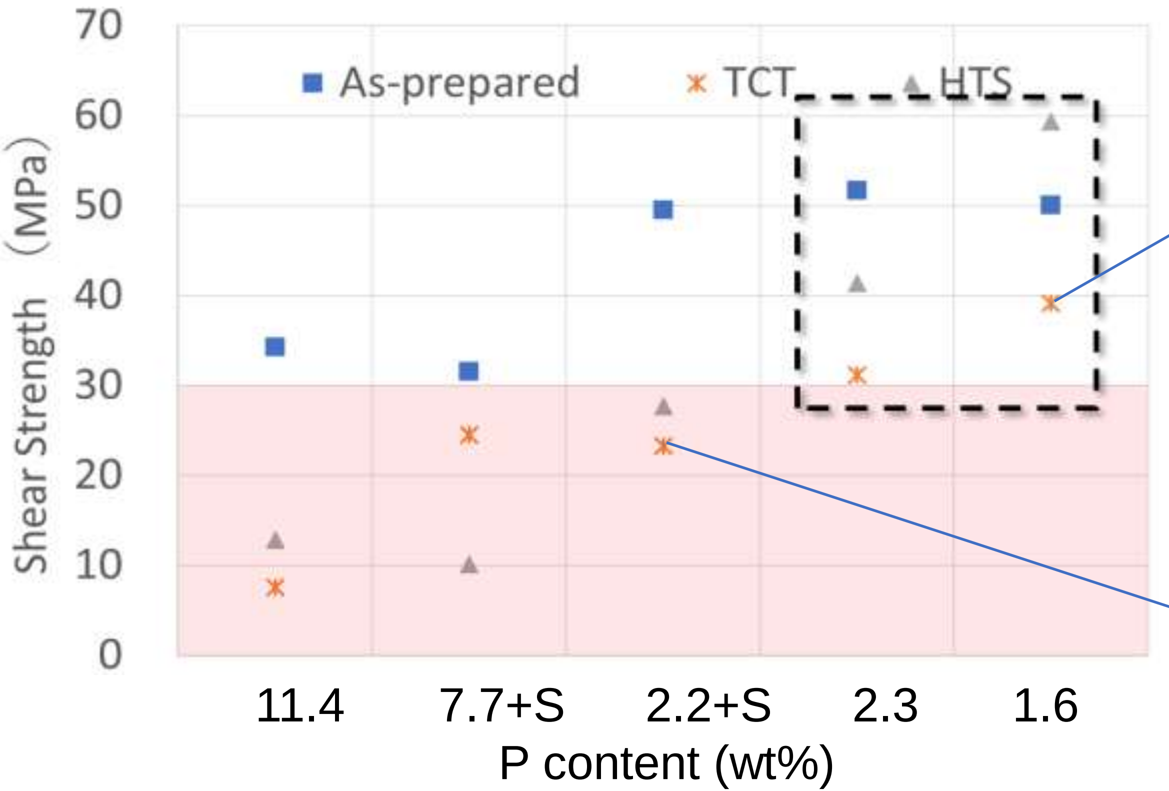


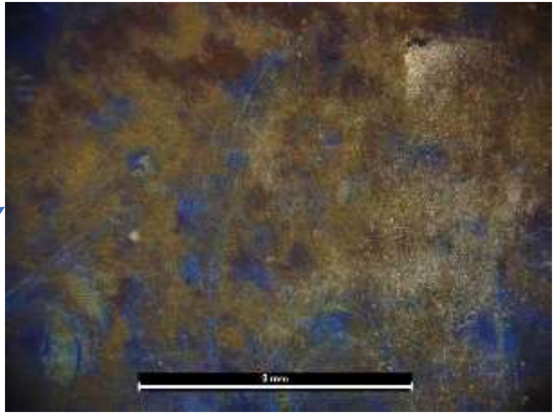


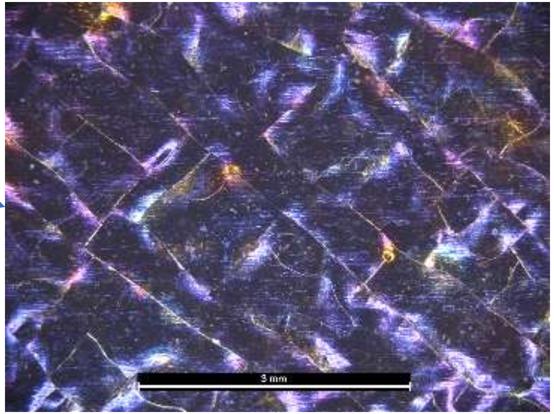


SANKEN

Improvement by Ag Bonding for Ni-P plating



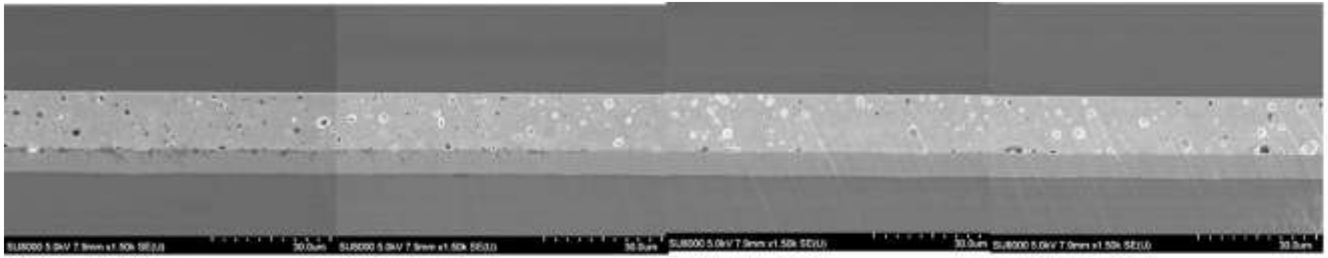




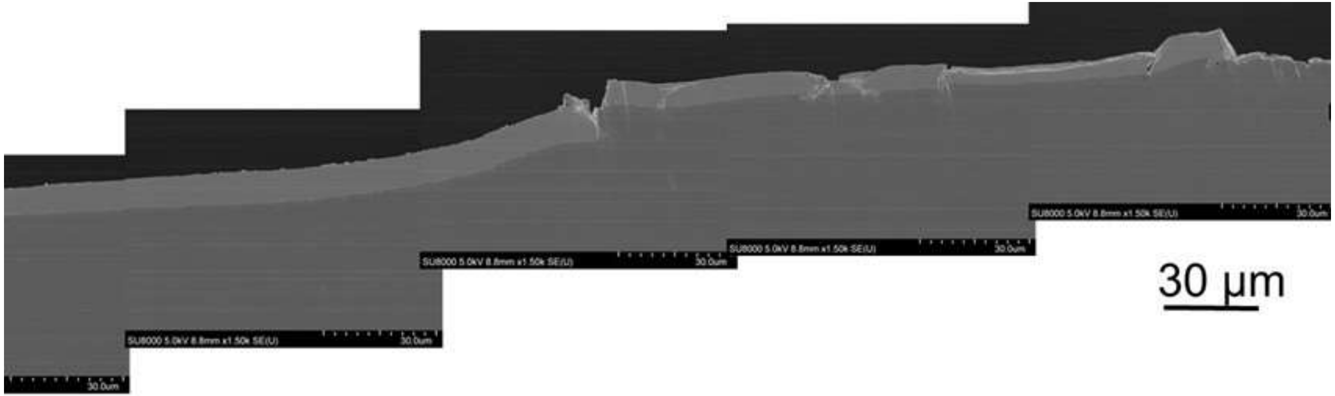
Interface after severe thermal shock test

-50 ºC ~ 300 ºC x 500 cycles

