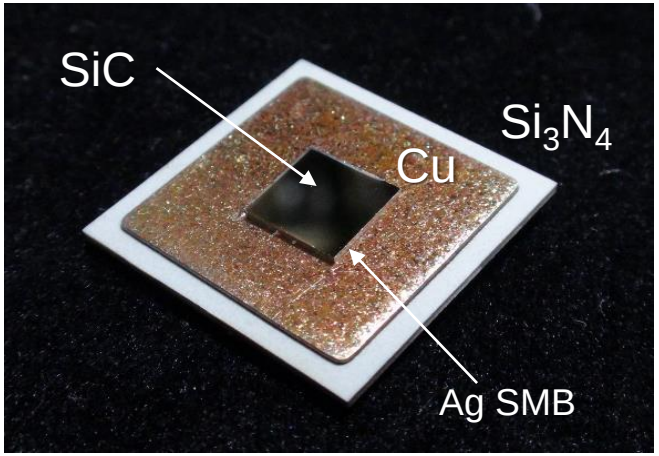
Ag Sinter Joining for WBG Interconnects



Katsuaki Suganuma,
Shoji Nagao,
Toru Sugahara,
Hao Zhang,
and Jinting Jiu

ISIR, Osaka University, Osaka, Japan

Outline

✓Introduction

- Wide band gap power device
- Die-bonding for power electronics

✓Sinter joining

- Ag sinter joining
- Thermal stability and its improvement
- Ag film stress migration bonding
- Low temperature sintering mechanism

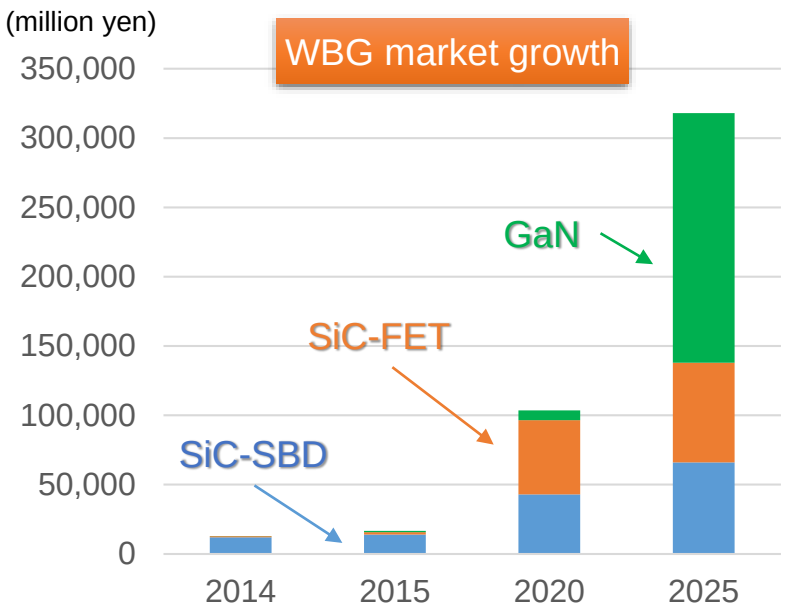
✓ Ceramic substrate

✓ Summary and future

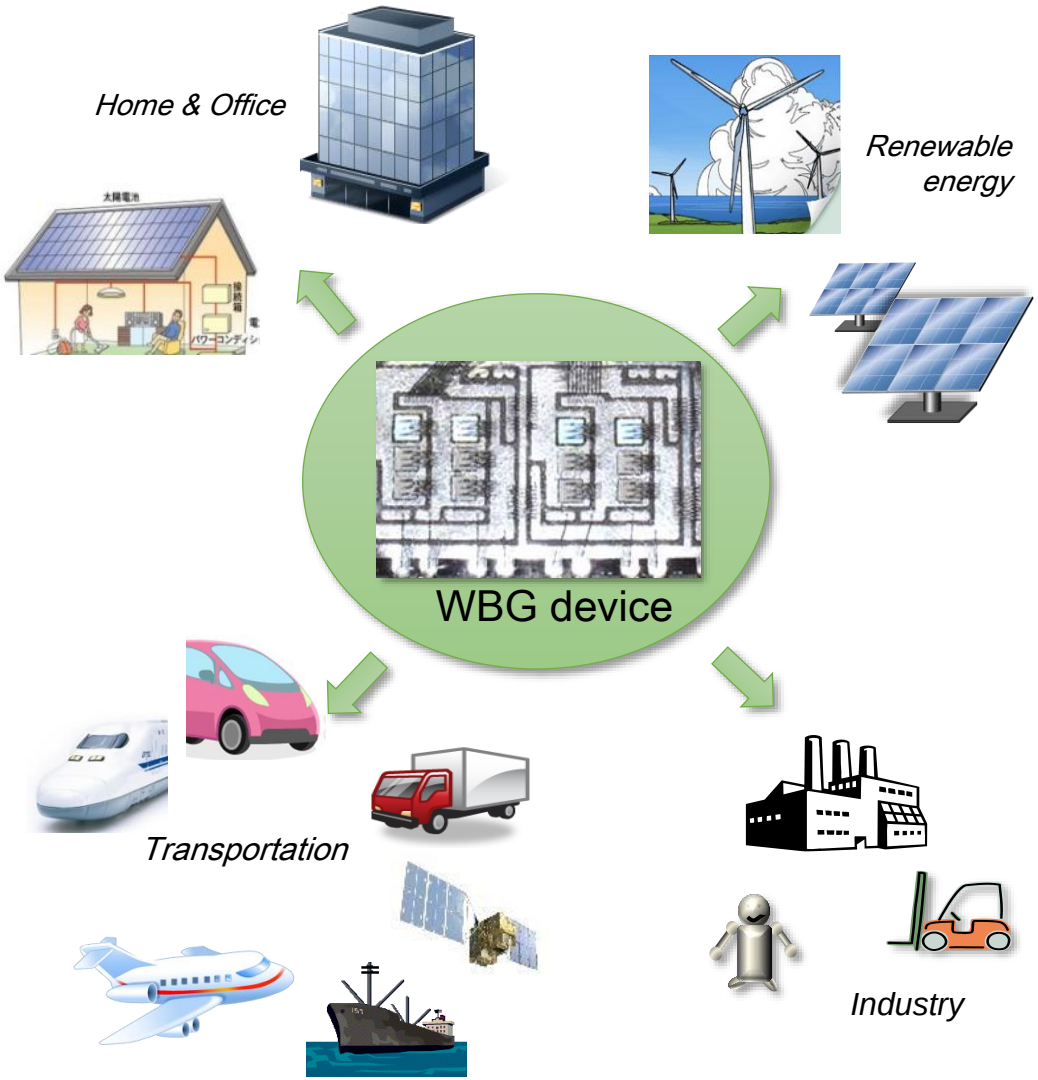
WBG benefits and market

Benefits:

	Si	SiC
Bandgap (eV)	1.12	3.26
Breakdown voltage (MV/cm)	0.3	2.8
Thermal conductivity (W/m·K)	160	490



From Fuji Keizai



SiC power devices in market

Toyota

SiC-SBD inverter

Toshiba

Mitsubishi Electric

FCV

SiC-SBD

Toyota

- ✓ ~ 40 % energy loss reduction
- ✓ ~ 1/5 size reduction

.....etc.

Air conditioner

Power conditioner

Mitsubishi Electric

Fuji Electric

New generation power interconnections

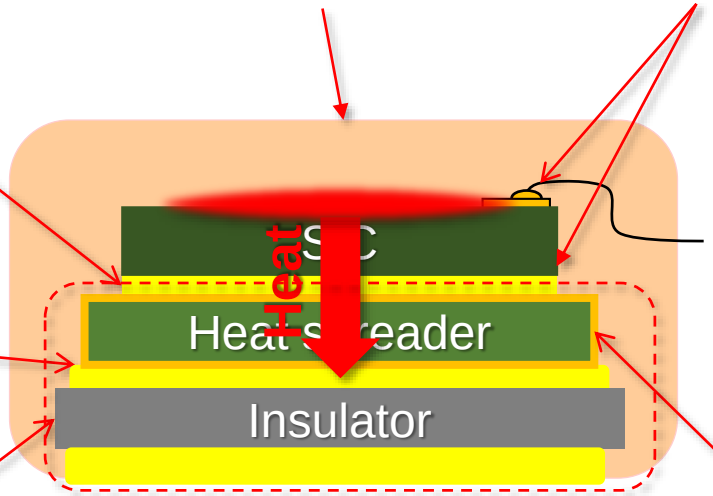
T_j = 250 ºC

- Ag sinter joining
- Stress migration bonding
- Pure Zn soldering

- Active metal brazing
- Ag sinter joining

- Si_3N_4, AlN, Al_2O_3

- Molding compound



- Electrode materials
- Bonding method
- Wire/ribbon/planer bonding

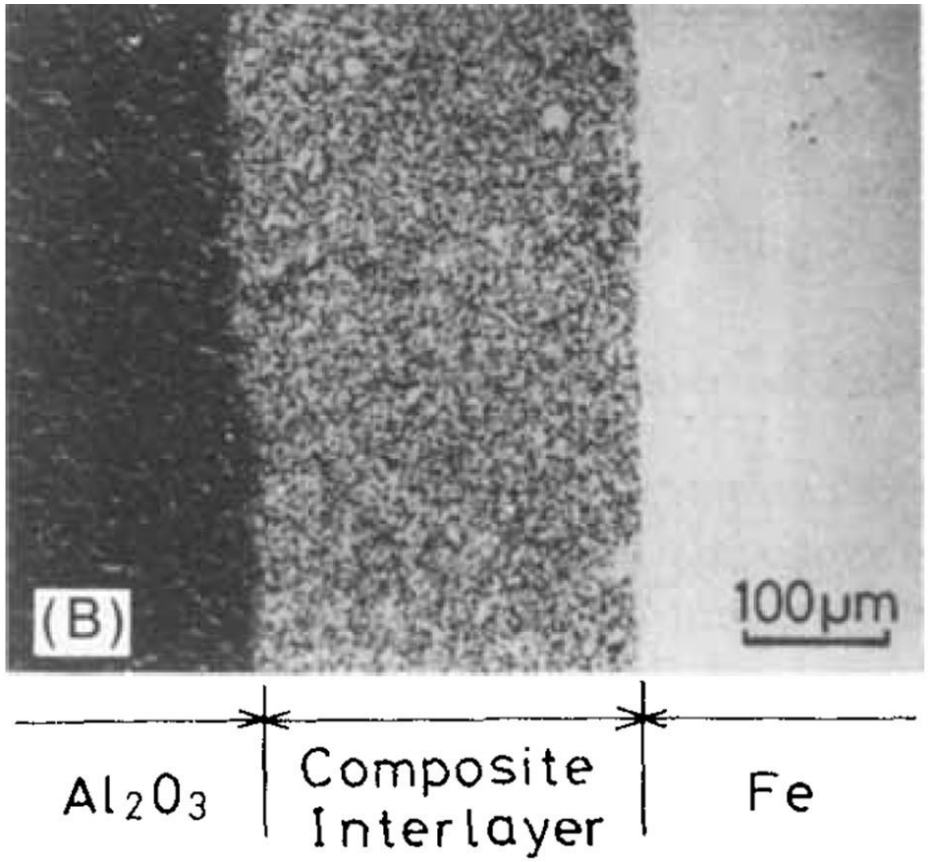
- Cu or Al?
- Plating or other oxidation/reaction protection?

