

ADVANCED INTERCONNECTION TECHNOLOGIES IN POWER ELECTRONICS FOR IMPROVED RELIABILITY AND PERFORMANCE

PSMA Packaging Industry Session, APEC 2022
Aarief Syed-Khaja, Habib Mustain

CONTENT

1 | HERAEUS GROUP

- › Heraeus – A globally Successful portfolio company
- › Heraeus Business Portfolio
- › Heraeus Electronics

2 | HERAEUS AND CHALLENGE OF NEW PACKAGING SOLUTIONS


3 | CHALLENGE PERFORMANCE

- › DTS®, sintering and Cu bonding technology for increased lifetime and current/power density
- › Si₃N₄ AMBs for enhanced heat dissipation and reliability

4 | CHALLENGE QUALITY AND YIELDS

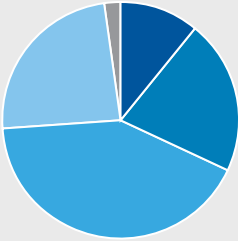
- › DTS for reduced production complexity
- › Pre-applied sinter paste for reduced complexity and improved yields

GLOBALLY SUCCESSFUL PORTFOLIO COMPANY



31.5 bn. €

TOTAL REVENUE
2020



Germany 11%

Rest of Europe 21%


Asia 42%

America 24%

Africa/Australia 2%

RESEARCH & DEVELOPMENT
expenditures

7%



Based on revenues excl. Precious Metals

11 market-oriented
GLOBAL BUSINESS UNITS

TOP 10
FAMILY-OWNED COMPANIES
in Germany

Listed in

FORTUNE 500



More than
SITES

100

in
COUNTRIES

40



14.800

EMPLOYEES



Germany 37%

Rest of Europe 17%

Asia 28%

America 17%

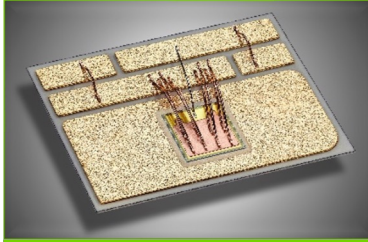
Africa/Australia 1%

including staff leasing

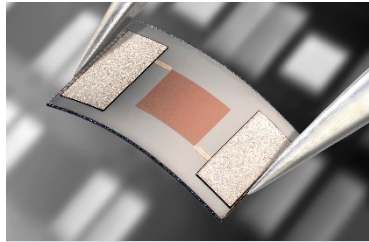
BUSINESS PORTFOLIO – LEADING IN GLOBAL MARKETS