Ni-1.6P



Ni-11.4P

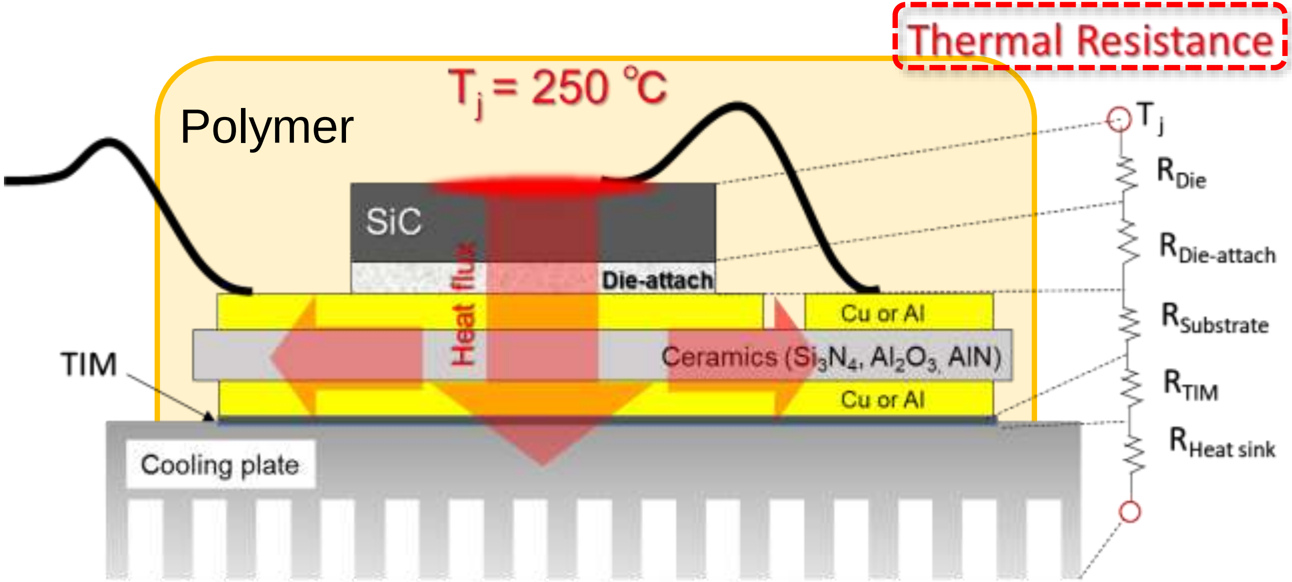


30 µm

Outline

- ✓ Introduction
- ✓ Advanced power modules & reliability
- ✓ Ag sinter joining & heat management
- ✓ Substrate and Ni-P plating
- ✓ Thermal property measurement
- ✓ Reliability and lifetime prediction by AE sensing + AI
- ✓ Summary