✓ Resistance to severe thermal cycles : -50℃-250℃

✓ 250℃ exposure & oxidation resistant interface design

Old sinter joining

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



Beginning of FGM

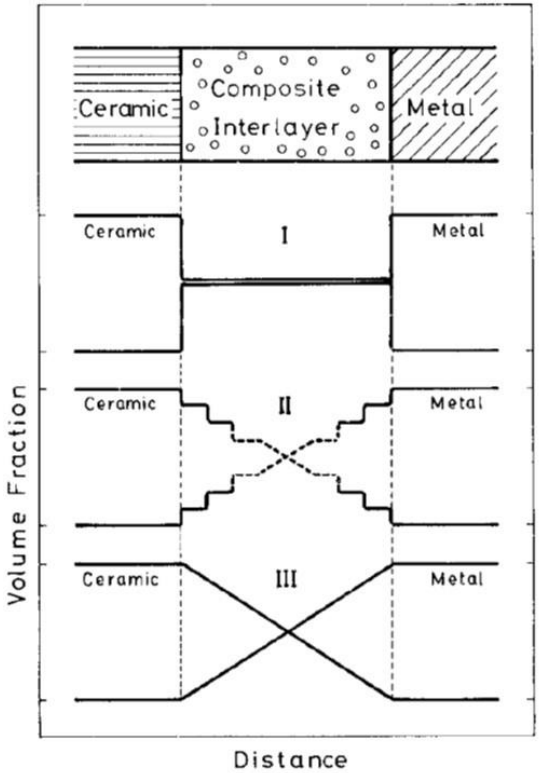
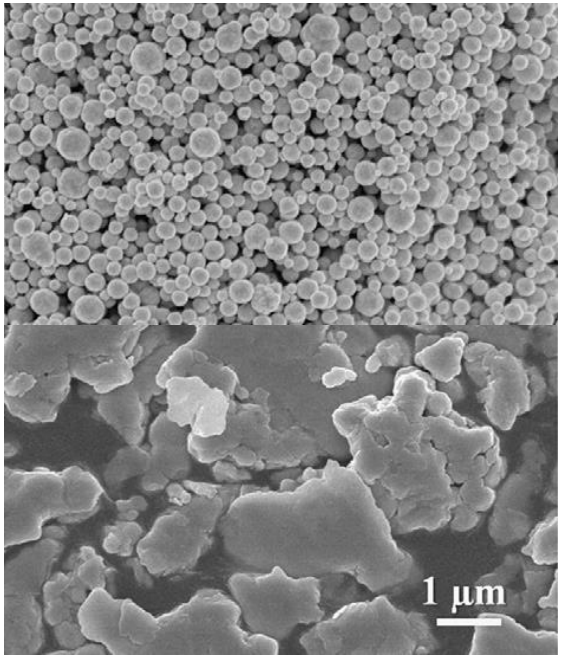


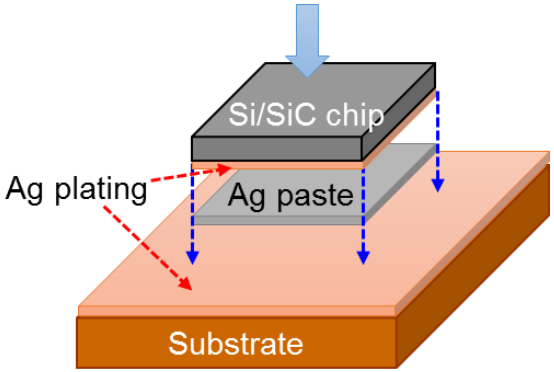
Fig. 1. Types of composite interlayers used in bonding.

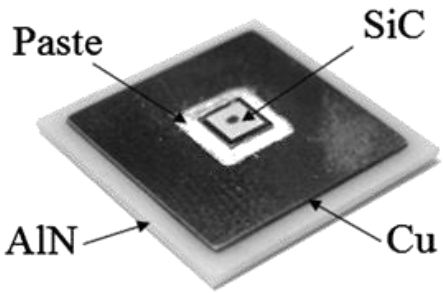
Very high pressure: 100 MPa/1GPa

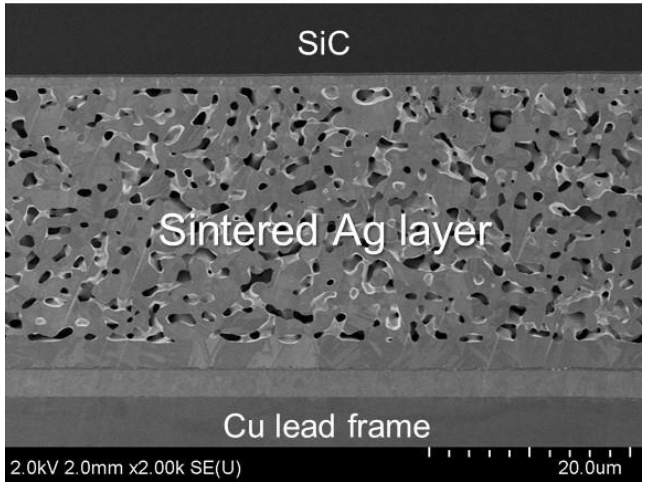
Ag sinter joining with hybrid paste

at 200-250 °C in air with no/low-pressure





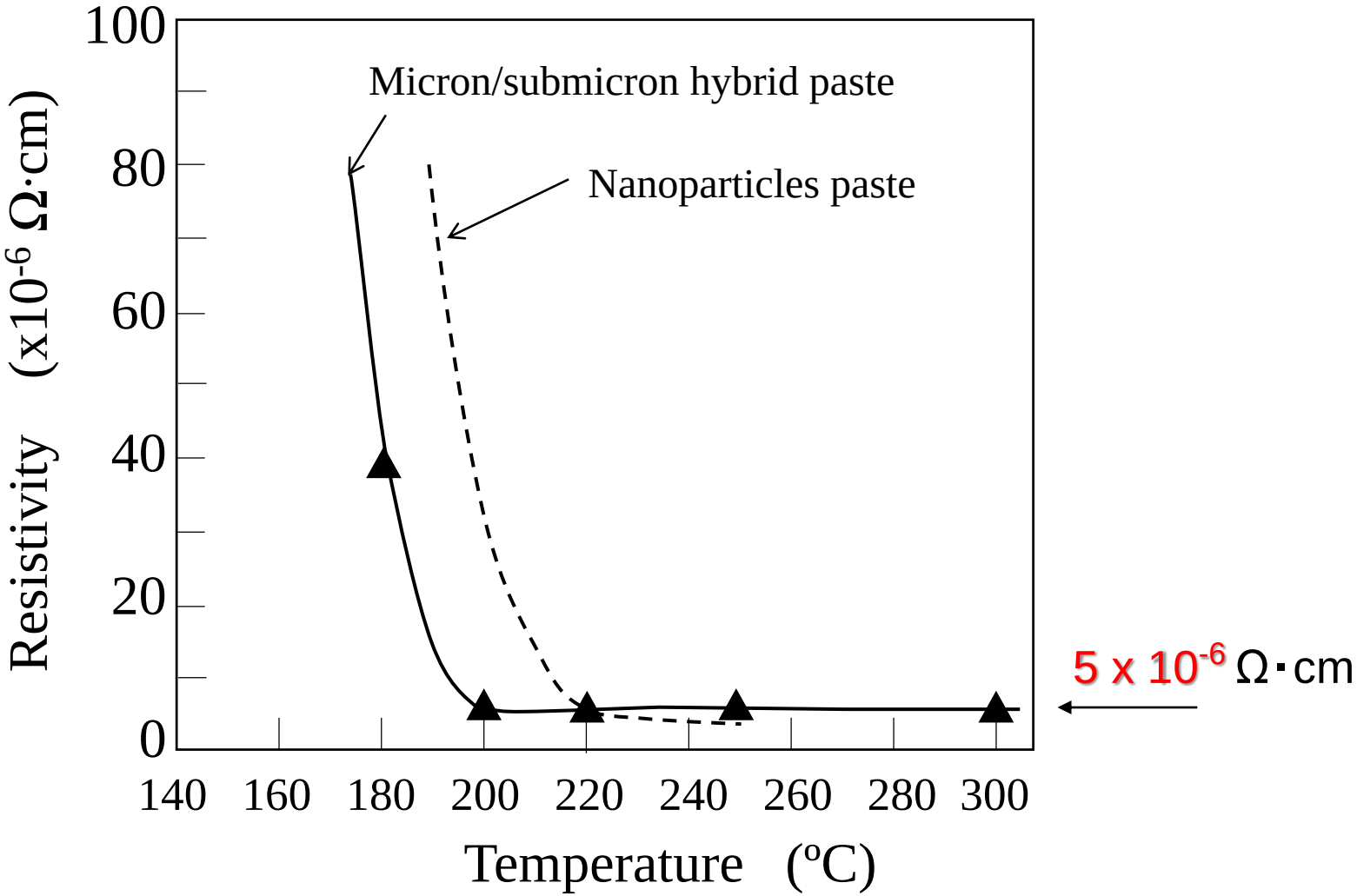




- ✓ High bonding strength > 40 MPa
- ✓ High thermal conductivity > 140 W/mK
- ✓ Excellent heat shock resistance : -50 – 300 °C

