INDIUM CORPORATION®

Processing and Reliability Testing of a Copper Pressure Sinter Paste for use in High Power Module, Die Attach Applications

Dean Payne. Product Manager – Semiconductor

Indium Corporation of America

iMAPS

19TH INTERNATIONAL CONFERENCE & EXHIBITION ON

DEVICE PACKAGING

FOUNTAIN HILLS, AZ • WWW.DEVICEPACKAGING.ORG • MARCH 13-16, 2023

001308

This presentation will cover…

- Why sinter?
- Introduction of the copper sinter paste and process conditions
- Test results
- Summary and planned future work

Why Choose Sintering?

- Power electronics continue to evolve due the increasing demands and mission profiles of "new" applications such as EVs

- Material properties of pressure sintered Ag and Cu make them very attractive materials for power die-attach

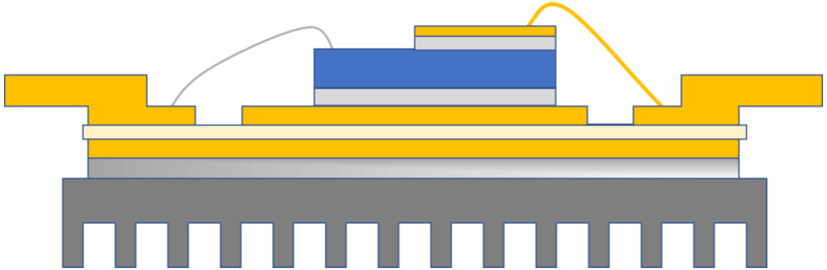
- Enables utilization of the benefits offered from WBG die technologies such as SiC and GaN

- Increased lifetime/reliability when compared to solder; critical for automotive and industrial applications

- Pb-free

Current State of the Art

- For EV inverters, power modules should have higher power densities, be smaller, lighter, and more efficient. WBG semiconductors and alternate bonding materials are just some of the methods to address this
- Pressure Ag sinter is becoming the material of choice for die-attach and potentially other applications
- Challenges with Ag are cost, compatibility with certain surface finishes, and the potential for Ag migration



Sintered power module schematic

Properties	Pb-free	High-Pb	Ag	Cu
Melting temperature °C	220	296	961	1084
Thermal conductivity W/m.K	~50	~30	>200*	>120*
Electrical conductivity MS/m	8	5	40*	25*
CTE ppmK	23.5	29	19	16

Typical material properties
*expected for pressure sinter

Copper Sinter Paste

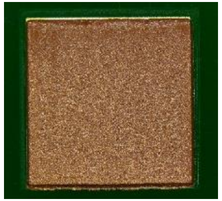
Constituent parts:
- Commercially available Cu powder, 1–20µm size range
- Proprietary binder chemistry

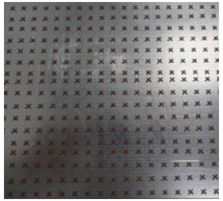
Packaging:
- Jar (printing)
- Syringe (dispensing)

Notable feature:
High metal content >90% (wt)

Copper sinter paste samples

Print and dispense deposits





Sintered die-attach process

Pre-mixing → Printing → Pre-dry → Die bond → Sinter

Pre-mixing
- **1000 rpm 1.5–2 mins**
- **Thinky or similar**

Printing
- **20–30mm/s print speed**
- **<2mm/s separation speed**

Pre-dry
- **85 to 100ºC**
- **3–5 minutes**

Die bond
- **5kg force**
- **110ºC**
- **1–2 seconds**

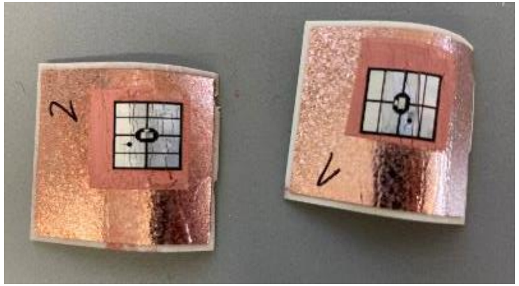
Sinter
- **15 to 20MPa**
- **250 to 270ºC**
- **5–10 minutes**