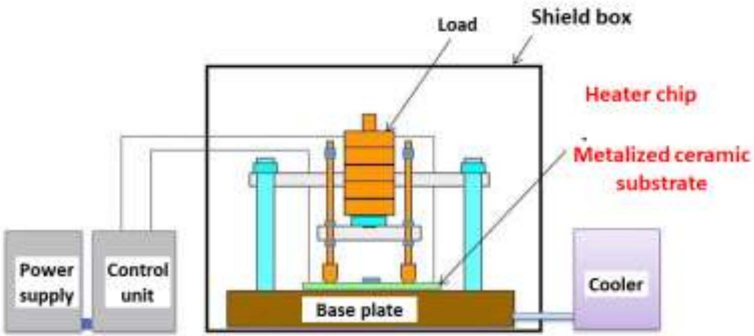
Thermal performance evaluation/management

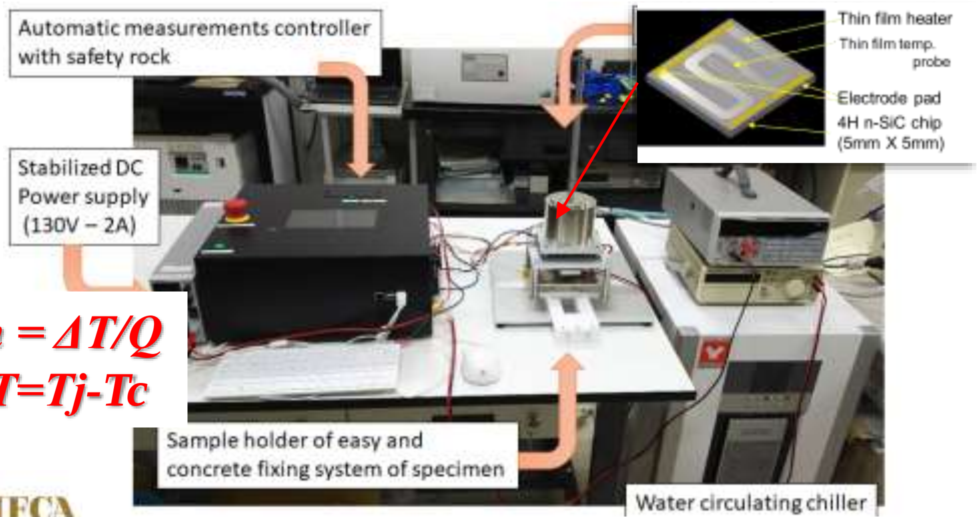


$$R_{total} = R_{die} + R_{die\text{-}attach} + R_{substrate} + R_{TIM} + R_{heat\text{-}sink}$$

We need to understand thermal dissipation performance of device structure

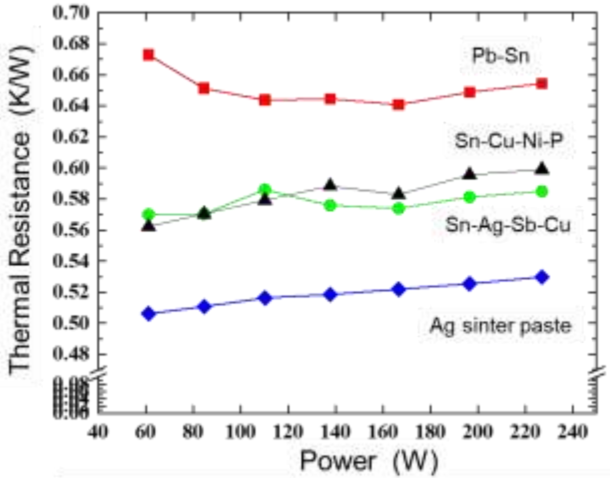
ISO 4825-1:2022 Test method for thermal property measurements of metalized ceramic substrates - Part 1: Evaluation of thermal resistance for use in power modules