**Heraeus
Precious
Metals**



**Heraeus
Electronics**



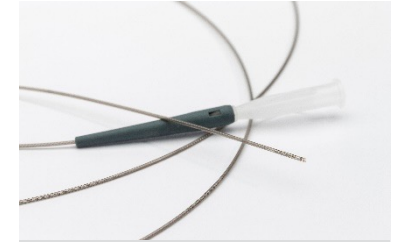
**Heraeus
Nexensos**



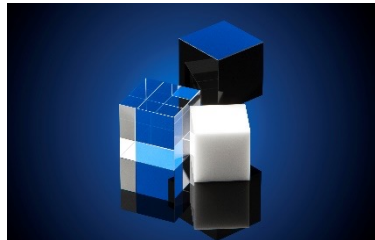
**Heraeus
Epurio**



**Heraeus
Medical**



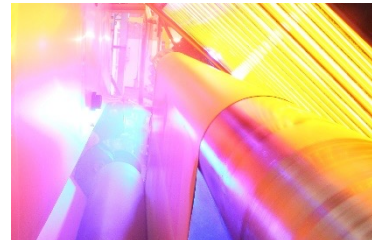
**Heraeus
Medical
Components**



**Heraeus
Conamic**



**Heraeus
Comvance**



**Heraeus
Noblelight**

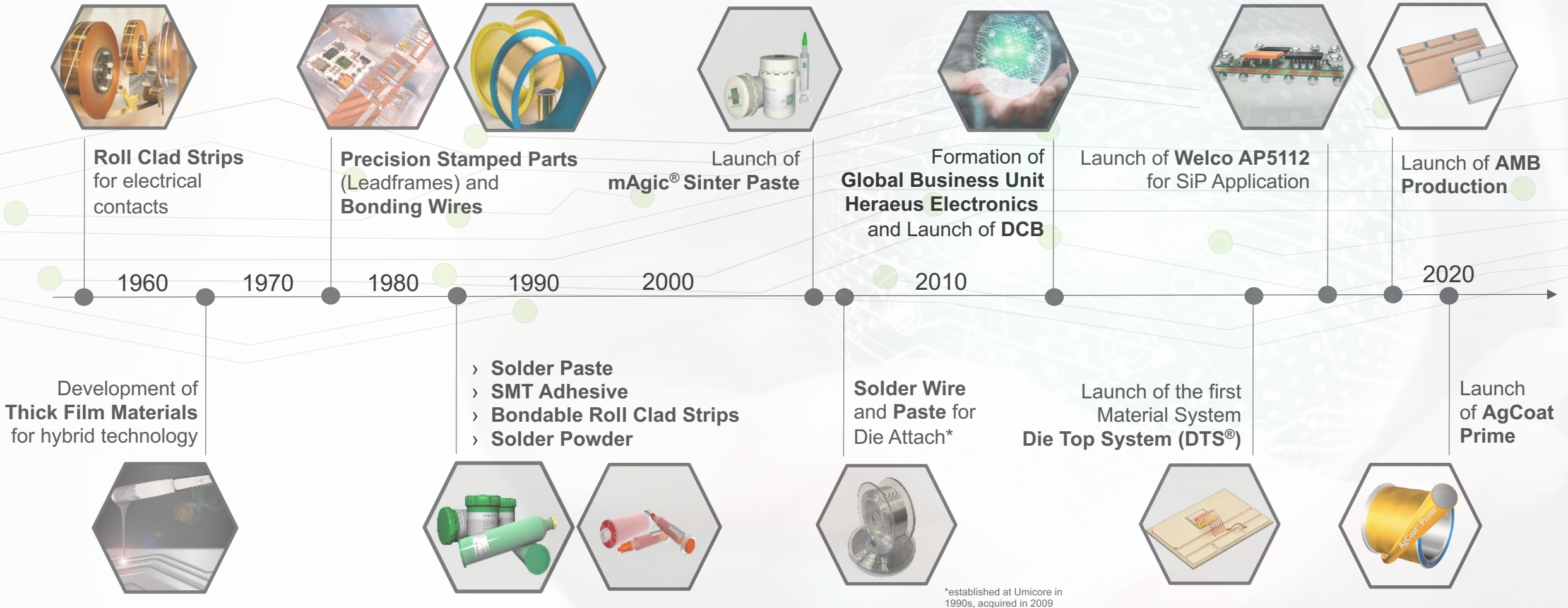


**Heraeus
Electro-Nite**

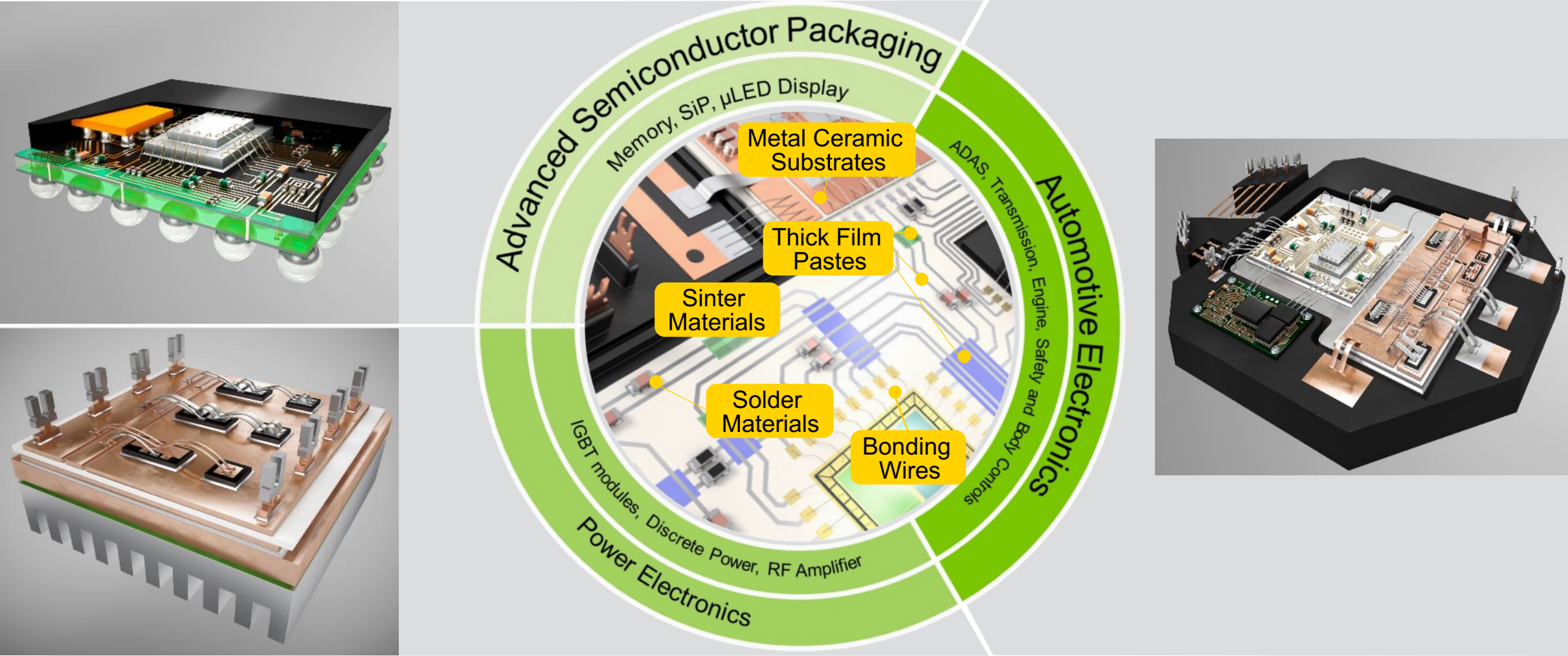


**Heraeus
Photovoltaics**

PROVIDING MATERIALS TO THE ELECTRONICS INDUSTRY FOR MORE THAN 60 YEARS



MATERIAL SOLUTIONS FOR THE ELECTRONICS PACKAGING INDUSTRY



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REVOLUTION OF POWER ELECTRONICS PACKAGING



Increase Power
Increase Efficiency
Decrease form factor

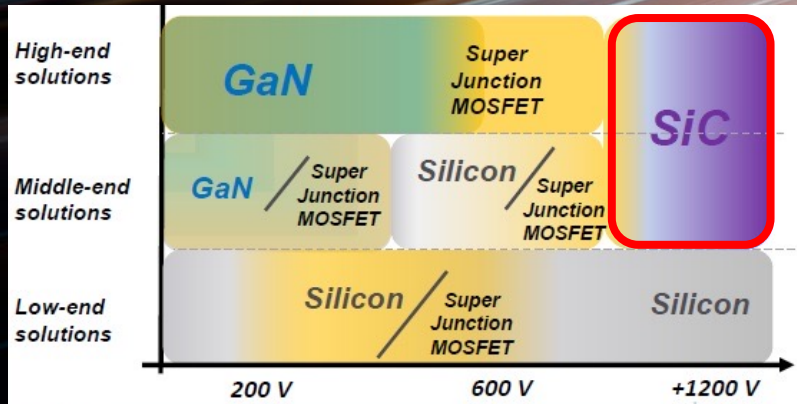


Higher traveling
distance per charge

WBG Material

Operating Temperature

Matching Assembly
Material

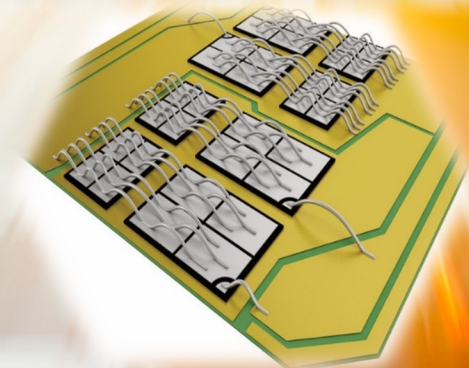


Up to
150°C

More than
175°C

Si

SiC



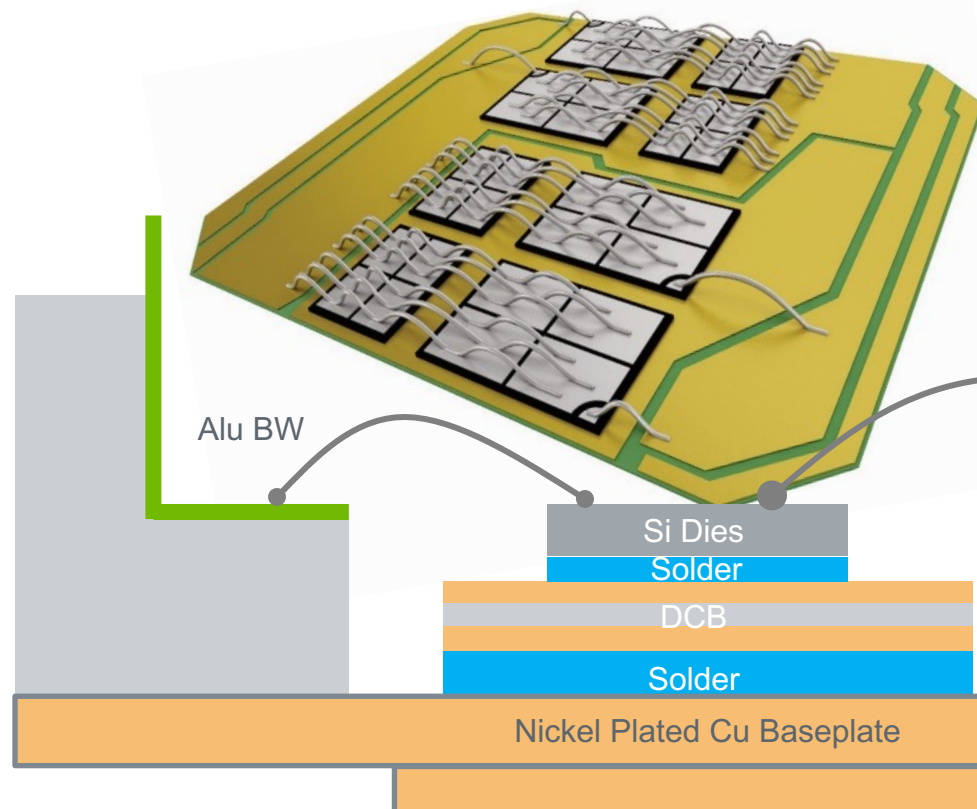
Traditional assembly and packaging
materials have reached its limits.