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

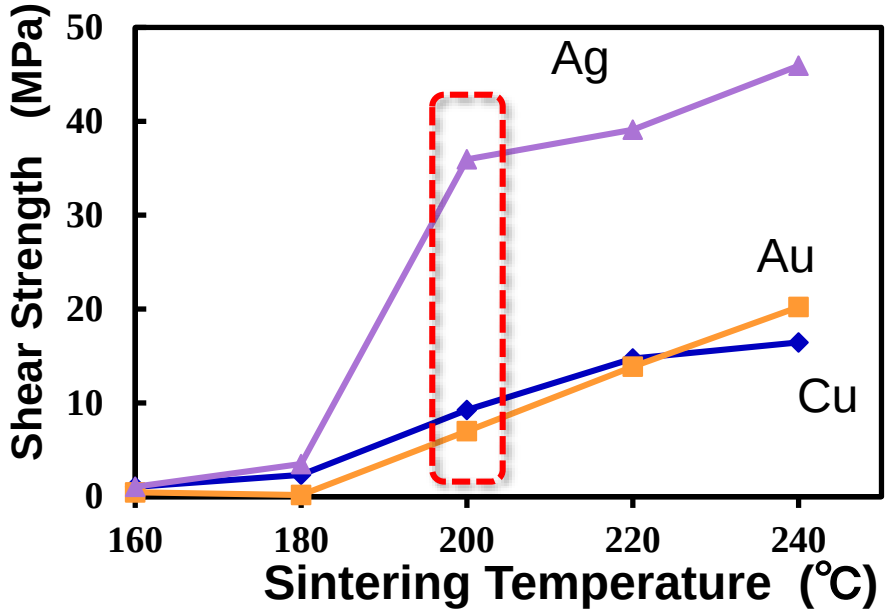
Low temperature & no pressure at 200 ºC

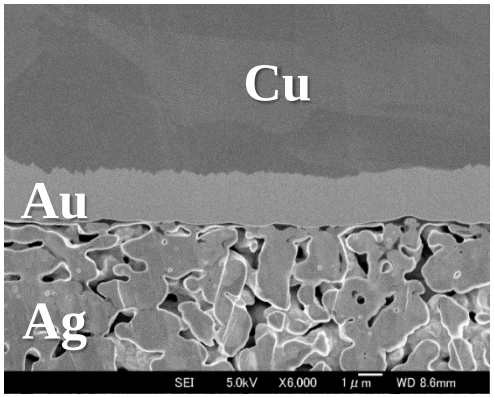


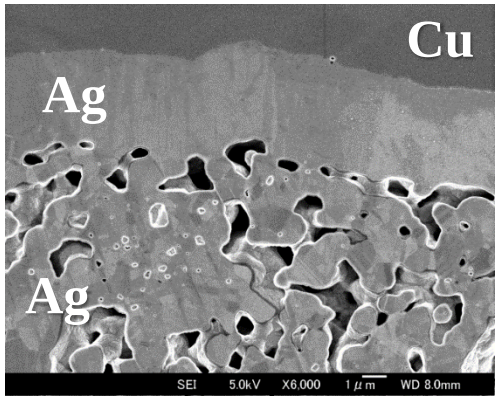
K.Suganuma, et al, Microelectronics Reliability 52 (2012) 375

Low temperature, no pressure, O_2 is needed!

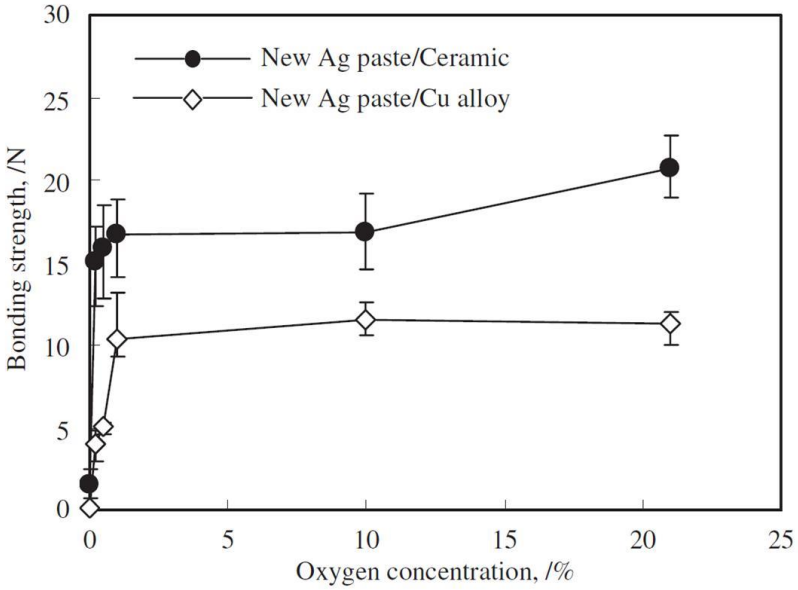
Ag metallization is the best







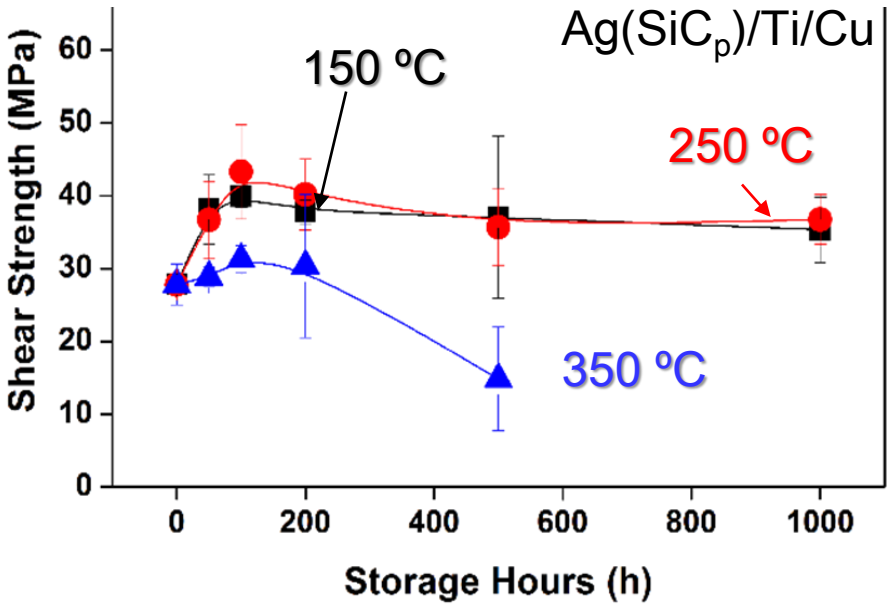
O_2 is required

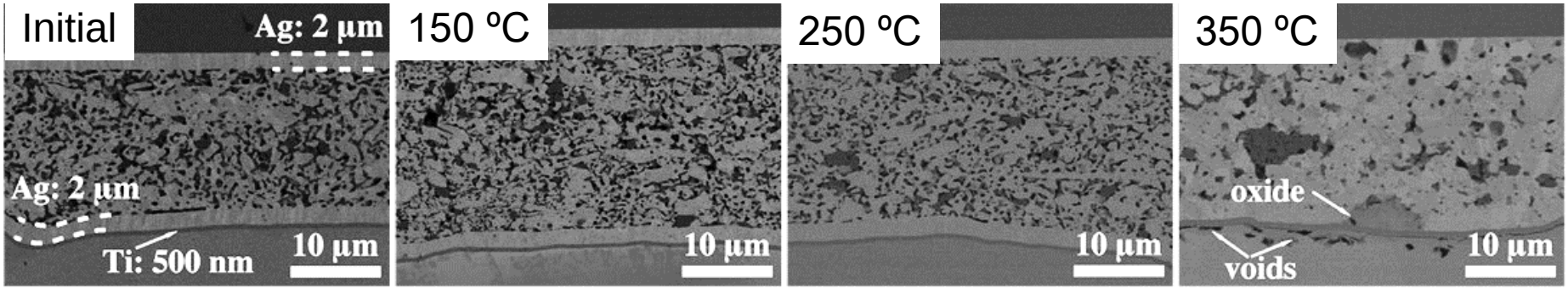


M. Kuramoto, et al, IEEE Trans CPMT, 33[4](2010), 801

S. Sakamoto, et al, J Mater Sci: Mater Electron, 24[4](2013),

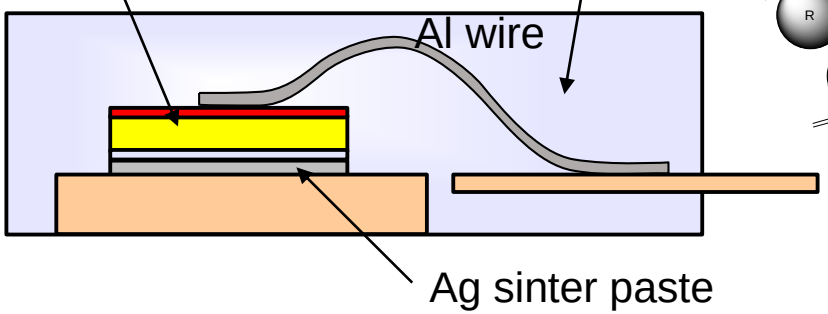
SiC_p addition and metallization effect in heat exposure