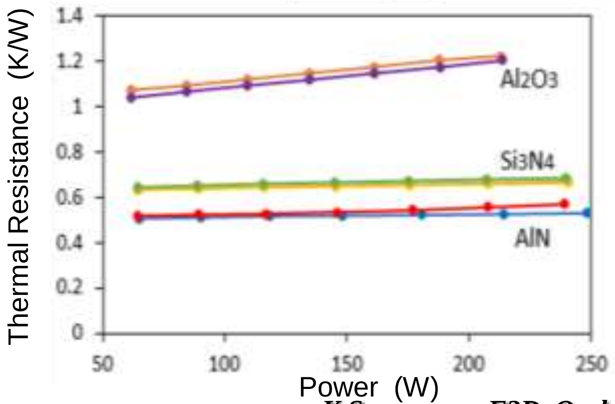




$$Rth = \Delta T/Q$$
$$\Delta T = Tj - Tc$$

By Yamato Scientific





K.Suganuma, F3D, Osaka University

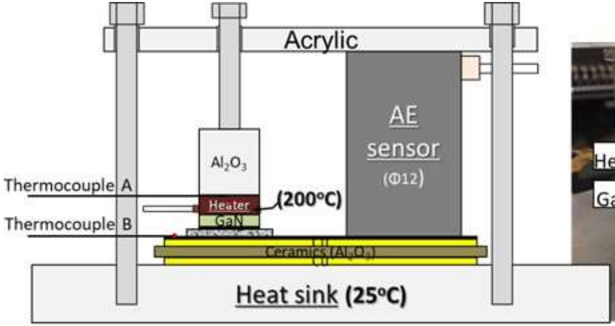
JFCA

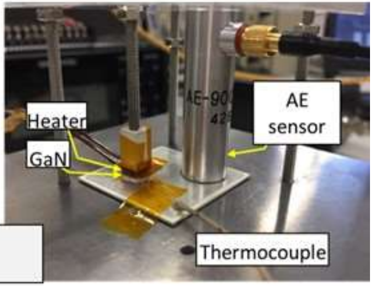
Outline

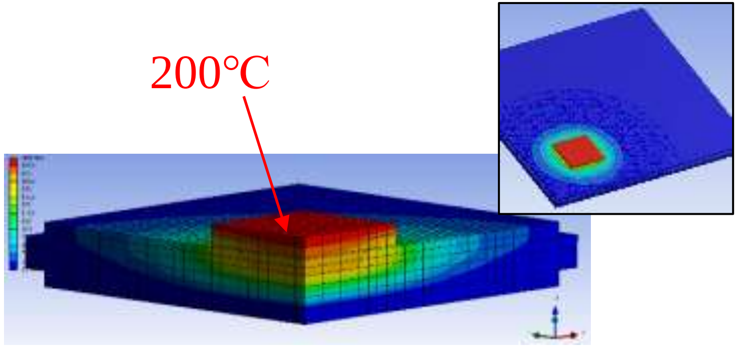
- ✓ Introduction
- ✓ Advanced power modules & reliability
- ✓ Ag sinter joining & heat management
- ✓ Substrate and Ni-P plating
- ✓ Thermal property measurement and management
- ✓ Reliability and lifetime prediction by AE sensing + AI
- ✓ Summary