REVOLUTION OF POWER ELECTRONICS PACKAGING

TRANSITION TO HIGH POWER DENSITY MODULE PACKAGING

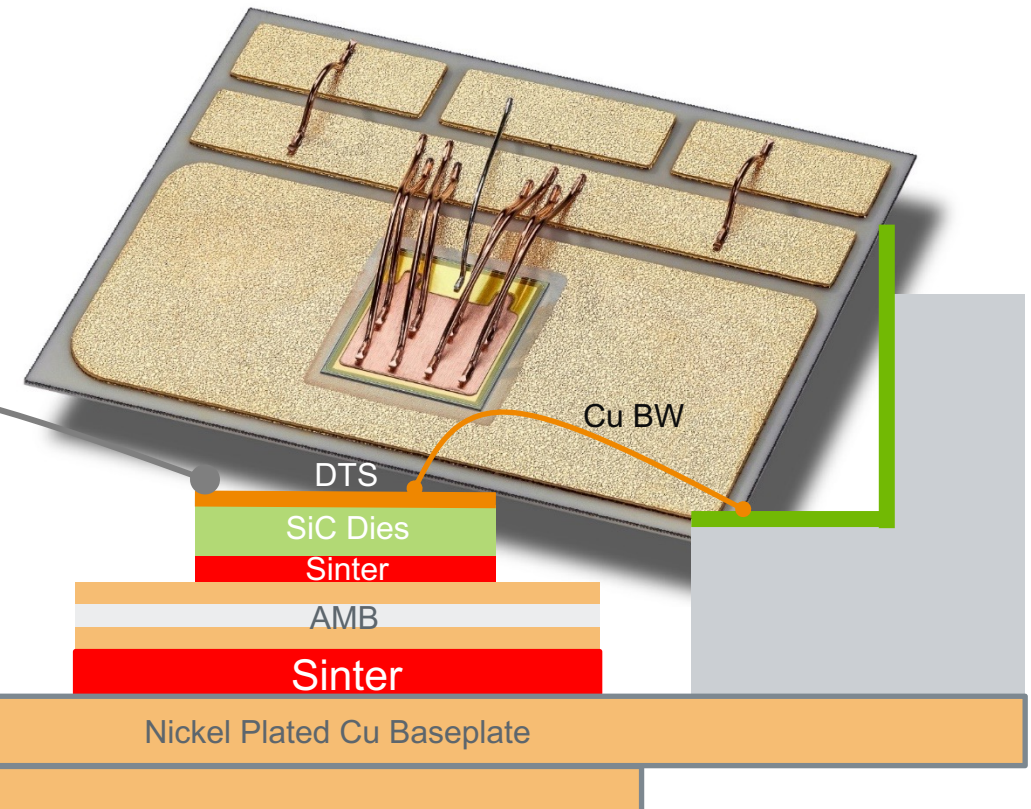
Present

Tj: Up to 150°C



Future

Tj: more than 175°C



POWER SEMICONDUCTORS AND NEED FOR NEW PACKAGING MATERIALS SOLUTIONS

Smaller and
Thinner Dies

Increased
Power Density

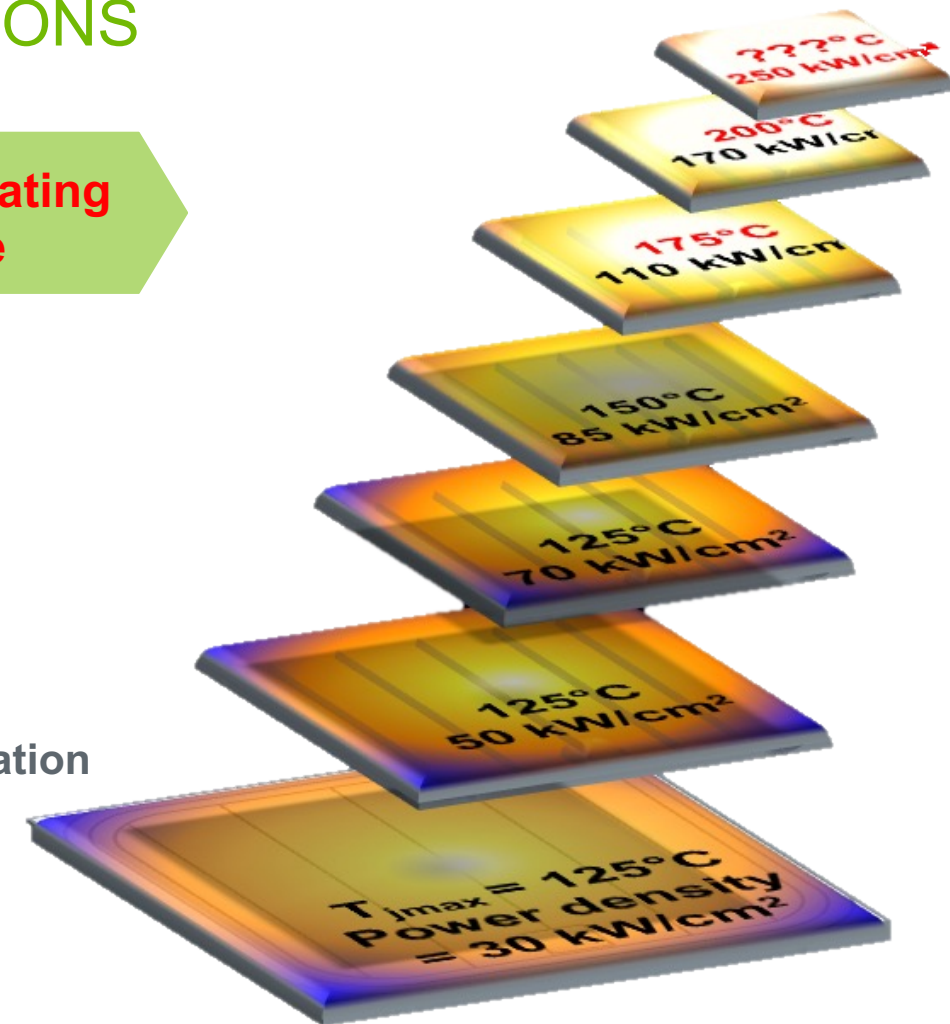
Higher Operating
Temperature

Benefit through smaller dies

- › Reduction of chip size / cost
- › Lower losses / higher efficiency
- › Increase of power & current density per chip

Packaging challenges

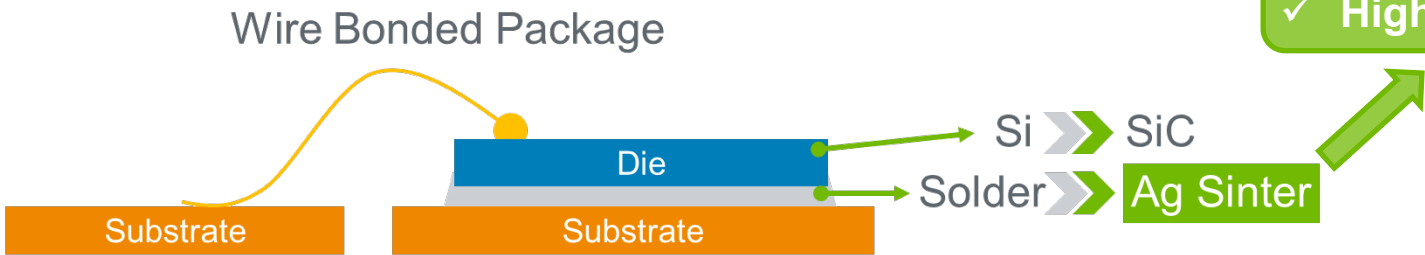
- › Increased power loss per chip area requires materials with **better heat dissipation**
- › More power needs better **current carrying capability** of packaging materials
- › Increased operating temperatures and **reliability** challenges



Source: Innovative Material Packaging Solutions for superior Power Electronics Devices, EDPC Conference Nov. 2016, Nürnberg, A. Miric, Dr. Frank Osterwald, P. Dietrich, A.S. Klein, A. Hinrich

WHY SINTERING?

High Power Packages Development Trend
Higher current capacity >>> Higher operating temperature >>> Higher reliability



- ✓ High melting temperature (961°C)
- ✓ High thermal and electrical conductivity

“Integration of new materials and technologies with increase in reliability”

Die Attach Materials	Lead-free solder Sn _{96.5} Ag _{3.5}	High-lead solder Pb _{92.5} Sn ₅ Ag _{2.5}	Silver sinter
Max. operation temp. (°C)	220	296	> 380
Thermal conductivity (W/mK)	60	25	> 150
Electrical conductivity (MS/m)	8	5	40
CTE (ppmK ⁻¹)	25	29	20
Young's modulus (kN/mm ²)	30	23.5	40-55

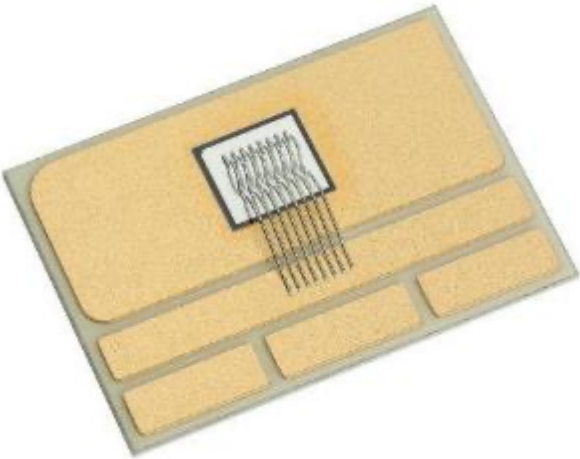
PRESSURE SINTER PASTE PROCESS & APPLICATION

mAgic Paste Pressure Process



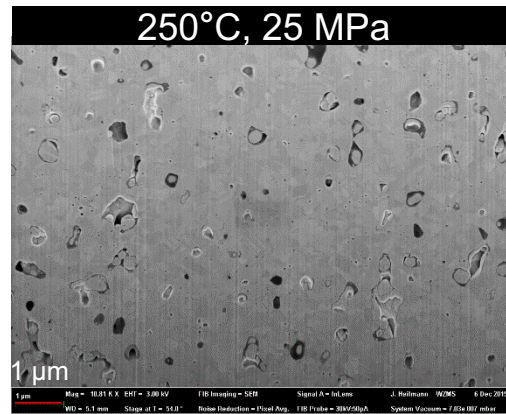
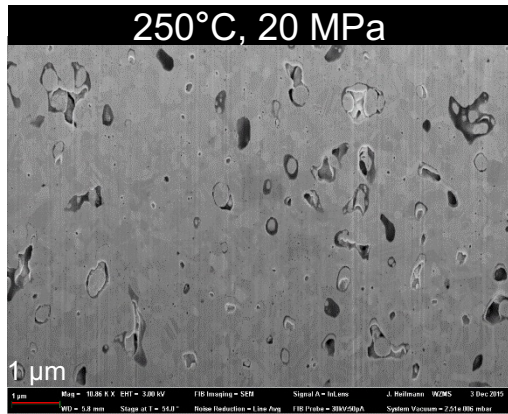
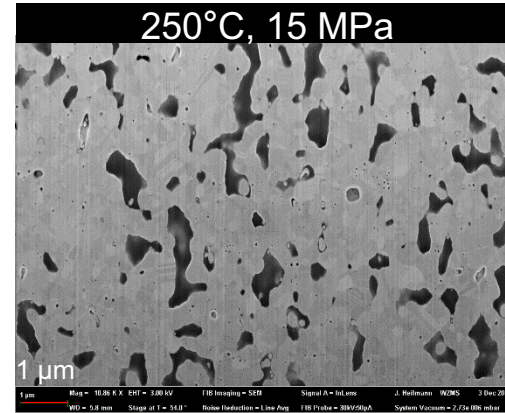
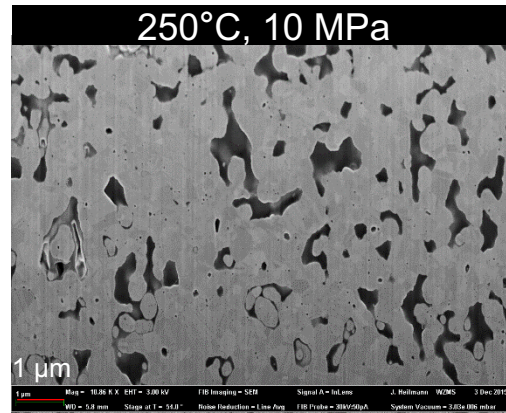
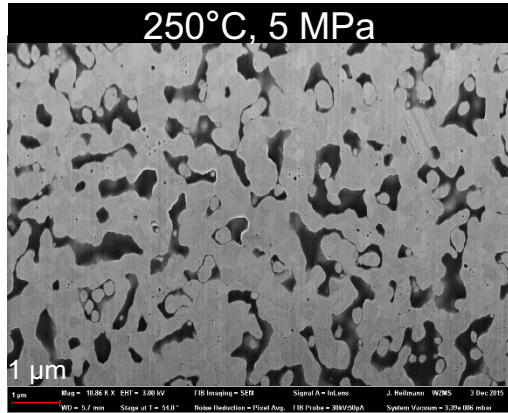
Applications