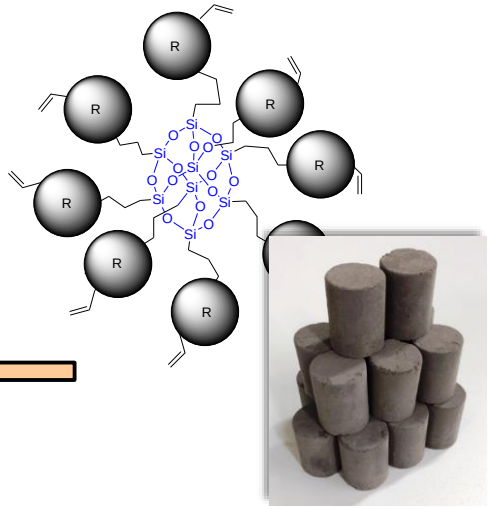


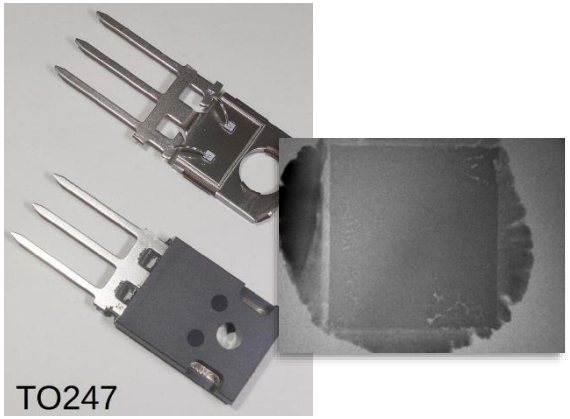


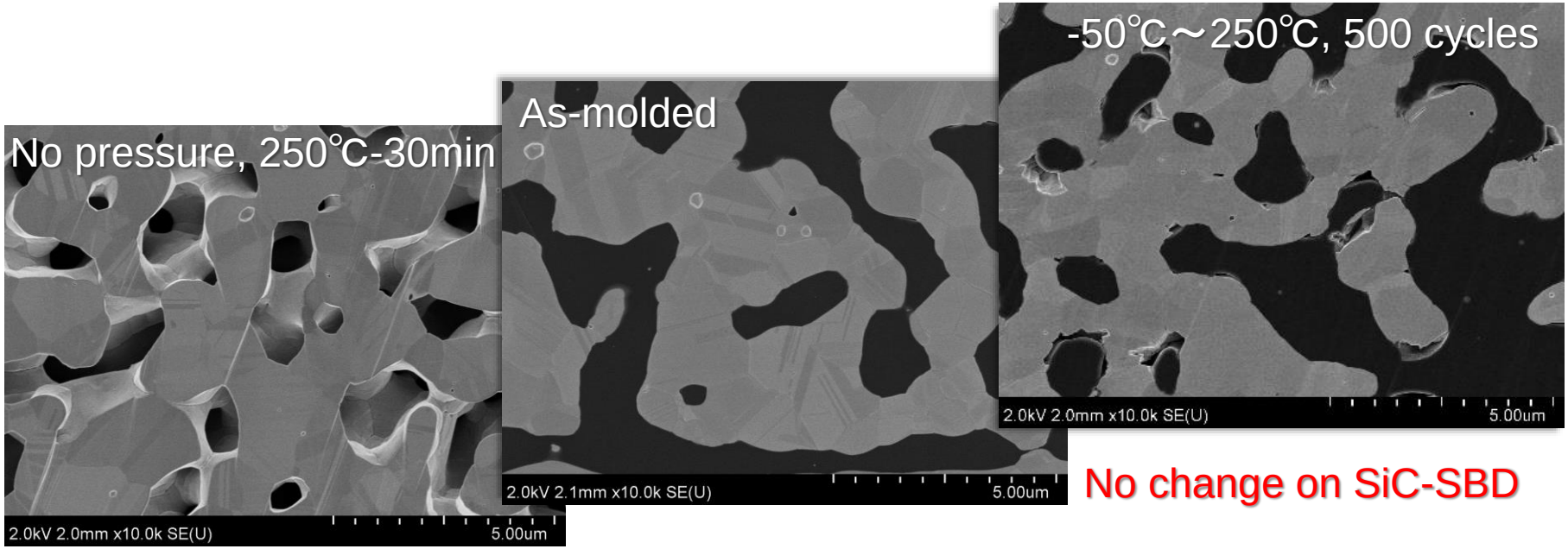
- ✓ SiCp addition stabilize sintered microstructure
- ✓ Ti underlayer has a great effect to avoid degradation

Imide-based nano-composite molding









No change on SiC-SBD

NEDO funded project in collaboration with Nippon Shokubai, Funaki-labo.

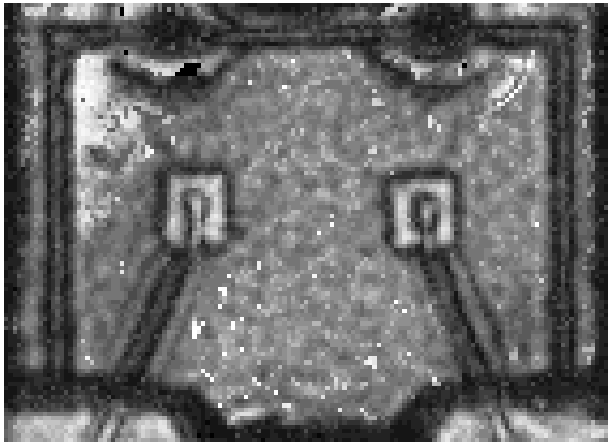
K. Suganuma, ISIR, Osaka University

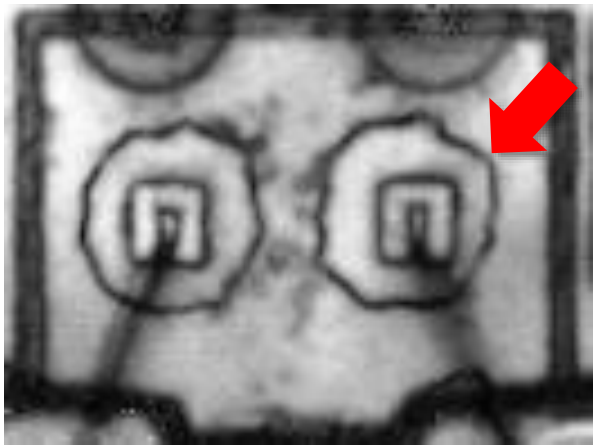
Delamination after thermal cycles

Initial

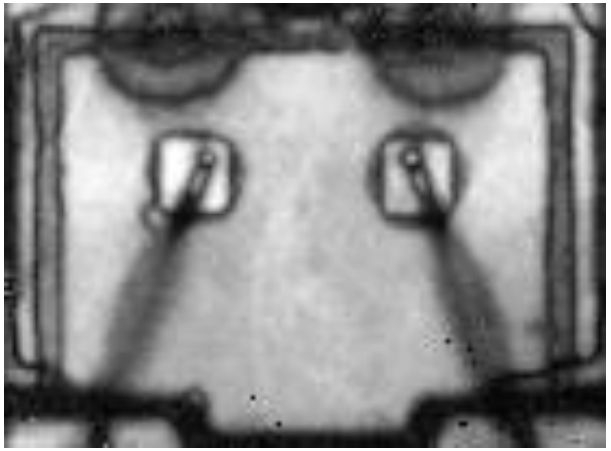
After thermal cycles

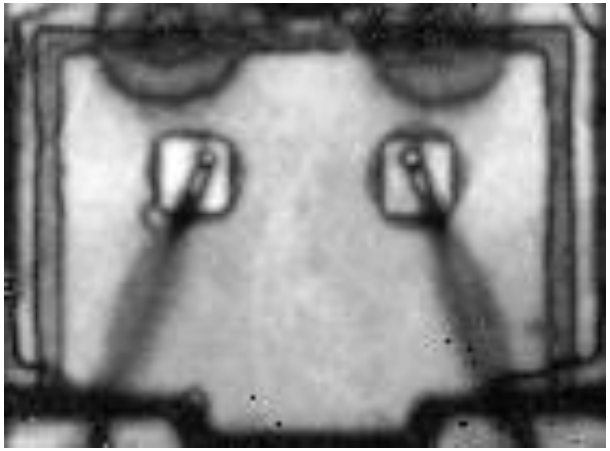
Sn-Pb solder





Hybrid Ag paste



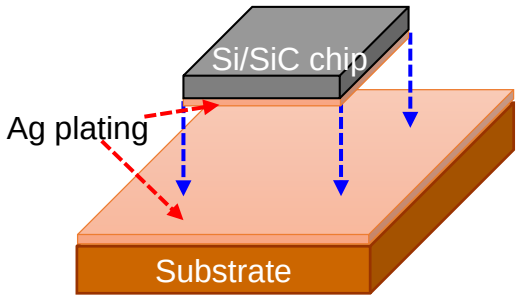


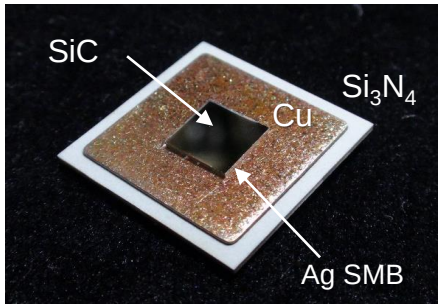
Ag nanoparticle paste and Au-12Ge solder also failed by delamination.