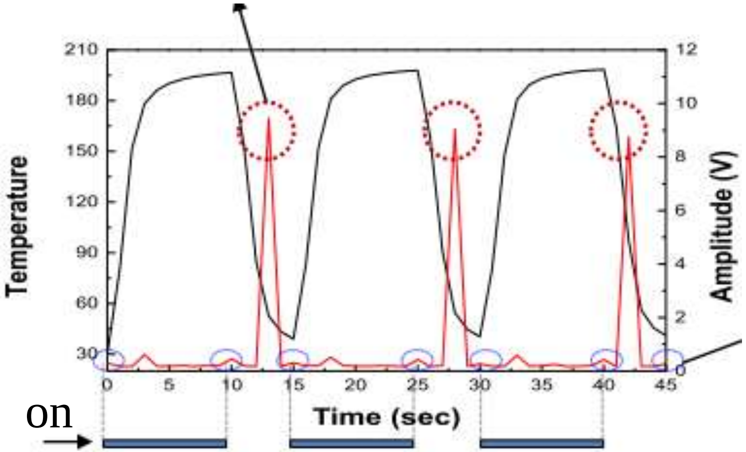
AE monitoring in power cycling

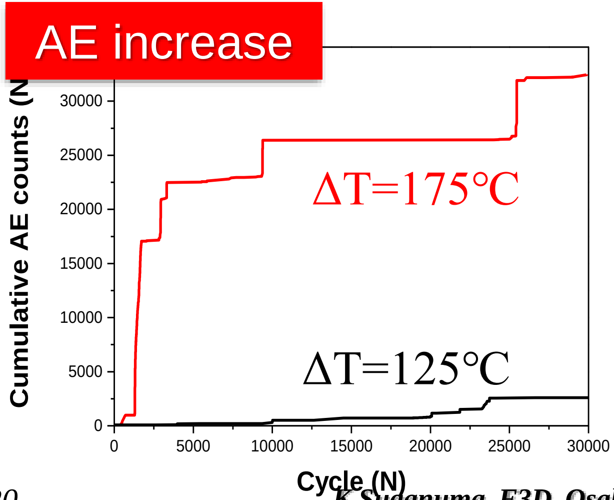
AE monitoring system









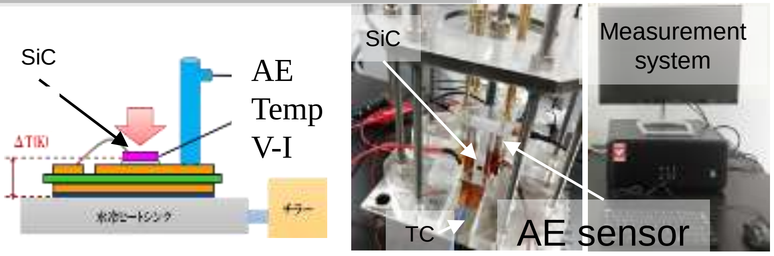


C. Choe et al, IEEE Transactions on Power Electronics, 36[4](2021), 4420

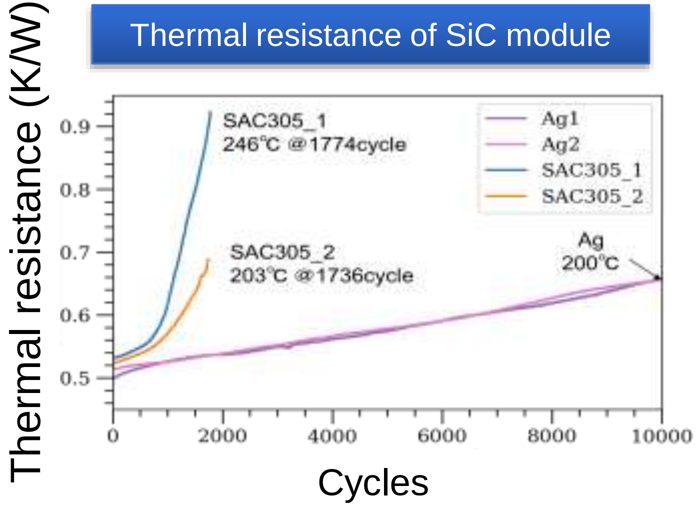
AE sensing and real-time life prediction by AI technology

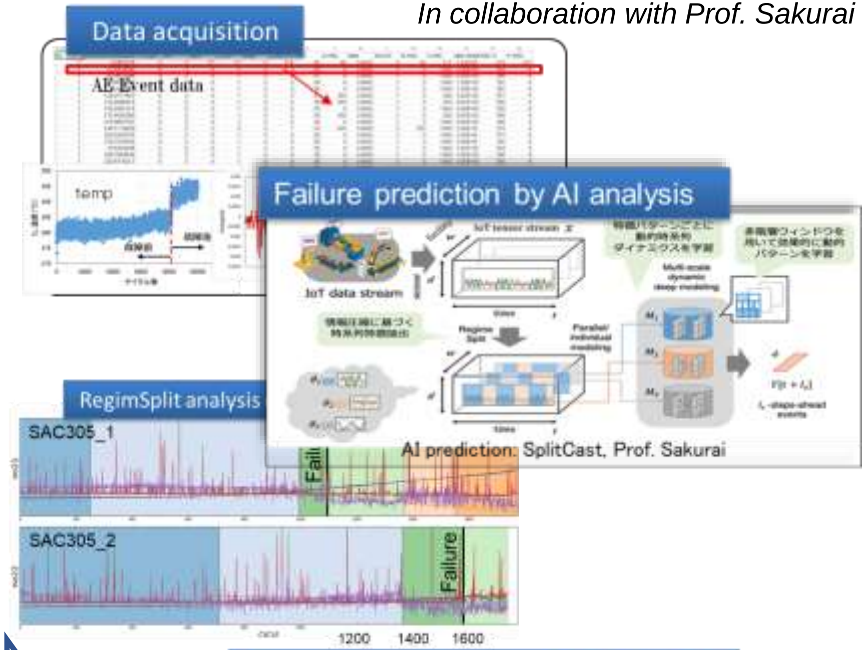
In collaboration with Prof. Sakurai

Temp + AE data acquisition system

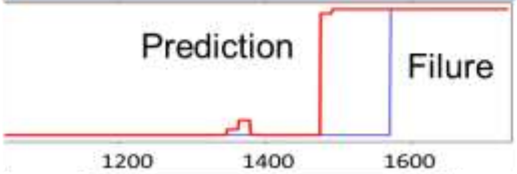


Thermal resistance of SiC module





Failure prediction of 11 min 40 sec before failure



Real-time AI prediction of power module failure

Prof. Y. Matsubara

Features

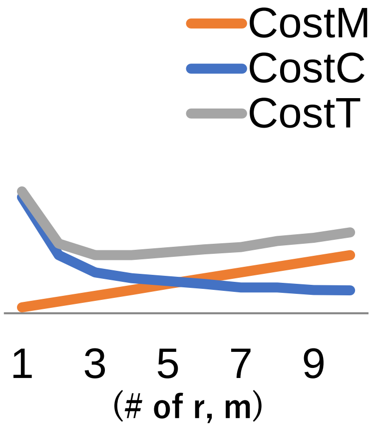
- Only one “time series” analysis in the world
- High accuracy with minimal cost compared to deep learning: 10000 faster & 10 times accuracy than others
- Real time correction/modification
- One can intuitively understand
- Effective technology for IoT-related industries such as smart factories and edges