High Power Packages

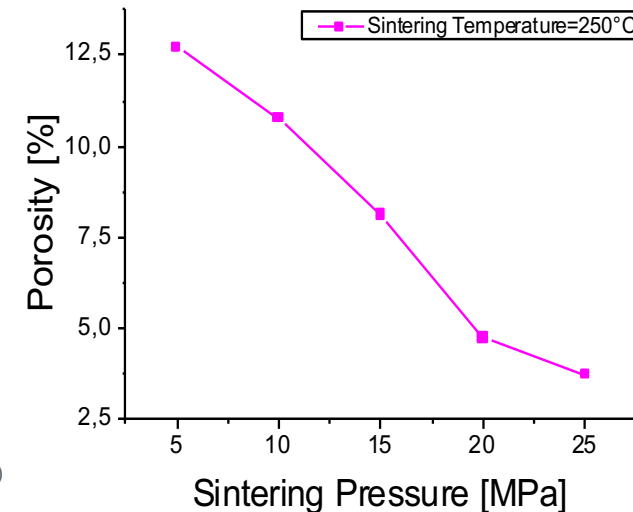
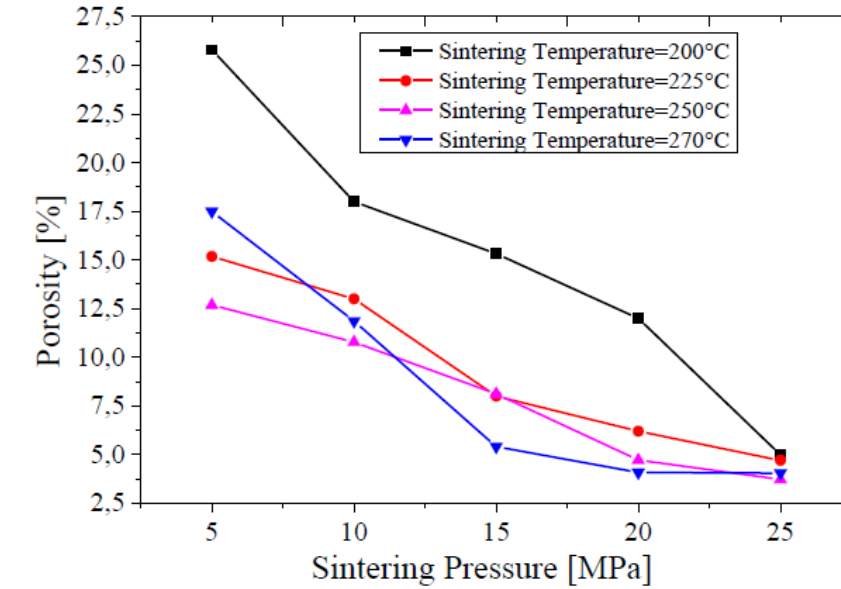


Properties		ASP043-04	PE338	PE338 F1510
Workable Surface		Ag, Au	Ag, AuCu	Ag, AuCu
CTE	ppm/K	19	19	15
Thermal Conductivity	W/mK	> 200	> 200	> 200

POROSITY AS FUNCTION OF SINTERING PRESSURE



Porosity as a function of sintering parameters



[1] M.A. Ras, D. May, J. Heilmann, S. Rzepka, B. Michel, B. Wunderle "Processing-Structure-Property Correlations of Sintered Silver", 2016 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)

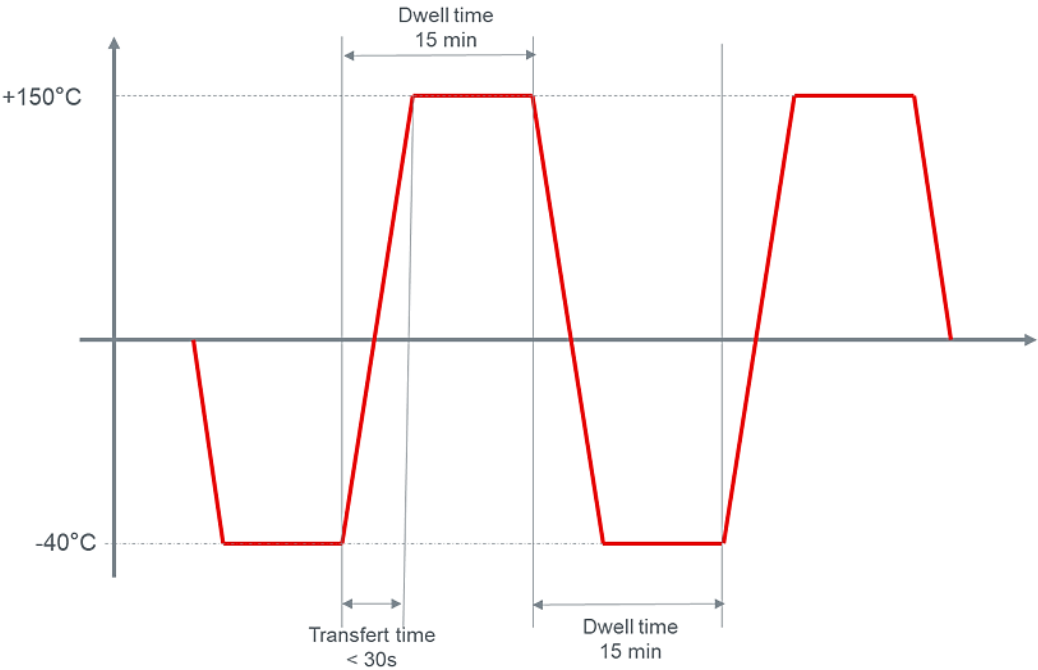


PE338 SINTERING ON DIFFERENT SURFACES

CSAM AT INITIAL, 1000X AND 2000X (TCT -40°C/+150°C)

Die Size: 10x10mm Ag BSM
AMB substrates
Sinter Parameters: 230°C, 10MPa, 3min

TCT Profile



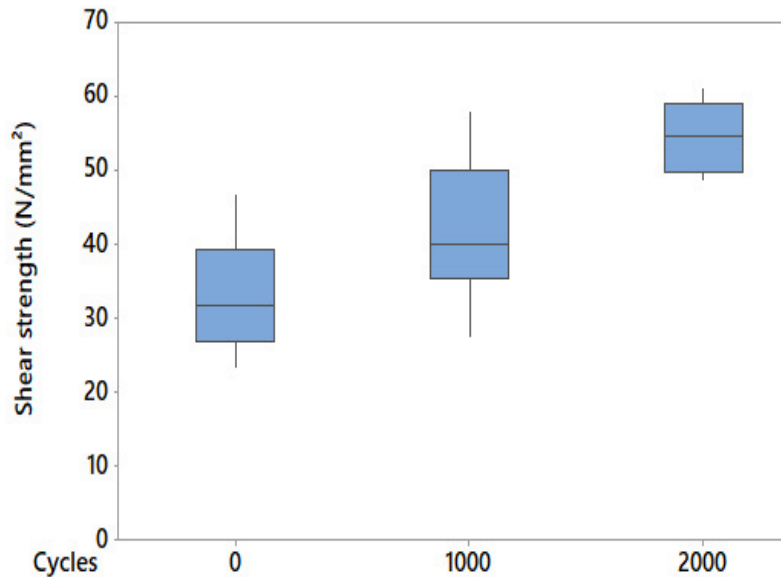
10x10mm Ag BSM	Initial	TCT 1000x	TCT 2000x
Ag			
NiAu			
Bare Cu			

PE338 SINTERING ON DIFFERENT SURFACES

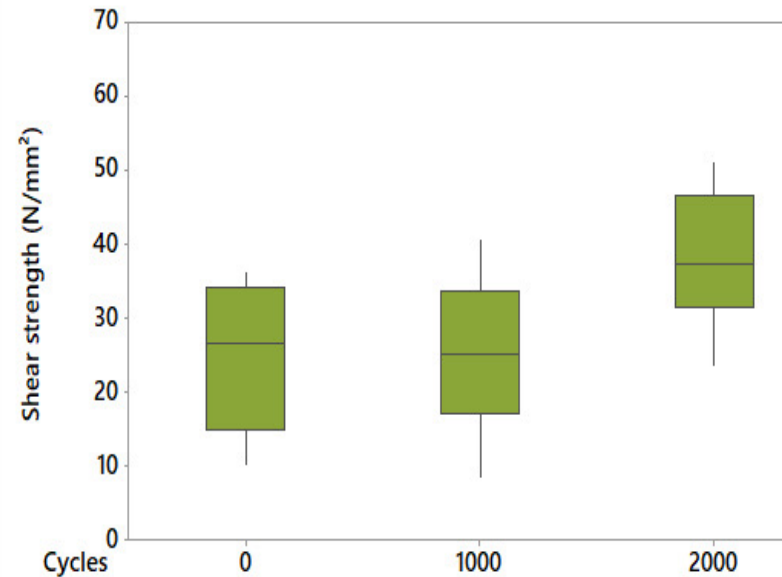
DIE SHEAR STRENGTH BEFORE AND AFTER TCT (-40°C/+150°C)