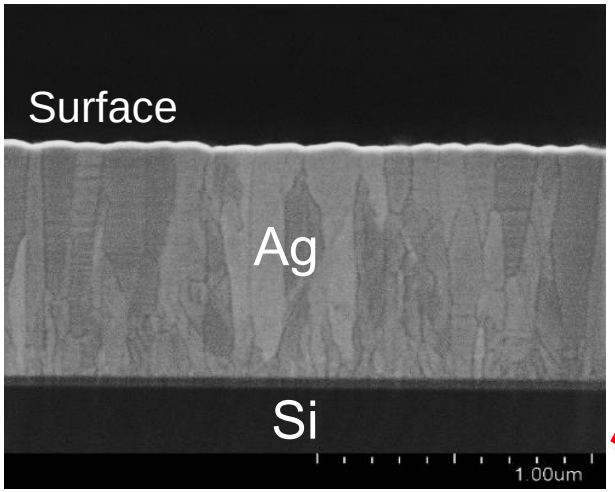
Ag thin film stress migration bonding

1μm thick Ag film can make prefect bonding

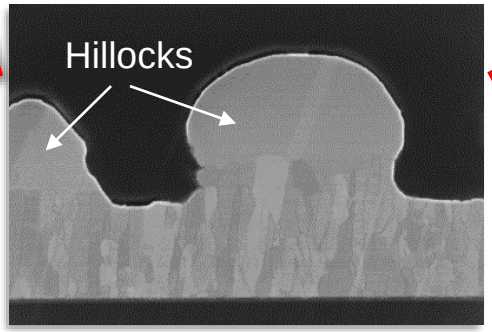
SMB

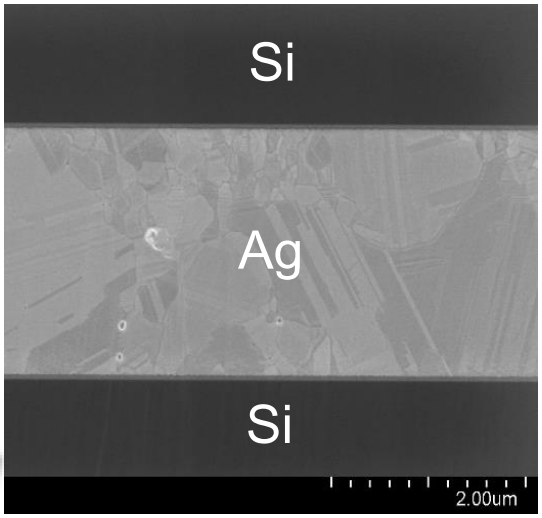






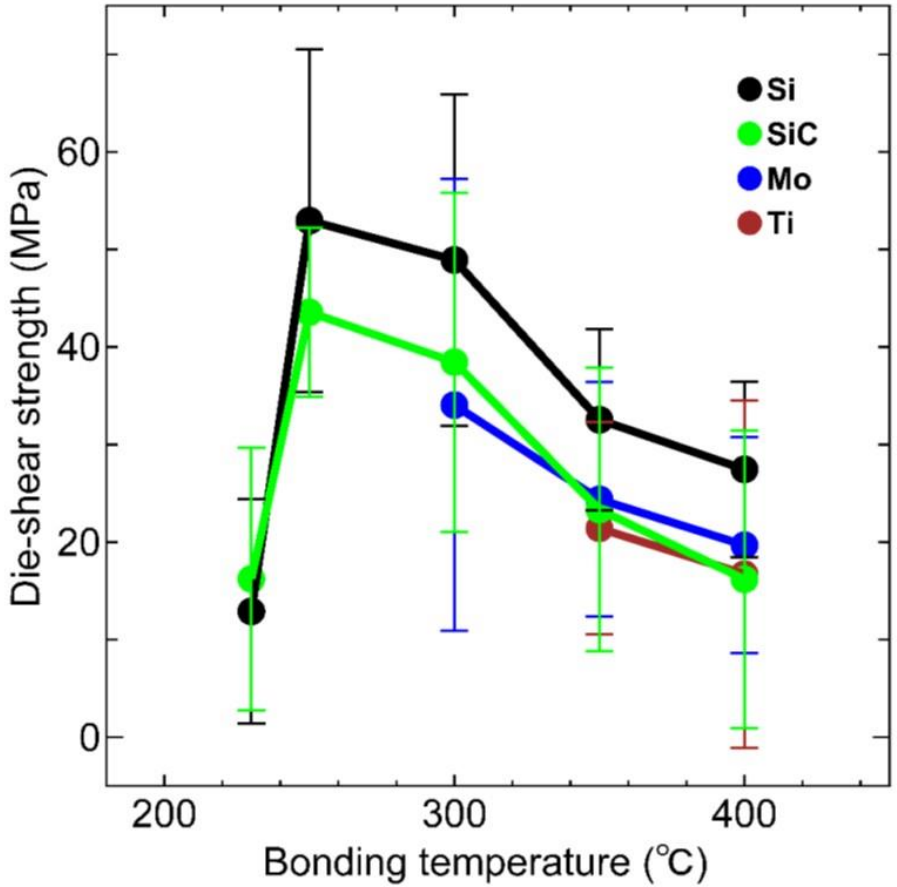
at 250 °C
in air
with no pressure



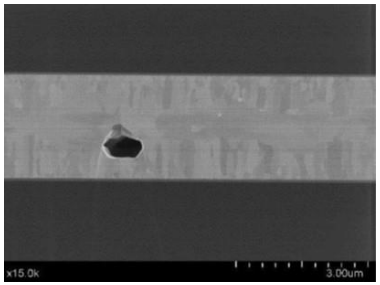


C. Oh, et al, Appl. Phys. Letters, 104(2014), 161603

Joining temperature and substrate effects

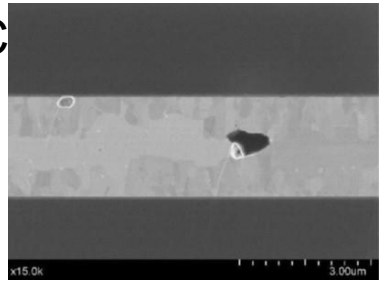


Si



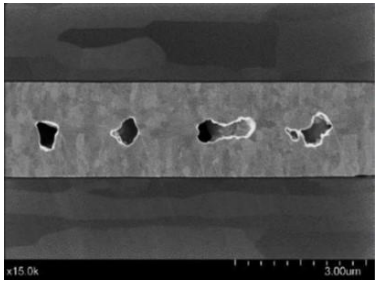
250℃

SiC



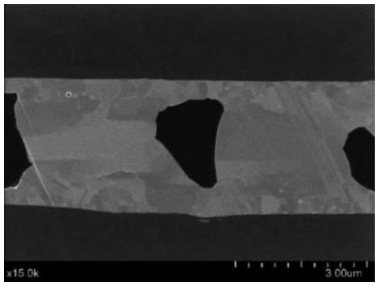
250℃

Mo



300℃

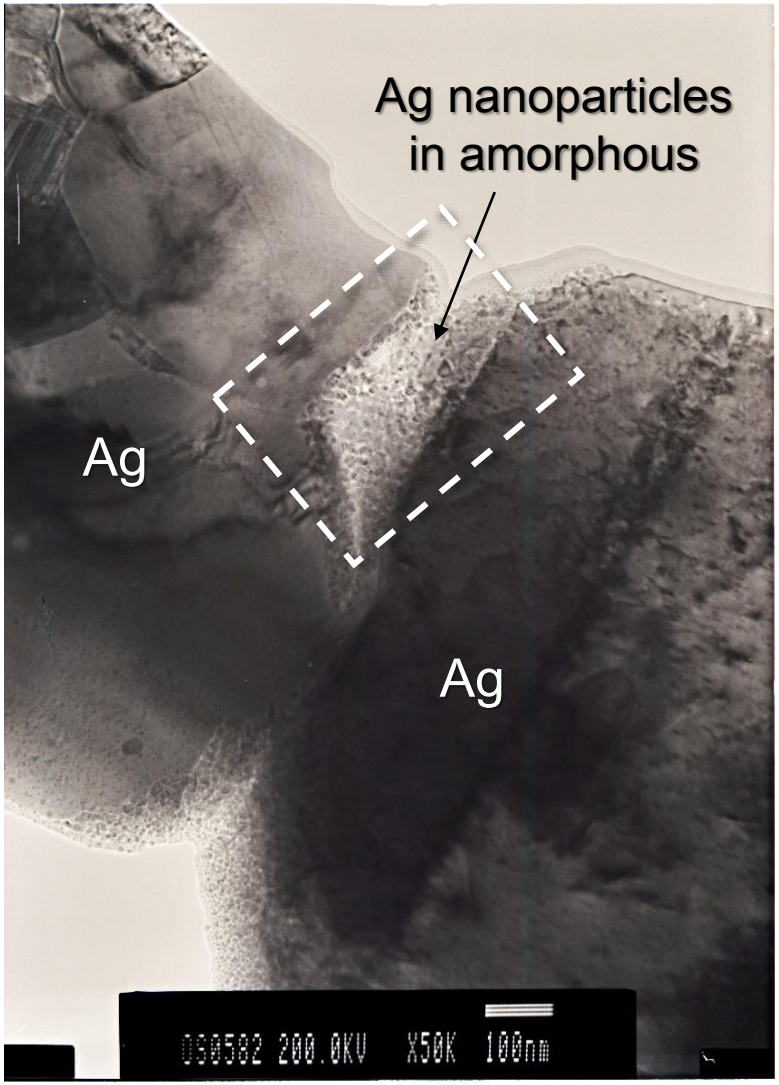
Ti

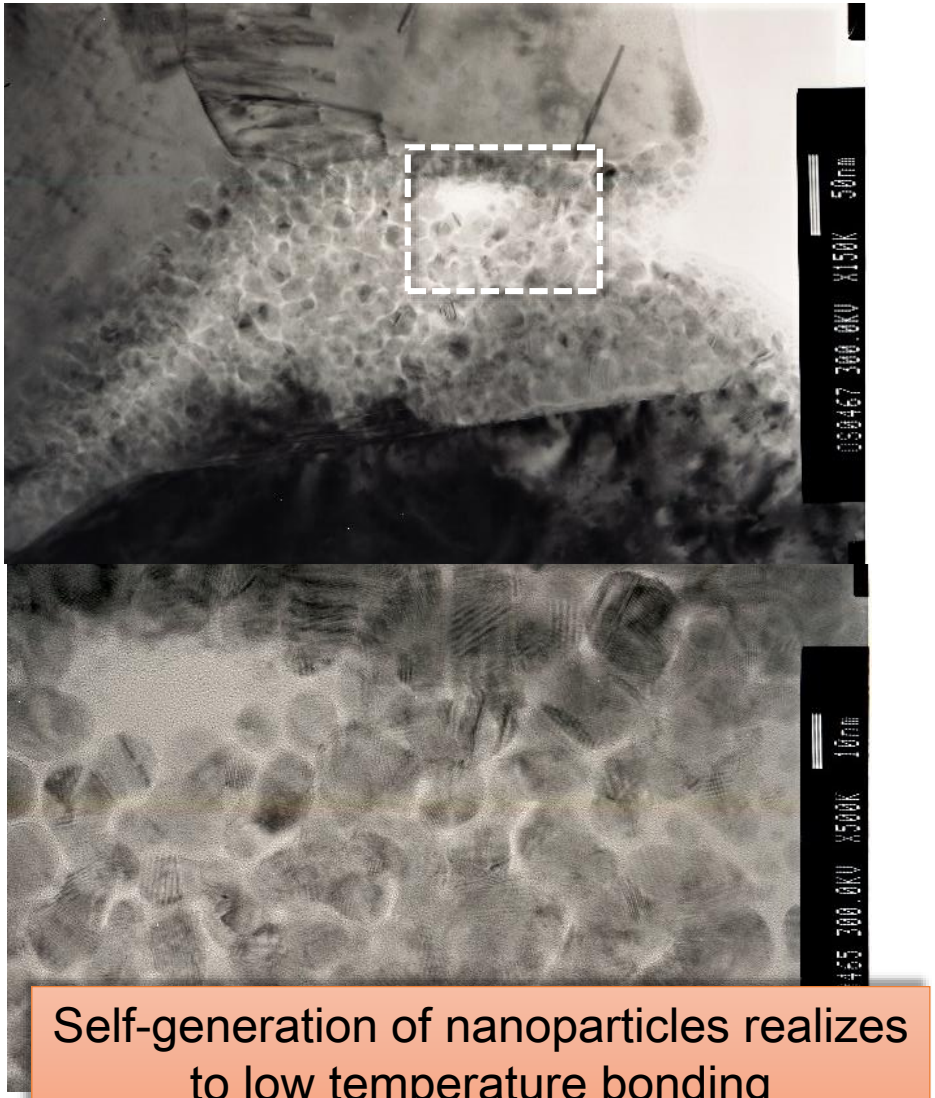


350℃

C.M.Oh, et al: J Mater Sci: Mater Electron (2015) 26:2525

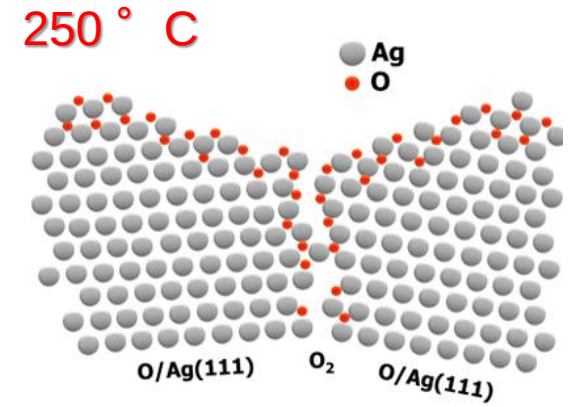
Low temperature Ag sinter joining mechanism