O2 <1000ppm

001312

Results – Sinter Quality

Test vehicle: 10mm x 10mm Si IGBT die on DBC (Cu) substrate
Mandrel bend test



- No lifting observed, joint and die conform to the bend
- Indication of strong adhesion
- Sintered at 250^{o}C, 15MPa for 5 minutes under H_2

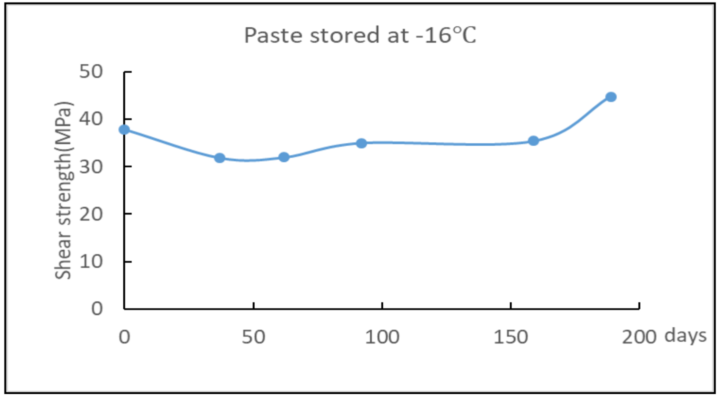
Test vehicle: 5mm x 5mm SiC MOSFET die on DBC (Cu) substrate
Shear test done using the XYZTEC Condor Sigma bond tester

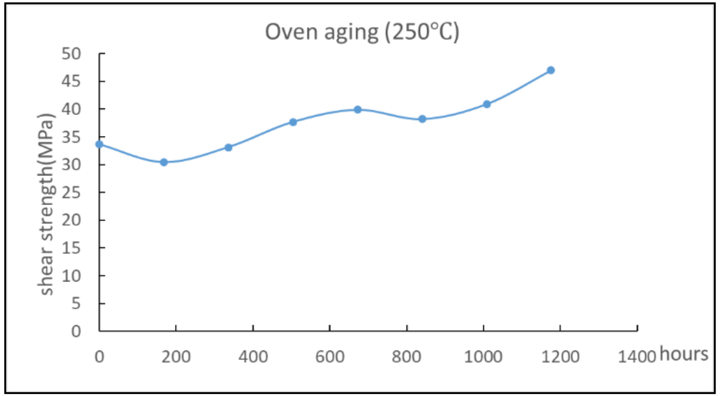
- Time 0 shear strength >32MPa
- Sintered at 250^{o}C, 15MPa for 5 minutes under N_2

Pre-dried using Budatec VS320: 85^{o}C, 3 minutes, vacuum (100mbar)
Pressure sintered using Budatec SP300

Results – Shelf Life and HTS

Test vehicle: 3mm x 3mm Cu die on 23.5mm x 23.5mm Cu substrate
Shear test done using the XYZTEC Condor Sigma bond tester