Die Size: 4x4mm Ag BSM
Sinter Parameters: 230°C, 10MPa, 3min

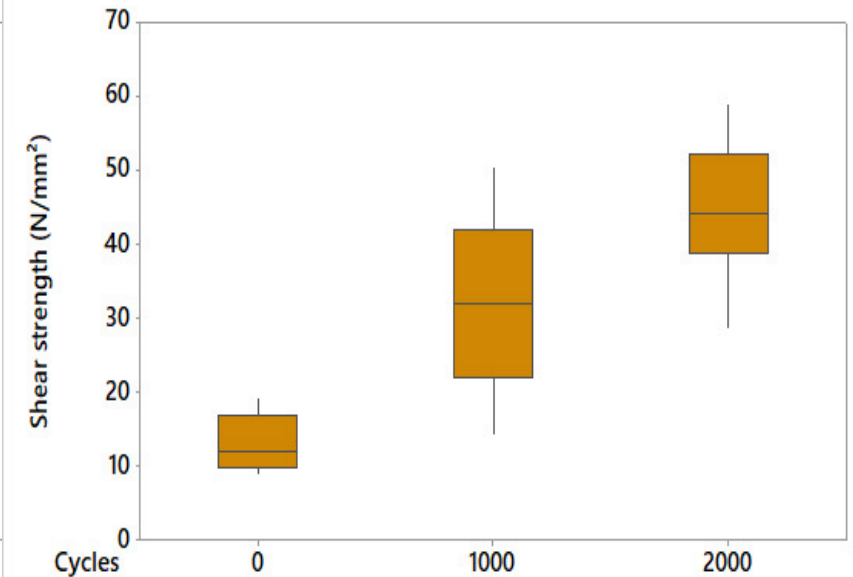
Ag metallized AMB substrate



Au metallized AMB substrate



bare Cu AMB substrate



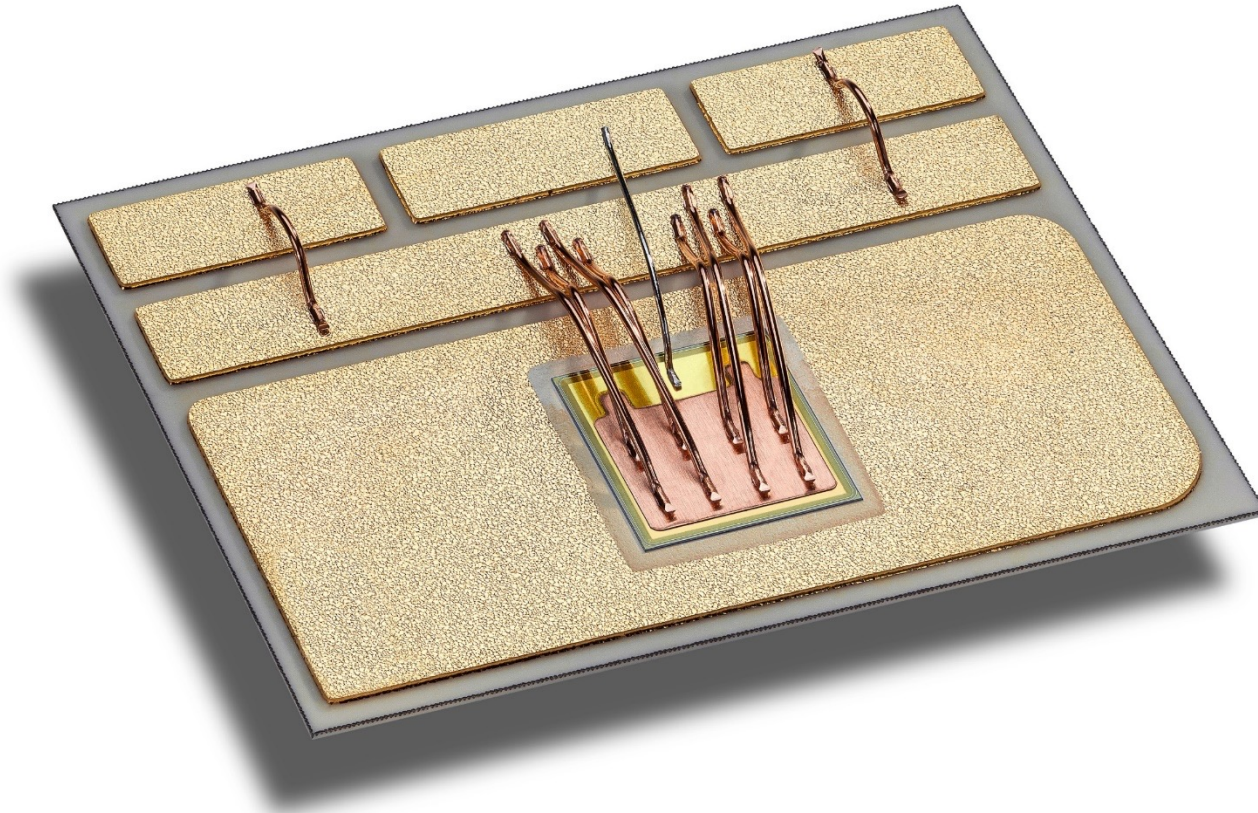
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DIE TOP SYSTEM[®] Get the most out of your Power Module



Key benefits

Die protection to enable Cu wire bonding with high yield

Best Performances

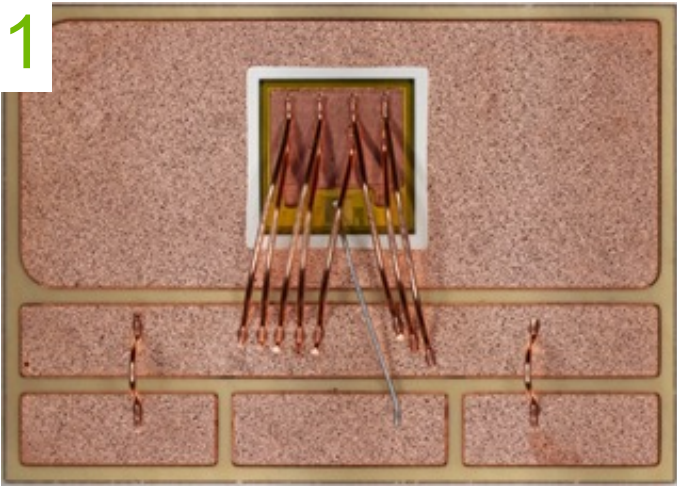
- Die current capability increases >50% vs. aluminum wire
- Significantly longer lifetime vs. solder die attach and Al-wire on system level
- Enables higher junction temperatures of more than 200°C
- Significant reduction of power derating or reduction of chip size

[®] Trademark registered in EU, JP

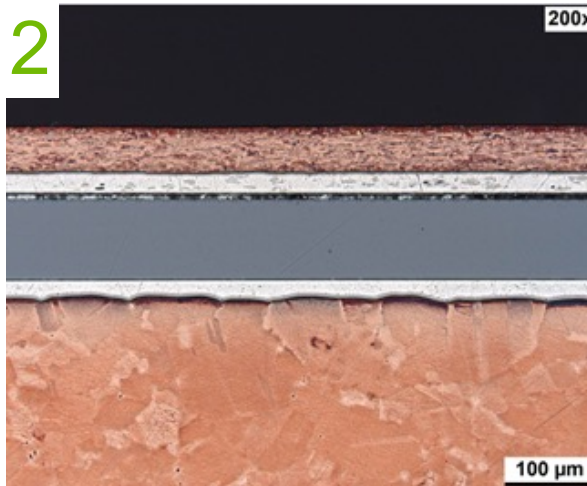
Picture: substrate layout by courtesy of Fraunhofer IISBs

DIE TOP SYSTEM

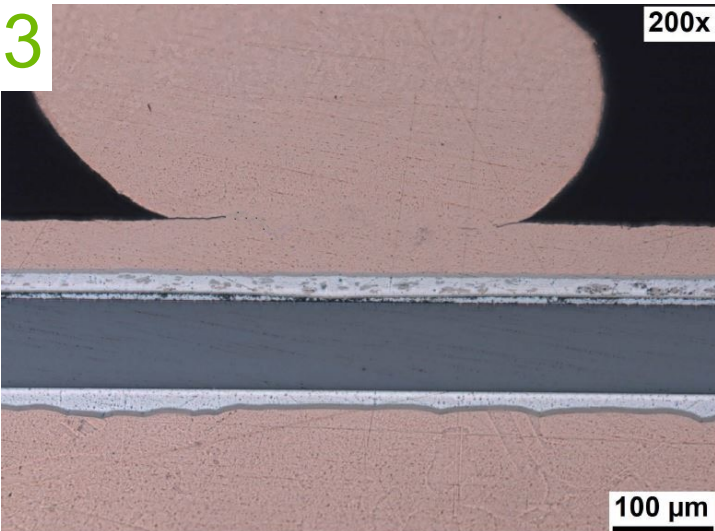
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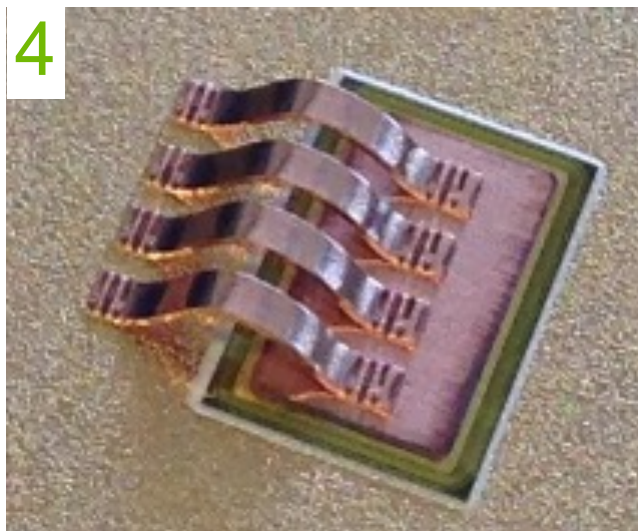
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3