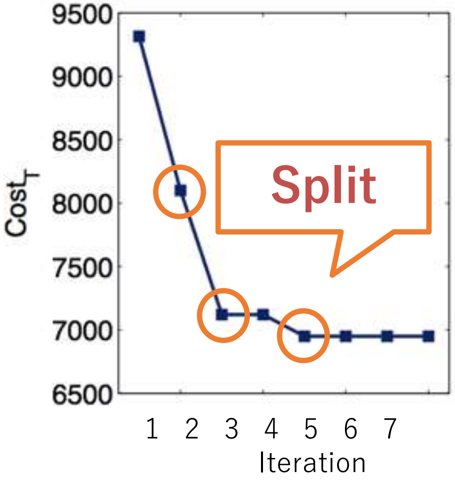
Self extraction of event feature

Model cost **Coding cost**

$$\min \left(\boxed{Cost_M(M)} + \boxed{Cost_C(X|M)} \right)$$

Good compression ⟷ **Good description**

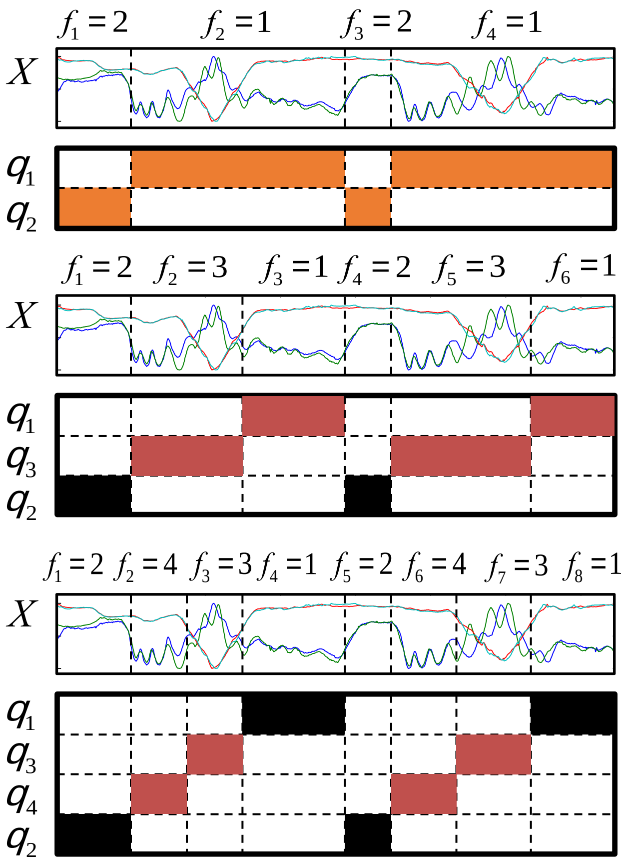




Iteration 1
r=2, m=4

Iteration 2
r=3, m=6

Iteration 4
r=4, m=8



SANKEN

K.Suganuma, F3D, Osaka University

Real time prediction

DEMO(RegimeCast)

Original data

Motion data of wrist and ankle

Forecasted values

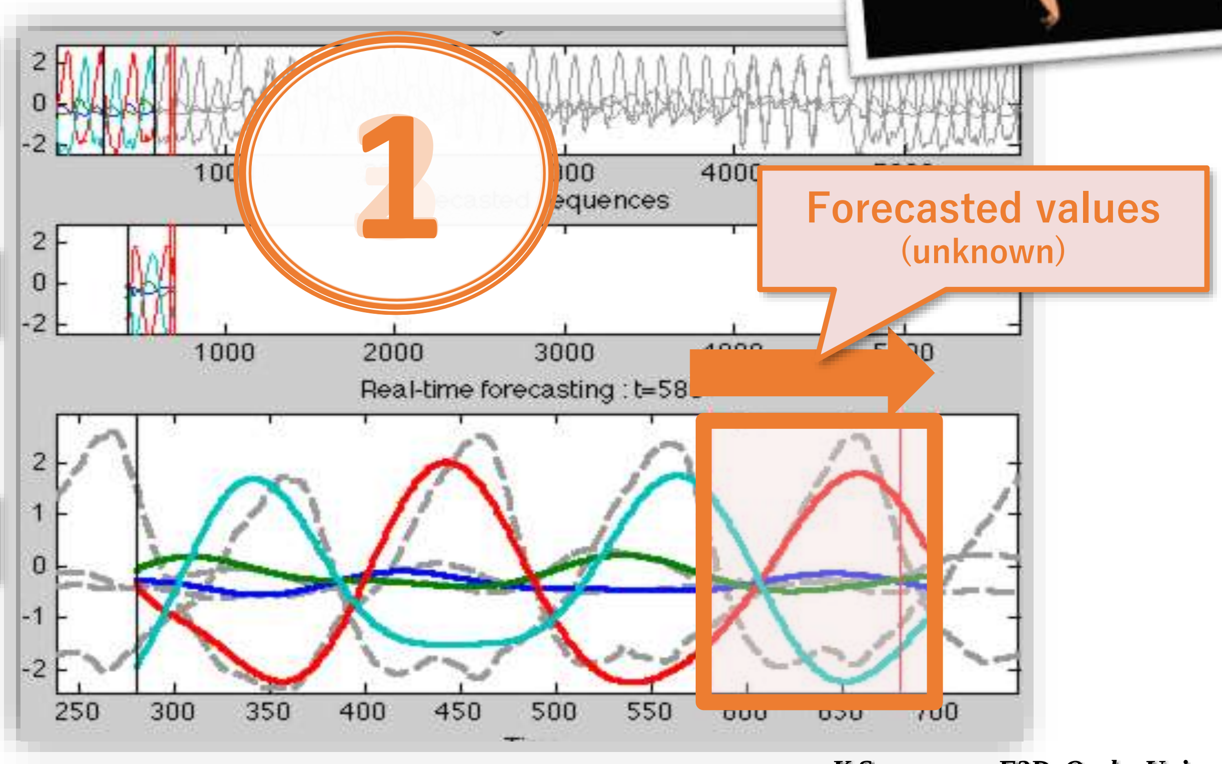
(100-steps-ahead)