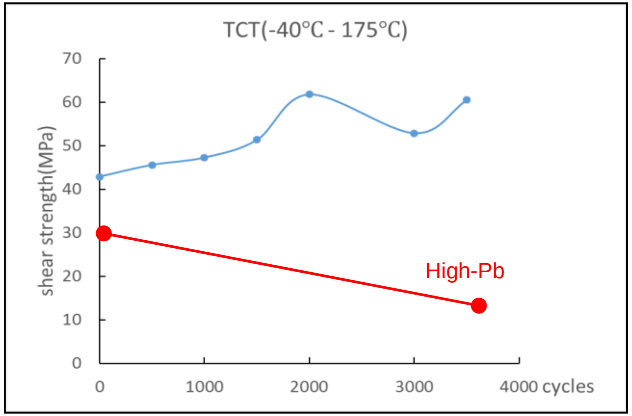


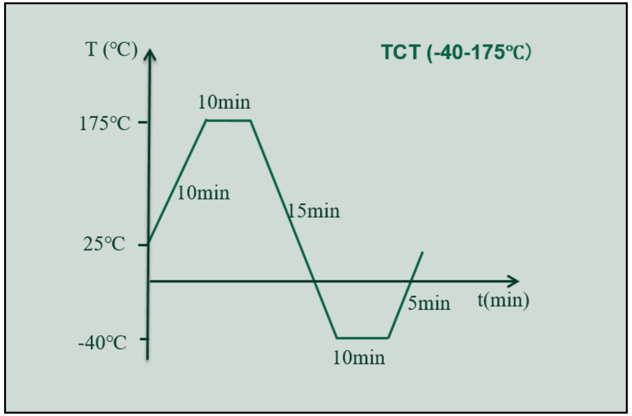
- One paste batched stored at -16ºC and shear tested periodically
- Consistent bond strength through six months

- HTS at 250ºC and shear tested periodically
- Increasing shear strength with aging time indicating extended sintering reaction

Results - TCT

Test vehicle: 3mm x 3mm Cu die on 23.5mm x 23.5mm Cu substrate
Shear test done using the XYZTEC Condor Sigma bond tester

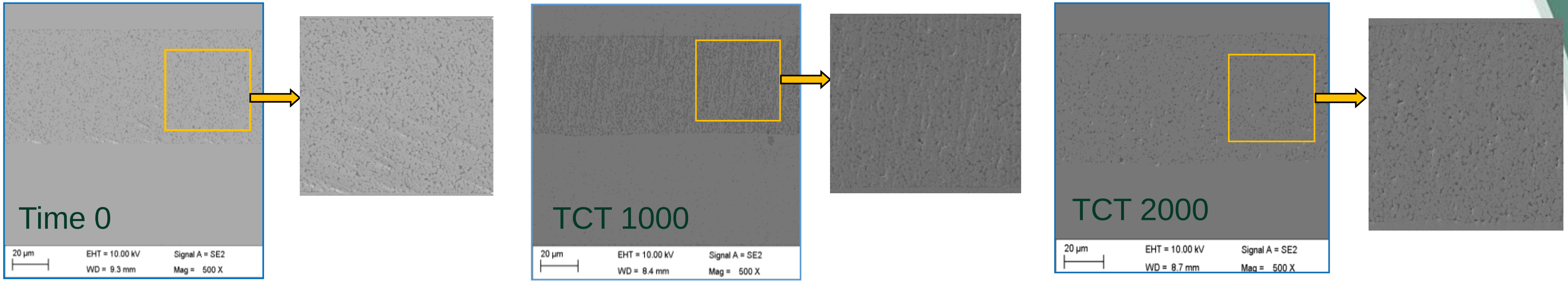




- Thermal cycling tests done under air from -40 to 175^{o}C and the shear strength was tested periodically
- Average shear strength at T0 was 42MPa increasing to close to 60MPa after 3500 cycles
- High-Pb solder (Pb/Sn5/Ag2.5) was also tested as a reference

Results – Microstructure Analysis

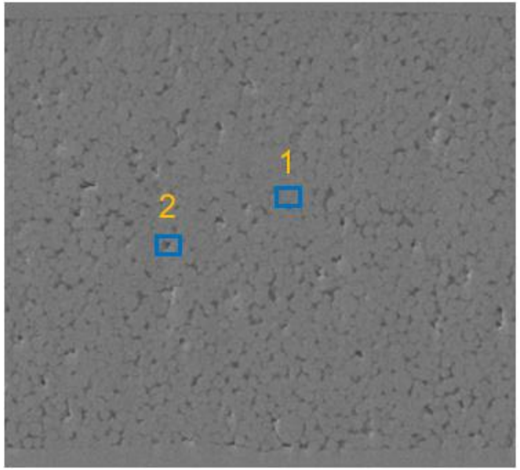
SEM images of the sinter joint microstructure after cross section