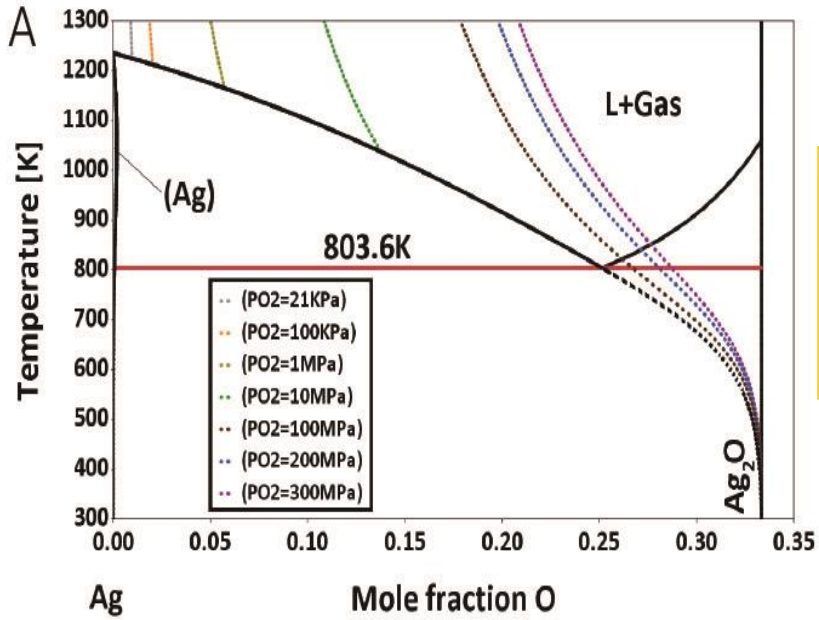




Self-generation of nanoparticles realizes to low temperature bonding

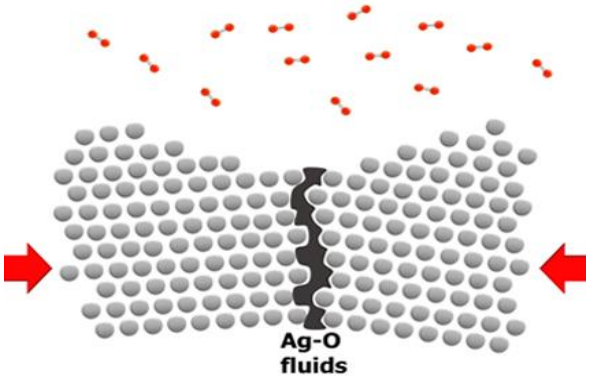
Ag-O liquid formation along G.B.

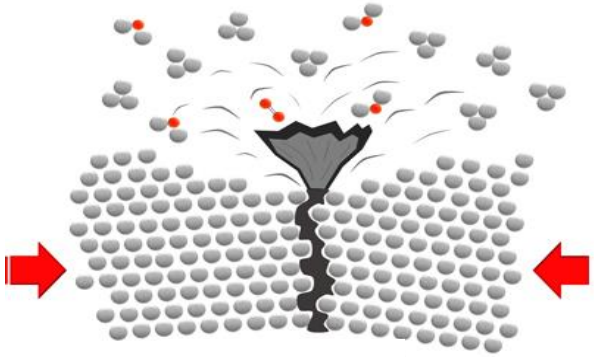




Ag-O liquid can be formed in Ag film G.B. under high PO_2

Assal et. Al, J. Am. Ceram. Soc. 80, 3054-3060 (1997).



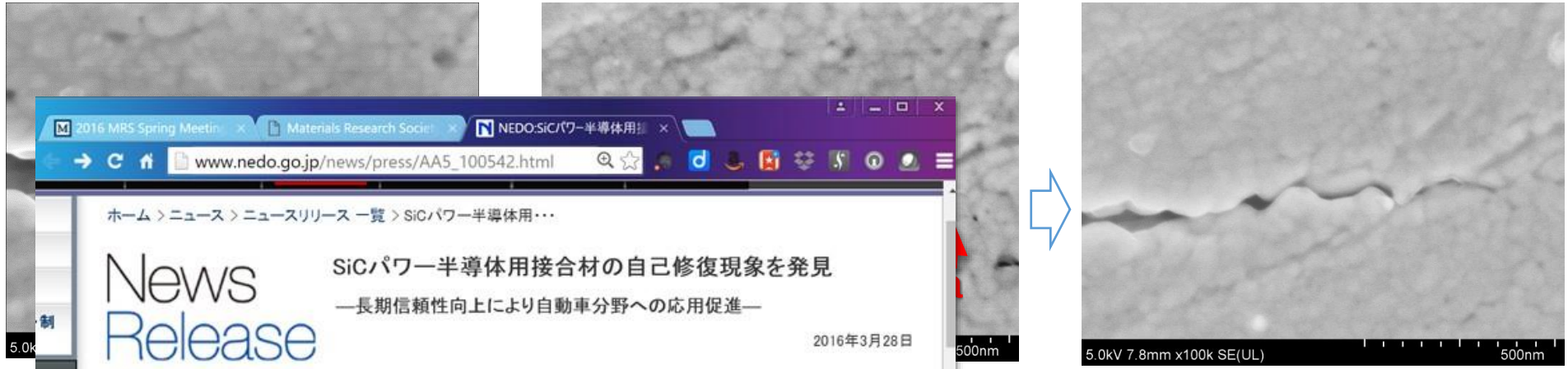


Self-healing of Ag sinter joint layer

Initial

200 ℃ - 50 h

+ 300 ℃ - 10 h



2016 MRS Spring Meetin
Materials Research Societ
NEDO:SiCパワー半導体用
www.nedo.go.jp/news/press/AA5_100542.html

ホーム > ニュース > ニュースリリース 一覧 > SiCパワー半導体用・・・

News Release

SiCパワー半導体用接合材の自己修復現象を発見

—長期信頼性向上により自動車分野への応用促進—

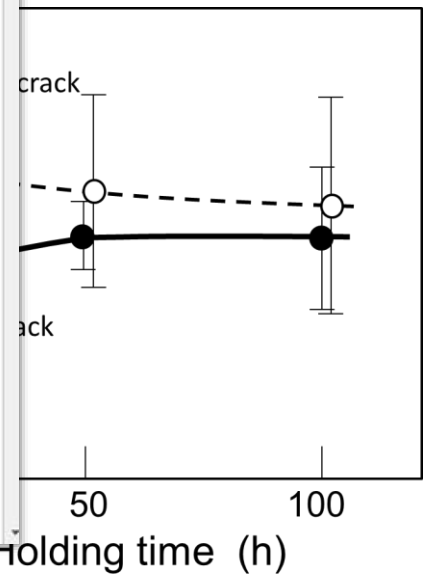
2016年3月28日

国立研究開発法人新エネルギー・産業技術総合開発機構
理事長　古川一夫

NEDOプロジェクトにおいて、大阪大学と(株)デンソーは、SiC(シリコンカーバイド)パワー半導体の長期信頼性向上が期待できる接合材の自己修復現象を発見しました。
高温の機器動作環境下で接合部の亀裂が自己修復するというもので、本成果は、自動車分野などSiCパワー半導体の適用可能性を大きく高めました。

5.0kV 7.5mm x100k SE(U)
5.0kV 7.8mm x100k SE(UL)
500nm

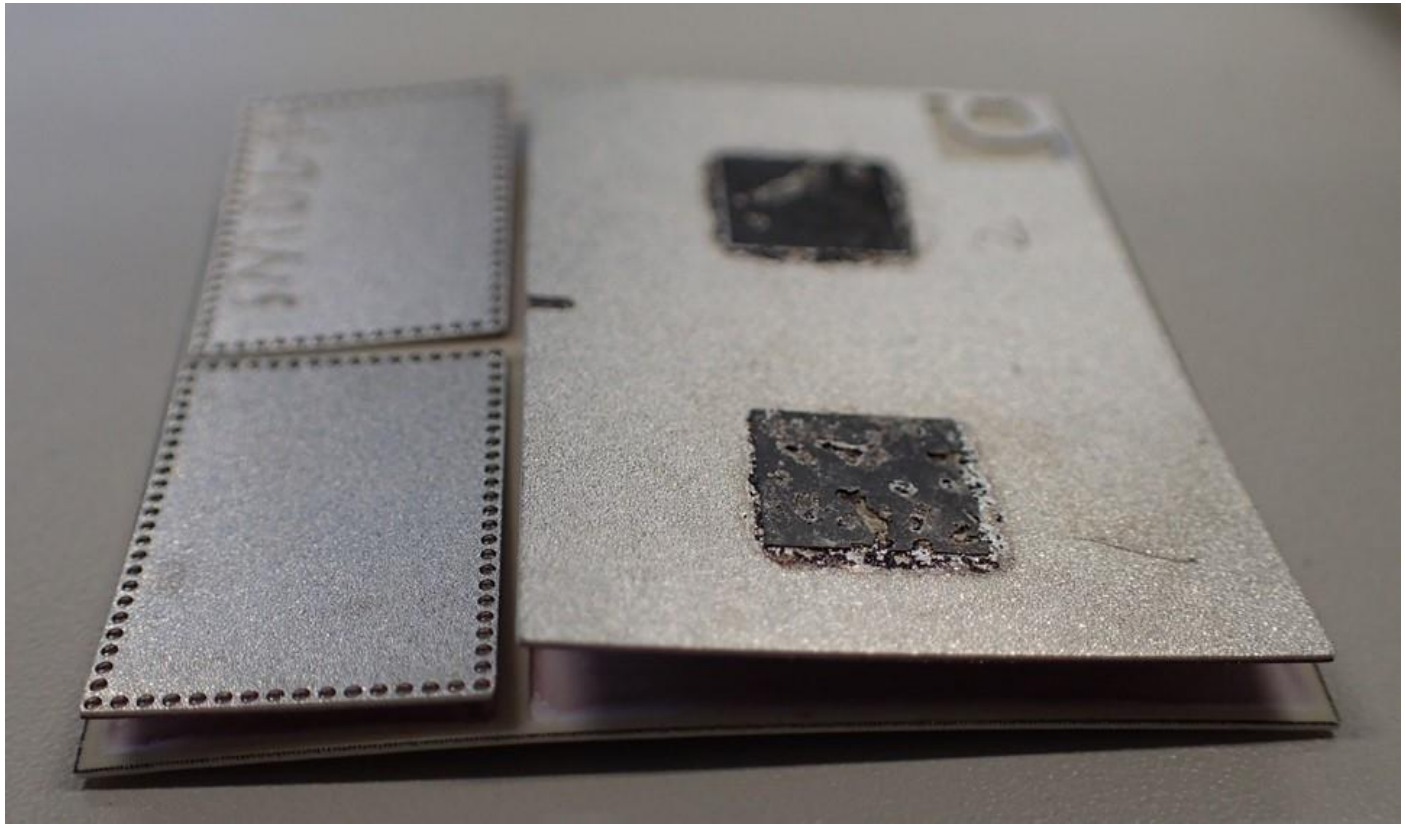
亀裂の自己修復の様子(左が修復前、右が修復後)



under the support of NEDO in collaboration with DENSO Corp.