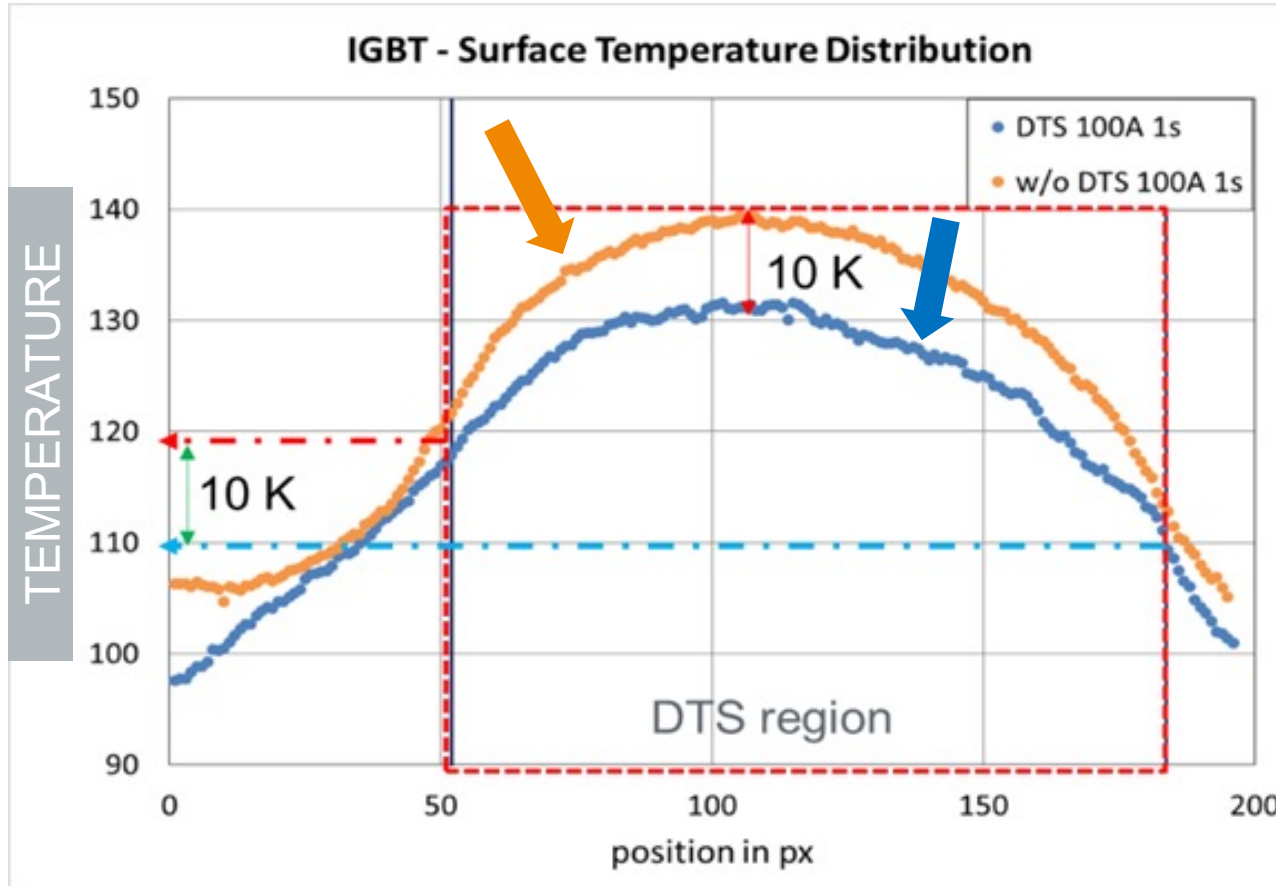
4



Die Top System®

- Silver-sintering Copper foil on top of each die
- Die protection against high bond forces during thick Copper wire bonding
- Spreads current flow
- Heat spreader → lowers hot spot
- Significant increase of lifetime

POWER CYCLING SOLDER & AL WIRE VS. SINTER & CU WIRE



SOLDER / AL WIREBONDING

- › **Bond wires:**
400µm Al wire
- › **Die attach:**
SnAg solder

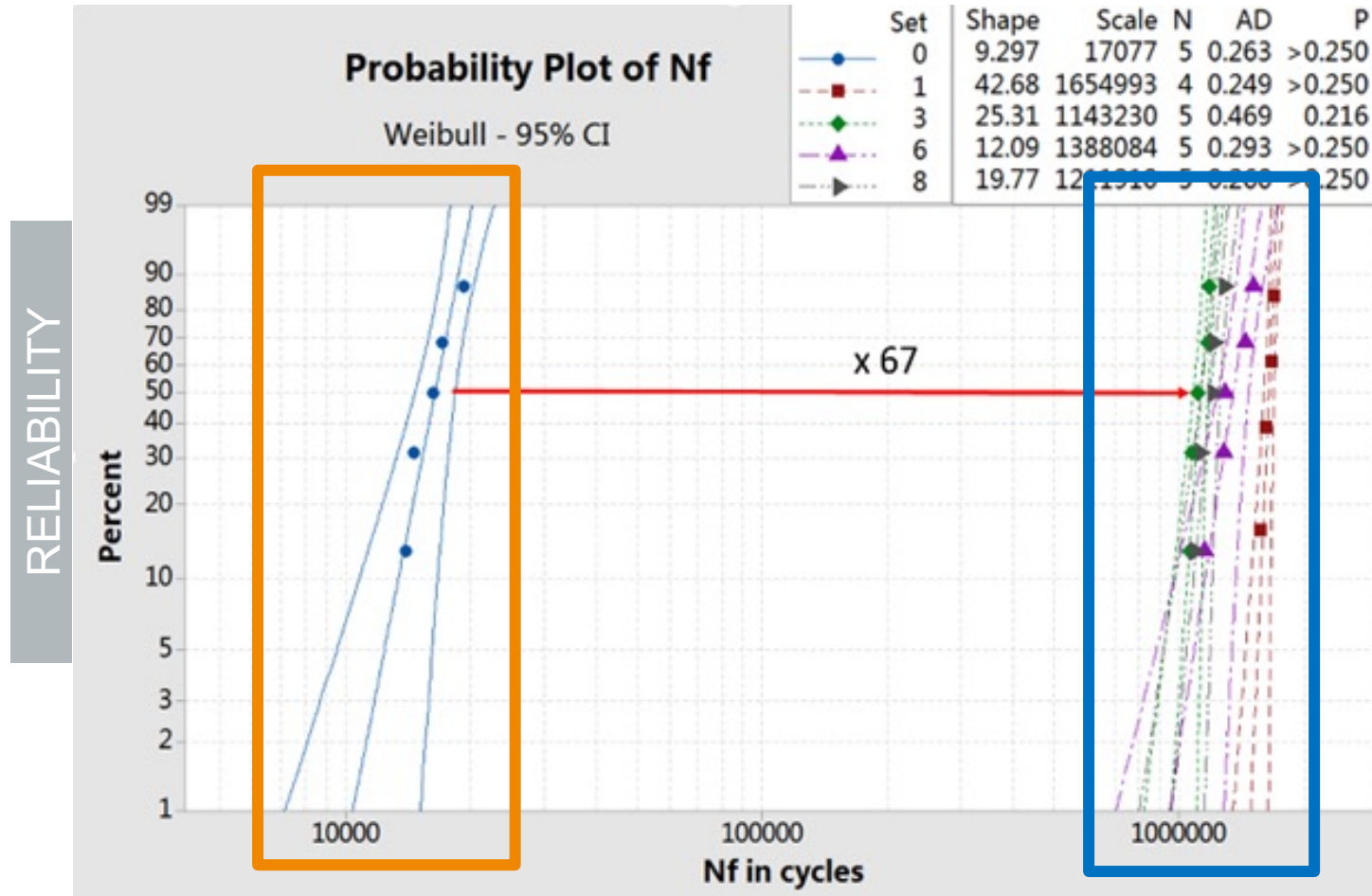


SINTER / CU WIREBONDING

- › **Bond wires:**
400µm Cu wire
- › **Die attach:**
Ag sinter
- ➔ **More homogenous heat distribution**
- ➔ **Reduced thermal stress on die topside**