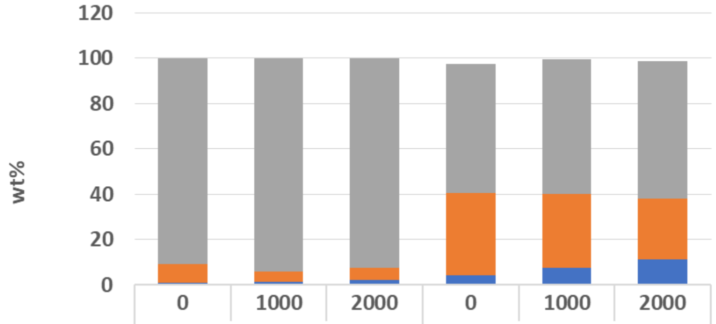
- Observed density of the sinter joint increases with the # of cycles, porosity reduces
- Extended sintering occurs through TCT, as shown by the increased shear strength

Results – Microstructure Analysis

EDS analysis of the "dense" and "porous" region



EDS Results

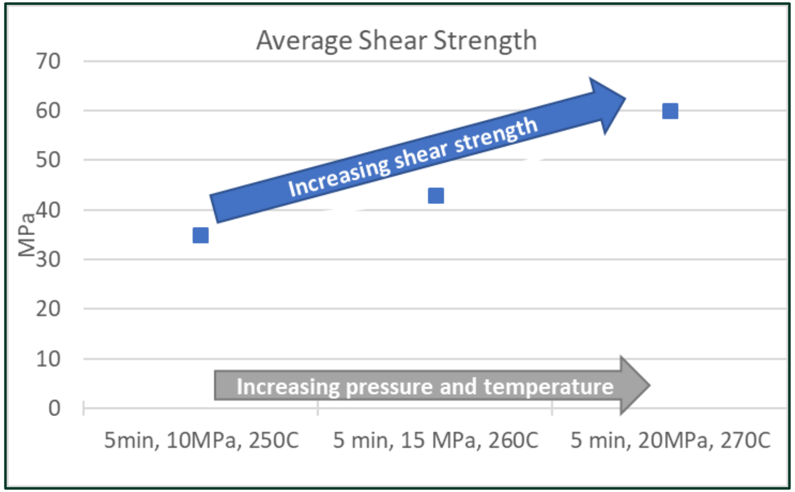


	1 Dense			2 Porous		
	0	1000	2000	0	1000	2000
Average of Cu (wt%)	90.94	94.13	92.59	56.95	59.43	60.54
Average of C (wt%)	8.24	4.52	5.39	36.15	32.26	26.66
Average of O (wt%)	0.81	1.35	2.02	4.43	7.72	11.42

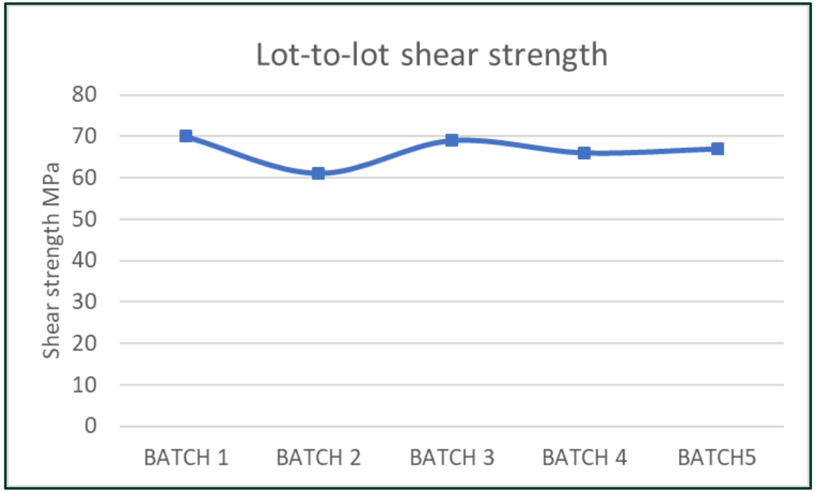
- Dense Cu region "1" and pore region "2"
- % of O detected increases with the # of cycles for both areas. The amount detected is higher for region 2
- % of C detected is significantly higher for region 2
- Higher C and O at region 2 is likely due to residual organics in the pores