Ceramic substrate fracture after thermal cycles

-40 ºC ~ 200 ºC / 500 cycles



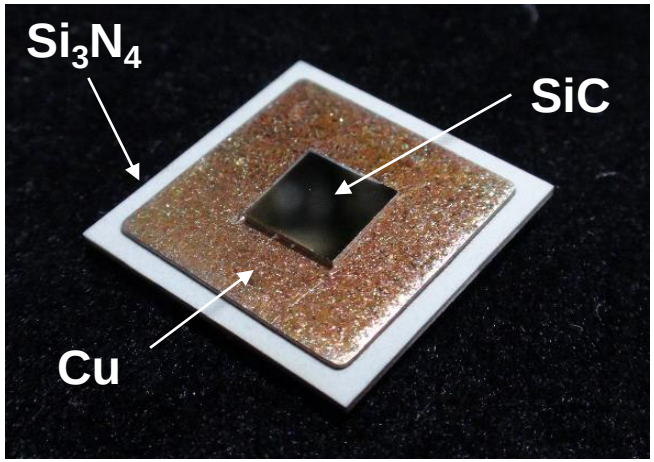
Typical substrate die-attach materials

Table Selected properties

	Al_2O_3	AlN	Si_3N_4	Cu	Al	Ag	Ni
Thermal conductivity (W/m·K)	30	170	27	398	236	420	73
Thermal expansion ($x10^{-6}$/K)	7.2	4.8	2.8	17.7	23.8	14.2	14.0
Strength* (MPa)	300	350	900	70	11	55	100
Fracture toughness ($MPa \cdot m^{1/2}$)	4	3	7	-	-	-	-
ΔT (Degree)	200	600	800	-	-	-	-

* 0.2 proof stress for metals

Previously proposed structure



Although it survives up to 300 ºC…

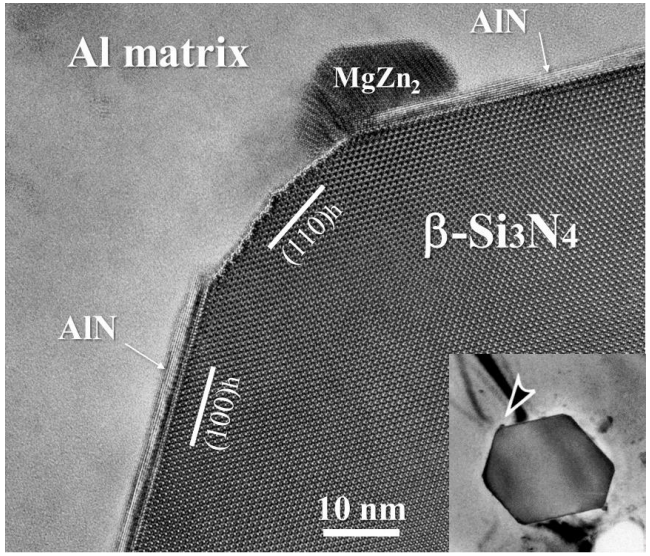
Problems:

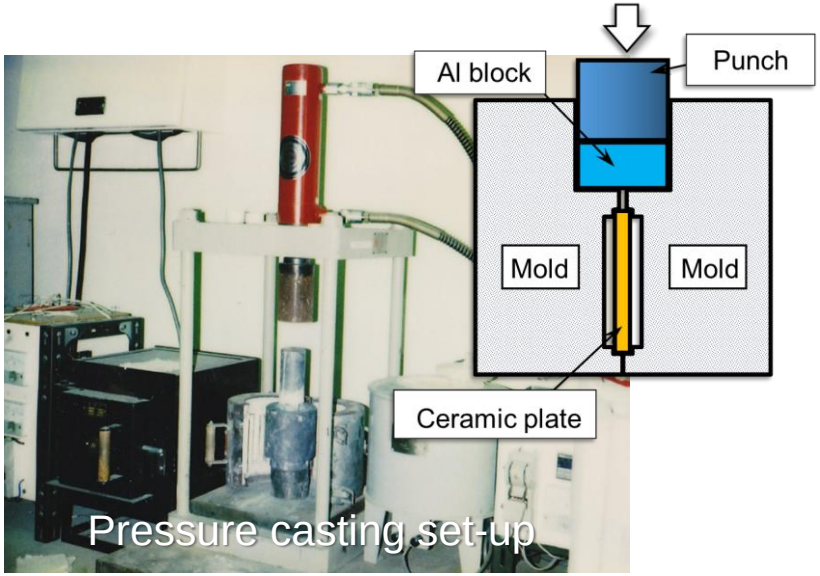
- ✓ High cost of Si_3N_4
- ✓ Poor thermal conductivity of Si_3N_4
- ✓ Oxidation of Cu

… etc.

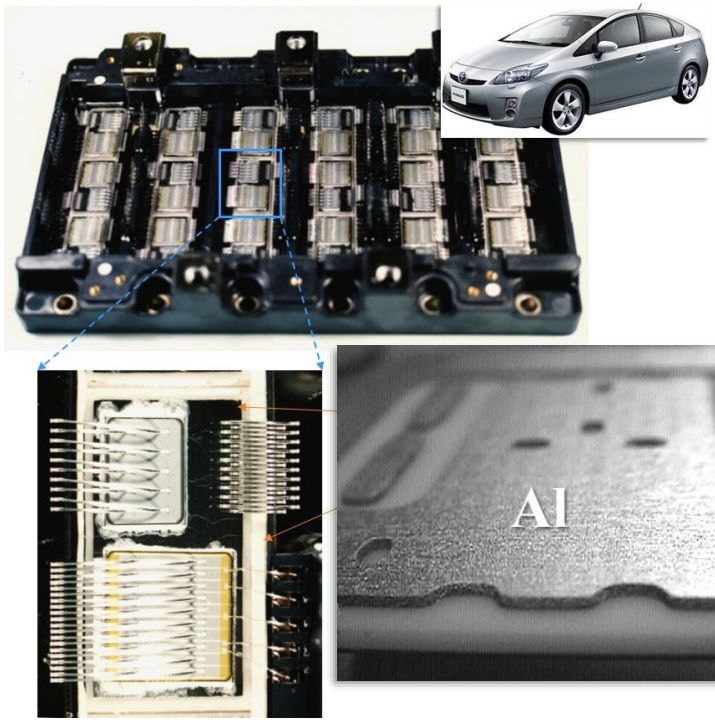
DBA invented from TEM

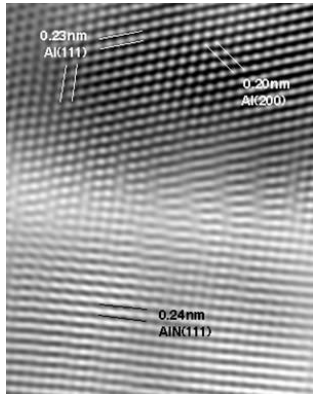
Al/ceramic interfaces were direct and clean.