POWER CYCLING SOLDER & AL WIRE VS. SINTER & CU WIRE



SOLDER / AL WIREBONDING

- › **Bond wires:**
400µm Al wire
- › **Die attach:**
SnAg solder



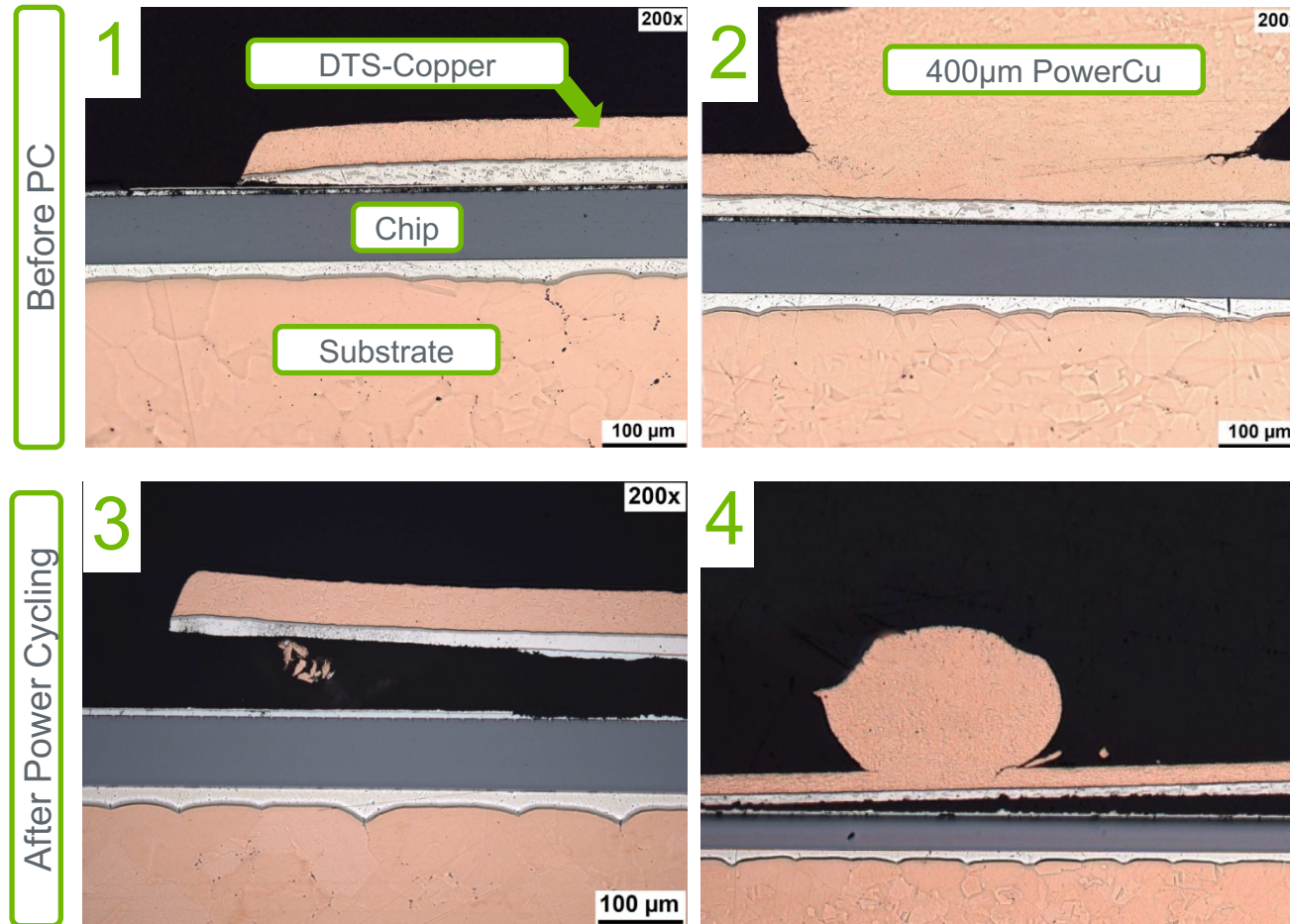
SINTER / CU WIREBONDING

- › **Bond wires:**
400µm Cu wire
- › **Die attach:**
Ag sinter



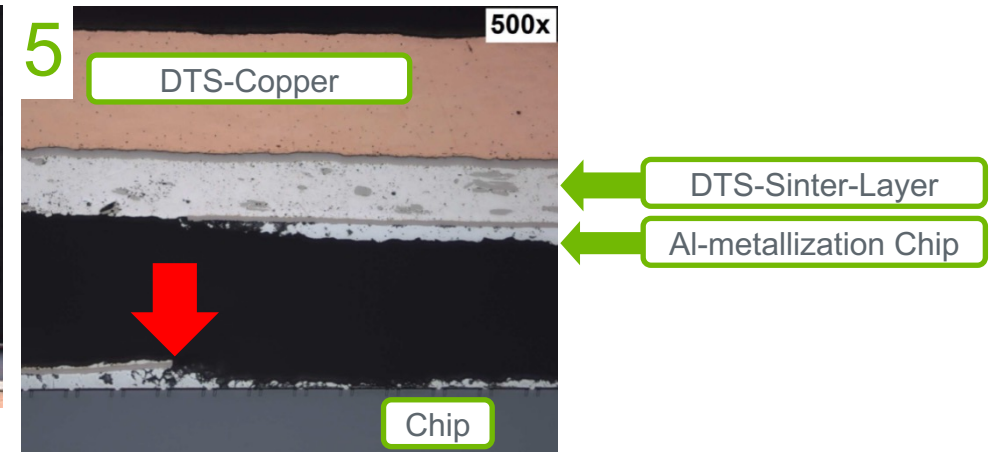
- ➔ **Number of cycles increased by a factor > 60**
- ➔ **Highest lifetime and performance**

DIE TOP SYSTEM - CROSS-SECTIONS



Die Top System® Power Cycling

- Cross-section images
- Very strong interconnection:
 - DTS-Sinter-Layer to
 - DTS-Copper to
 - PowerCu soft wire
- Failure mechanism:
 - Degradation layer moves from DTS-Sinter-Layer into Al-metallization of the chip (cohesive crack)



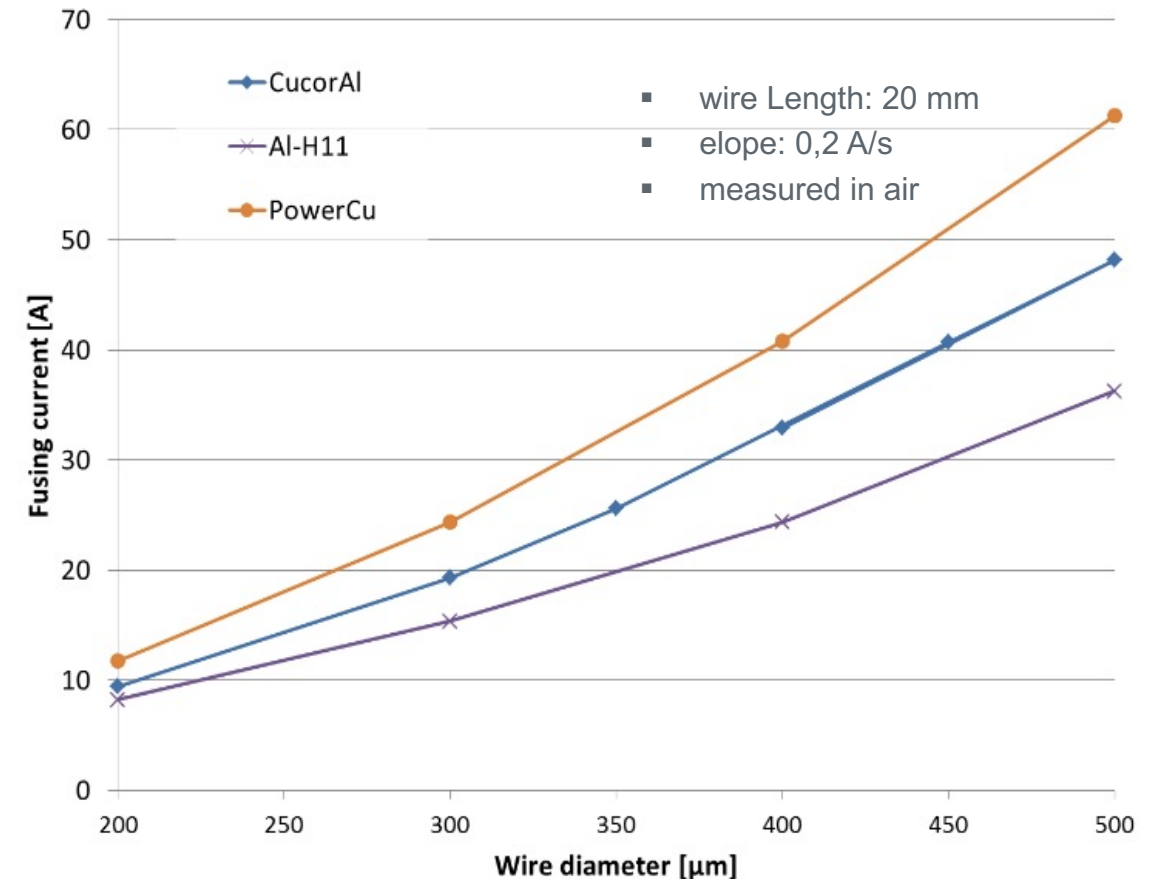
- Failure mode equal to baseplate-free sets