Snap-Shot

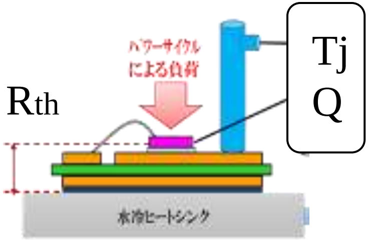
(Current window)

Dashed lines: real data

Color lines: model data



Real sensing data from power devise



Tj

Q

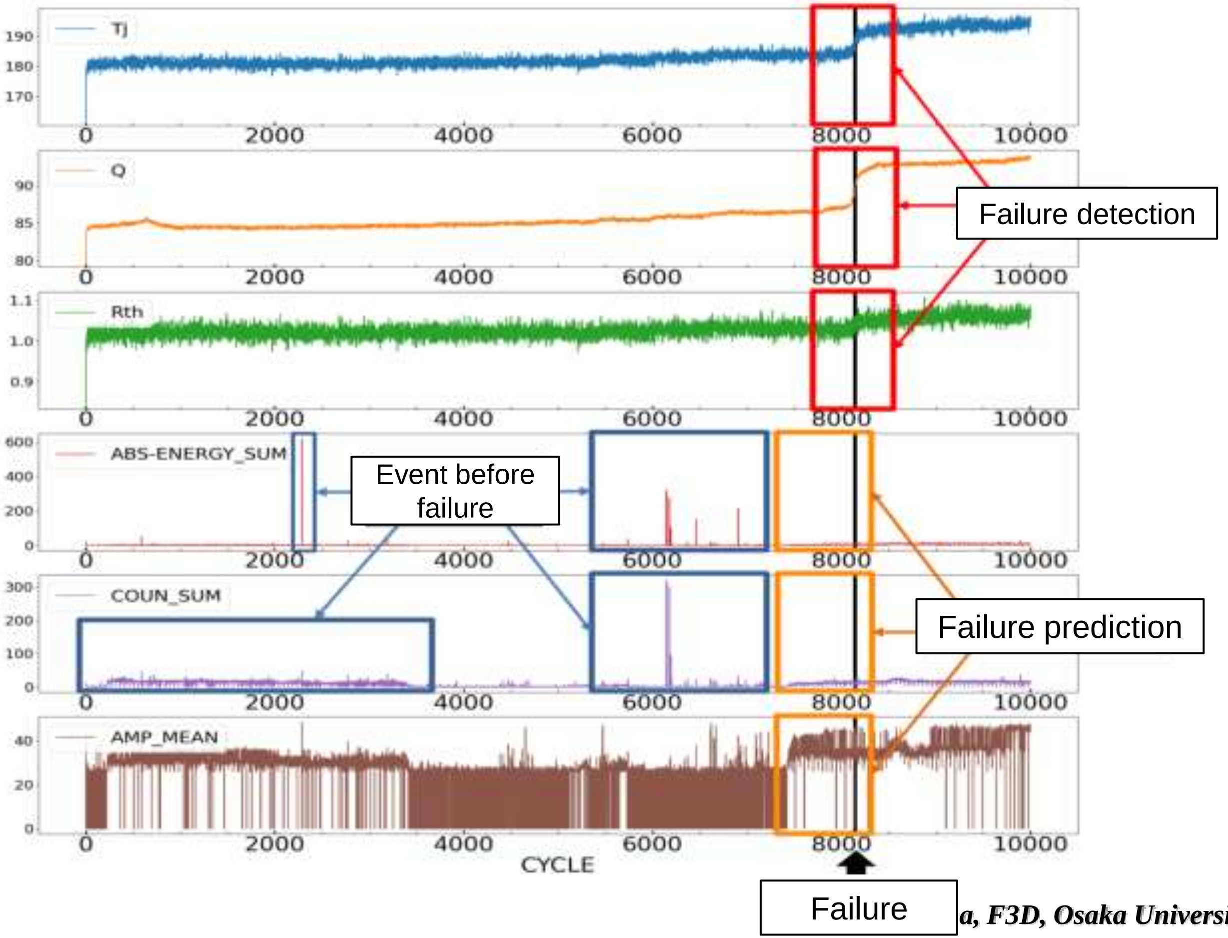
Rth

AE

Total -energy

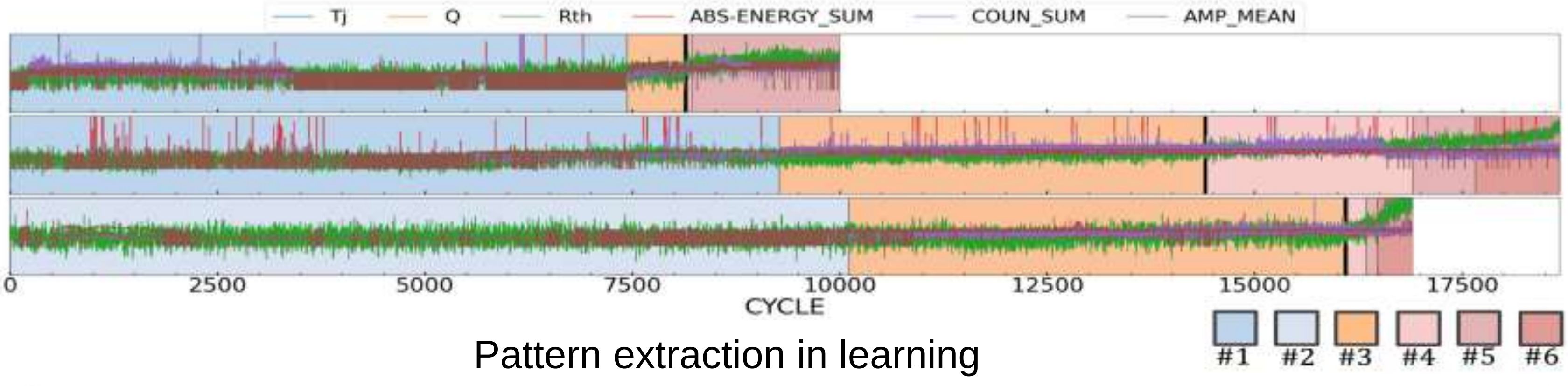
Count

Amplitude

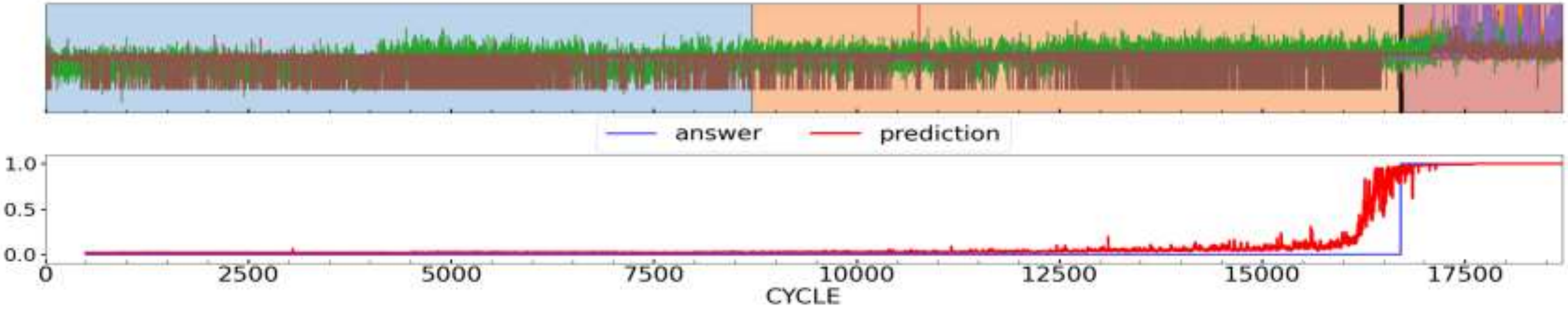


SANKEN

Failure prediction



Pattern extraction in learning



Sensing of target device and life time prediction

Summary

1. Mechanism of Ag nano eruption joining is well understood.
2. Ag sinter joining provides high heat dissipation capability as well as high strength and stability by adjustments of process conditions and a direct Ag sinter joining becomes possible to Al/Si/SiC/GaN…..etc.
3. Low pressure all Ag sinter joining has the great cooling performance.
4. New simple thermal property measurements were proposed for ISO.
5. AE monitoring with AI real-time prediction can provide the information on damage initiation and propagation inside package rather than Tj change.

Questions are welcome to:

suganuma@sanken.osaka-u.ac.jp

Acknowledgements

This work is carried out as a part of METI J-Innovation HUB/Local Innovation Promotion Project since 2020. A series of the development on WBG power electronics has been supported by NEDO and METI Thermal Property Measurement Standardization I, II. The results were achieved by many students and staffs in Suganuma's laboratory. This work is also strong support of Daicel, Okuno Chemicals, and Yamato Scientific for F3D activity.