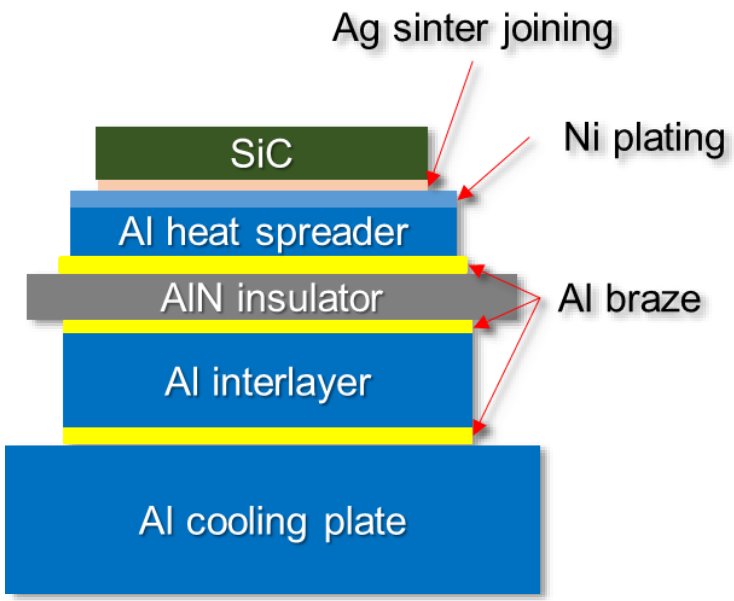
IGBT with DBA was released in 1998



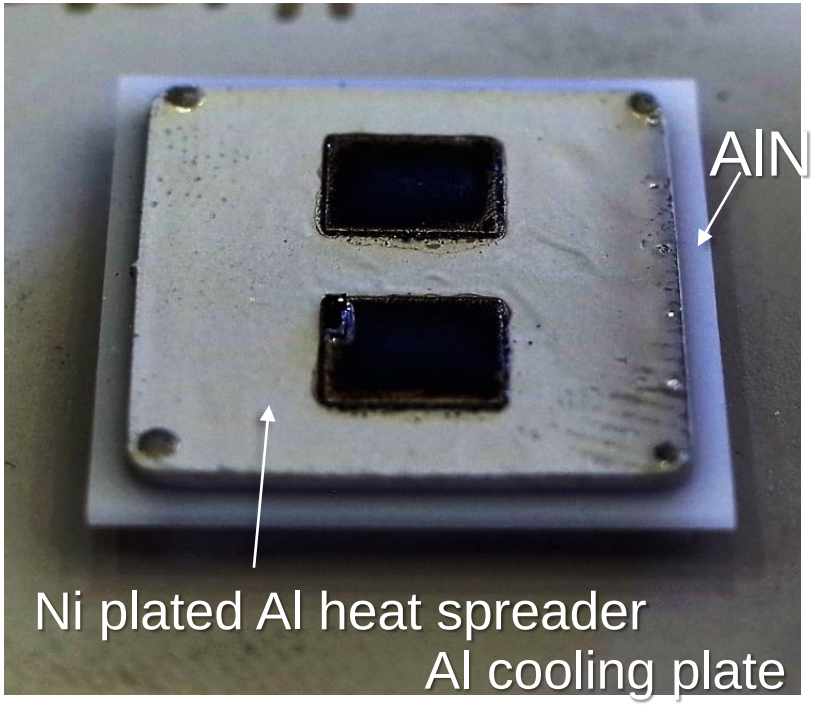


Last proof given to engineers

DBA can survive up to 300 ℃ temperature cycles



after - 40 ～ 300 ℃/110 cycles

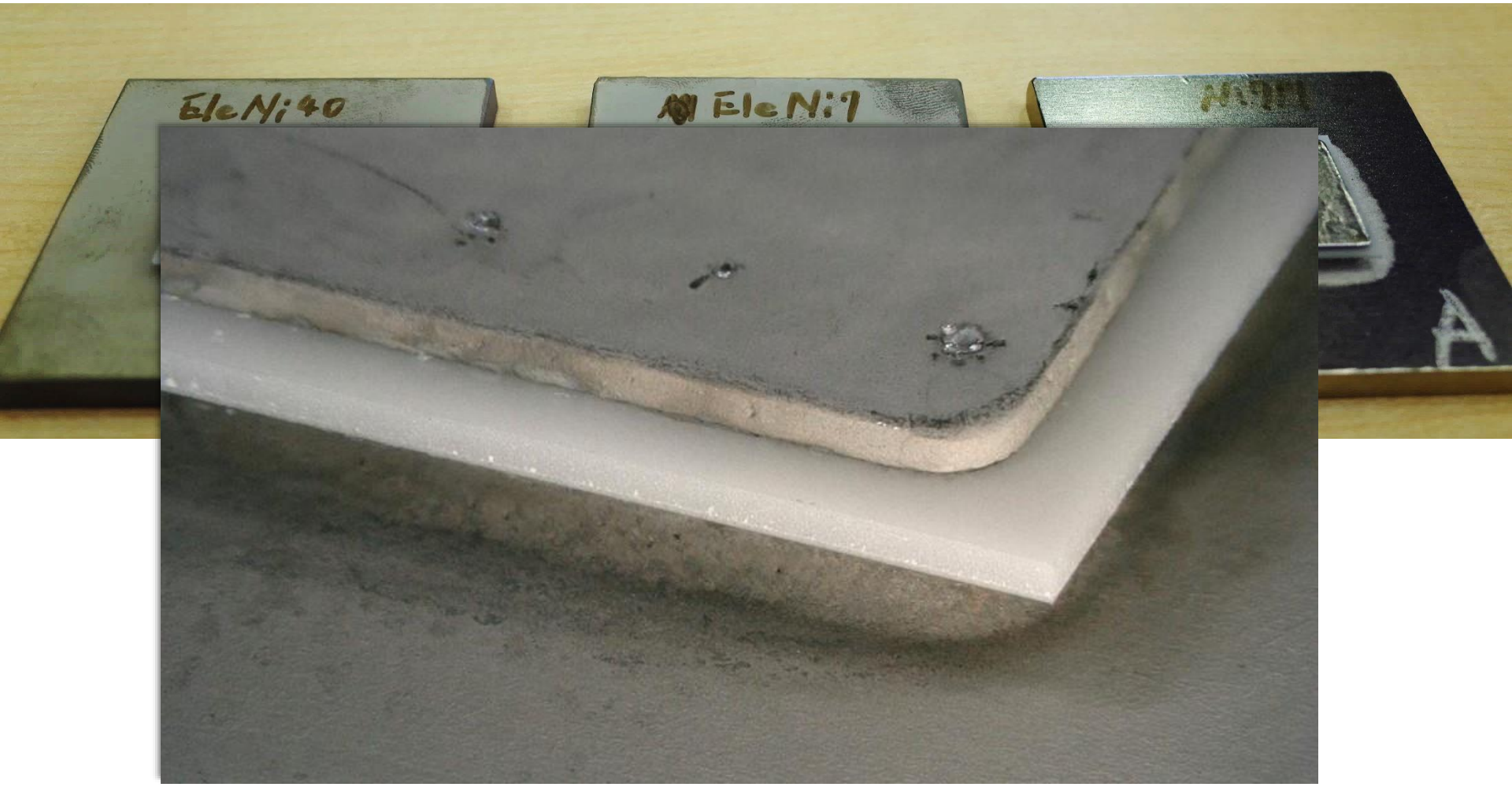


Ni plating
Ni-1%P electroless plating
Ni electroplating

In collaboration with
Siemens, Showa Denko, Uyemura
Senju Metals

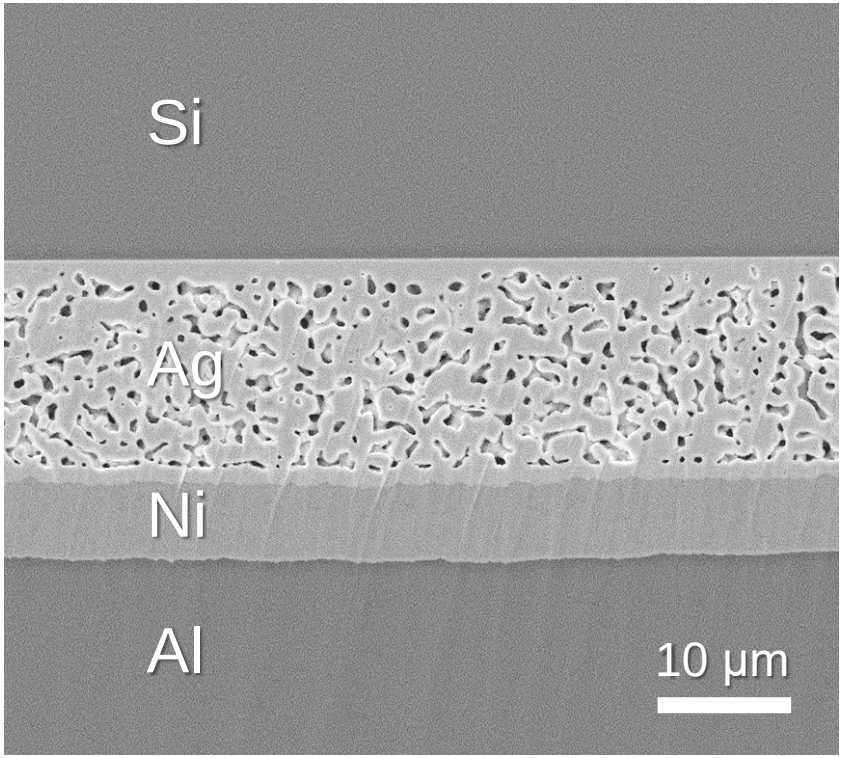
Electroplated Ni is better

-40 ～ 300 ℃ / 110 cycles

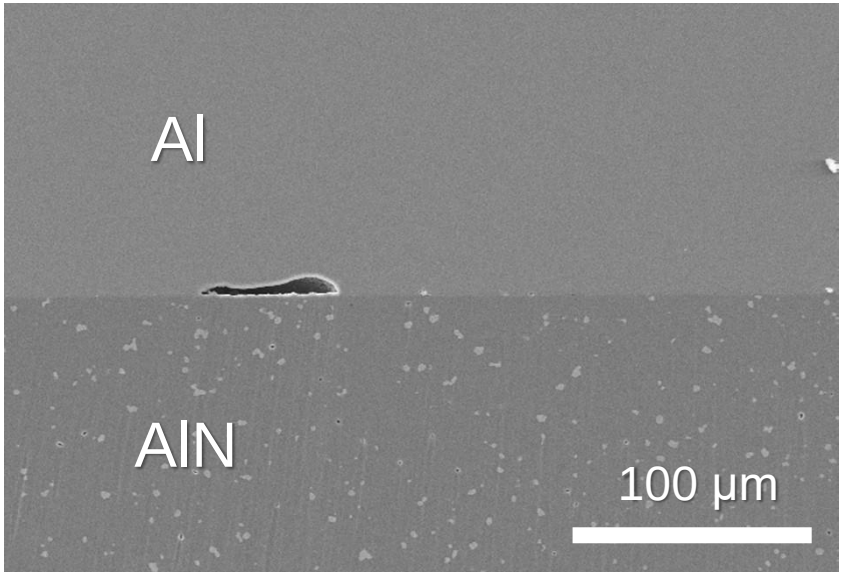


Ag sintered die-attach and Al/AlN interfaces

-40 ～ 200 ℃ / 100 cycles

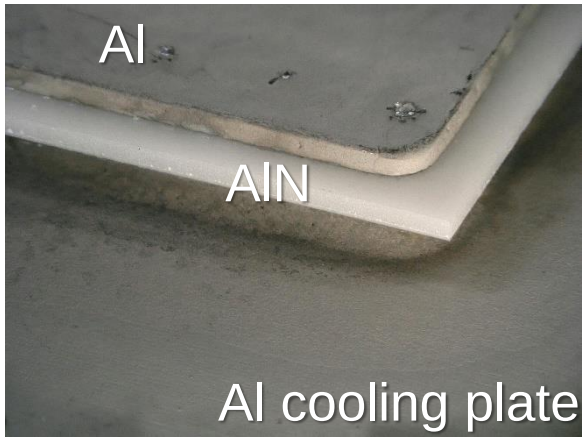


Ni electroplating



Summary

- ✓ The Ag sinter joining is one of the most promising die-attach methods for WBG applications.
- ✓ SiC submicron particles addition improves durability up to 250 ºC.
- ✓ The imid based molding nano composite exhibits excellent thermal/power cycling stability with a Ag porous interlayer.
- ✓ Sintering Ag at low temperature in air can be achieved by self-generated Ag nanostructure with oxygen. Ag-O formation in grain boundary has a key role for low temperature joining with Ag.
- ✓ DBA has potentials up to 300℃.



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Thank you!

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