Paste Lot-to-Lot Validation

Test vehicle: 3mm x 3mm Cu die on 23.5mm x 23.5mm Cu substrate
Shear test done using the XYZTEC Condor Sigma bond tester



Impact of process conditions on shear strength

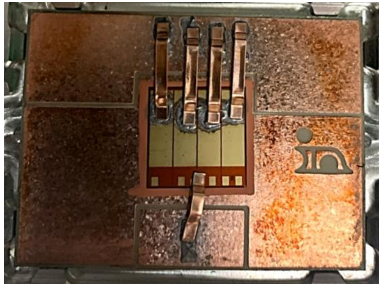


Shear strength of five different paste batches

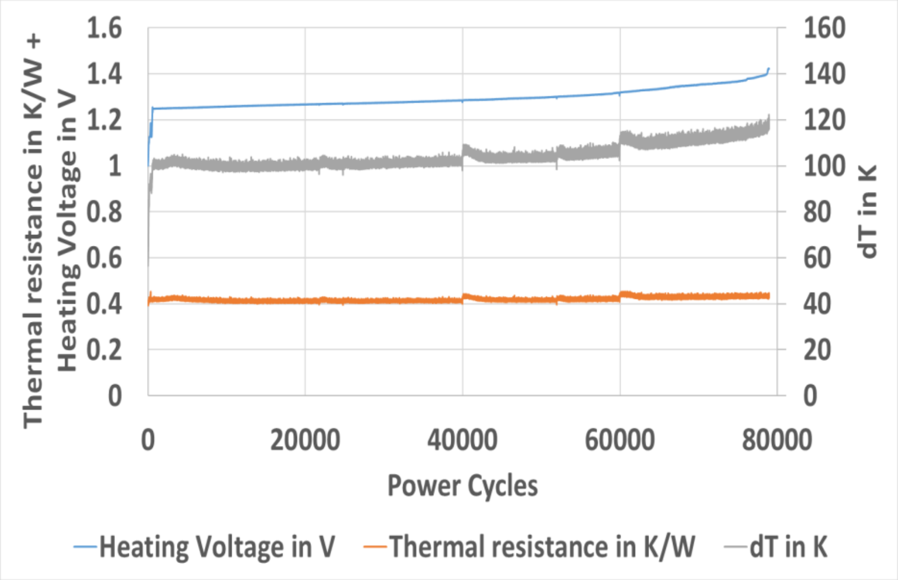
Shear strength is consistently 60 to 70 MPa with optimized sinter parameters

Results – Power Cycling

Internal power cycling reliability tests



Test vehicle:
Si3N4 Substrate
Sintered Si IGBT die
Soldered Cu clips



Summary and Future Work

- Pressure copper sinter paste for die-attach in high power modules is showing great potential
- Made with commercially available copper with proprietary binder chemistry
- Binder chemistry offers excellent resistance to oxidation and the paste exhibits 6-month shelf life
- Thermal cycling and aging tests both exhibited positive results with shear strength increasing throughout the test campaign
- Low oxygen requirement may need new or adapted equipment

Future work

- Further reliability testing
- Collaboration with customer/module manufacturer

Thank You!

dpayne@indium.com
www.indium.com