DTS™ IS BASED ON HIGH RELIABILITY AND PERFORMANCE OF SINTERING AND CU BONDING TECHNOLOGY

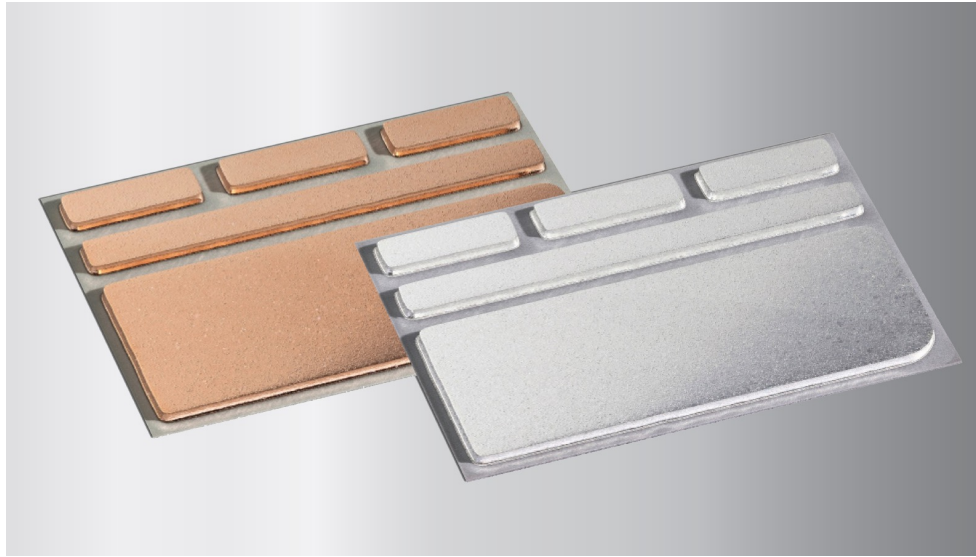
COMPARISON OF BULK MATERIAL PROPERTIES ALUMINUM VS COPPER



	Unit	Al	Cu	Cu vs. Al in %
Thermal Conductivity	W / (m * K)	237	401	169 %
Electrical Conductivity	A / (V*m)	37.7 * 10 ⁶	59.1 * 10 ⁶	157 %
Tensile Strength	MPa	40 – 50	200 – 300	500 – 600 %
E-Modulus	GPa	70	100...130	143 – 186 %
Vickers Hardness	Mpa	167	369	221 %
CTE	ppm / K	23	17	74 %
Melting Point	°C	660.3	1084.6	164 %
Density	g / cm ³	2.70	8.96	332 %

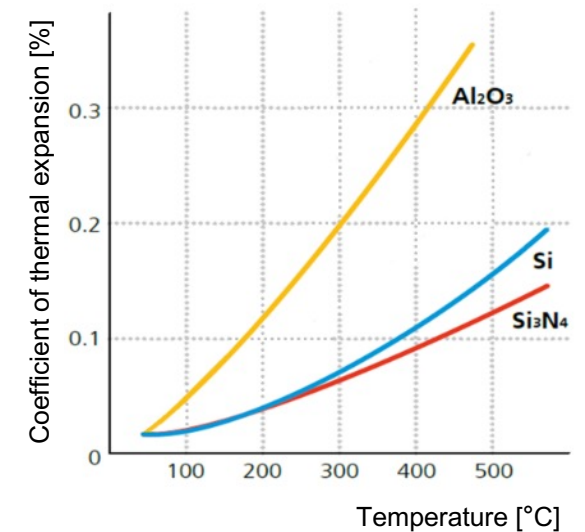
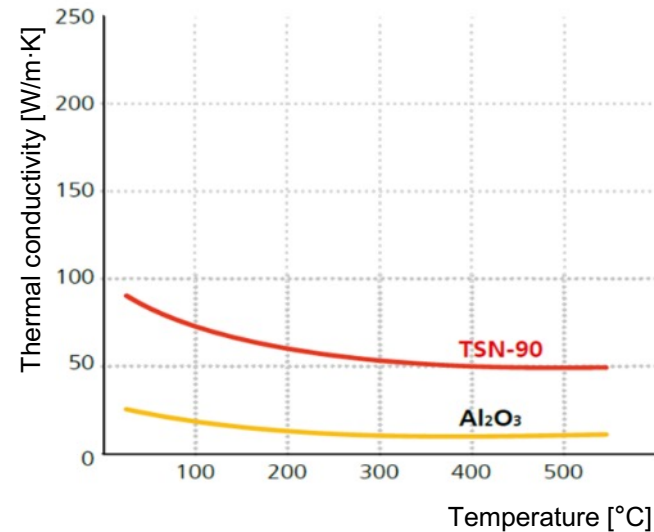


Si_3N_4 AMB COMES WITH ESSENTIAL TECHNICAL ADVANTAGES VS. Al_2O_3



*Graphic: layout by courtesy of Fraunhofer IISB

- 5 times better thermal conductivity for excellent heat dissipation
- By factor of 3 reduced thermal expansion ideally matching semiconductor materials and resulting in low thermo-mechanical stress
- 50 times better reliability proven in thermal shock tests
- 3 times thicker copper layers for increased current capability



heat dissipation

reliability

current carrying capability

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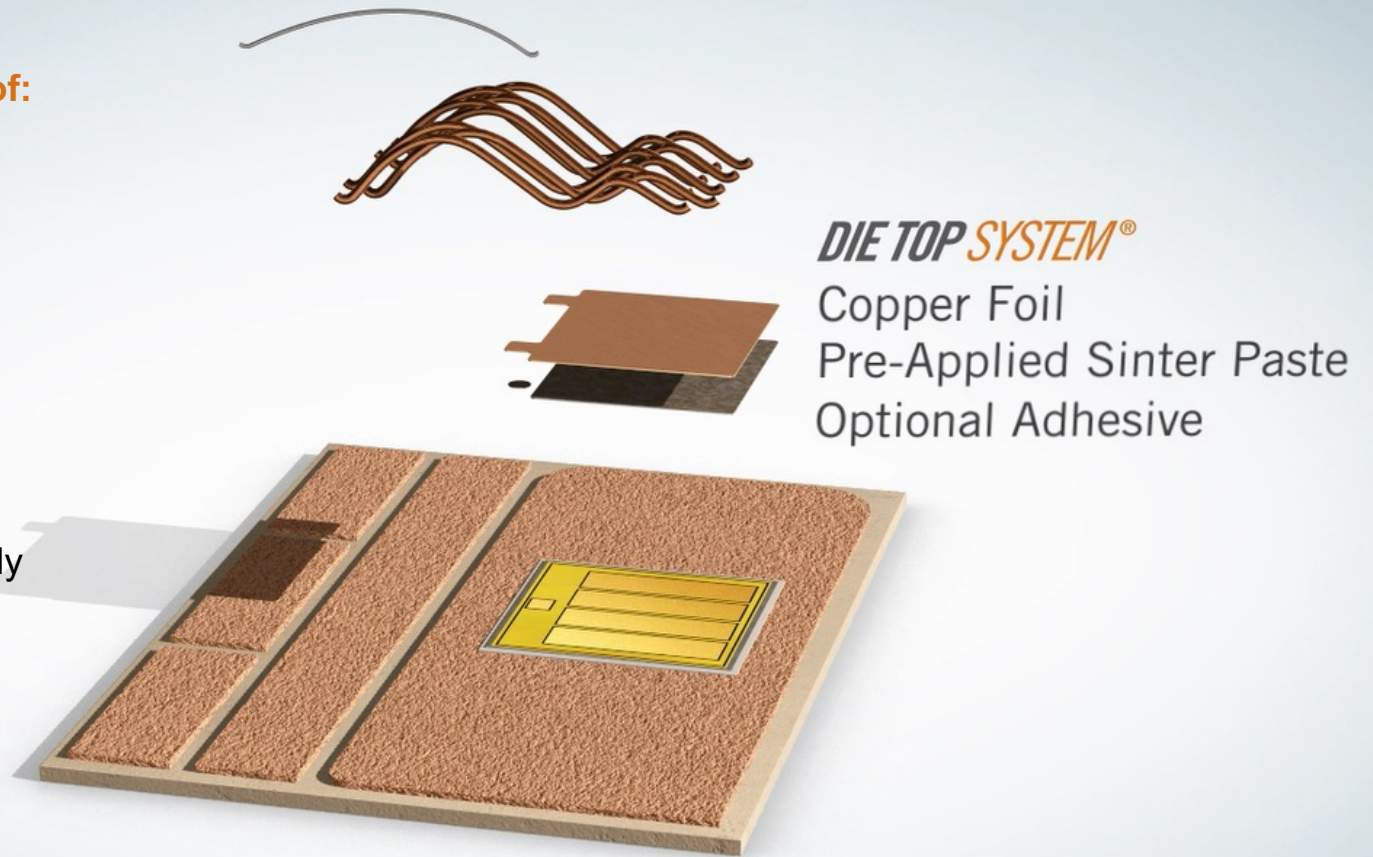
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The Die Top System (DTS®) is a Material System consisting of:

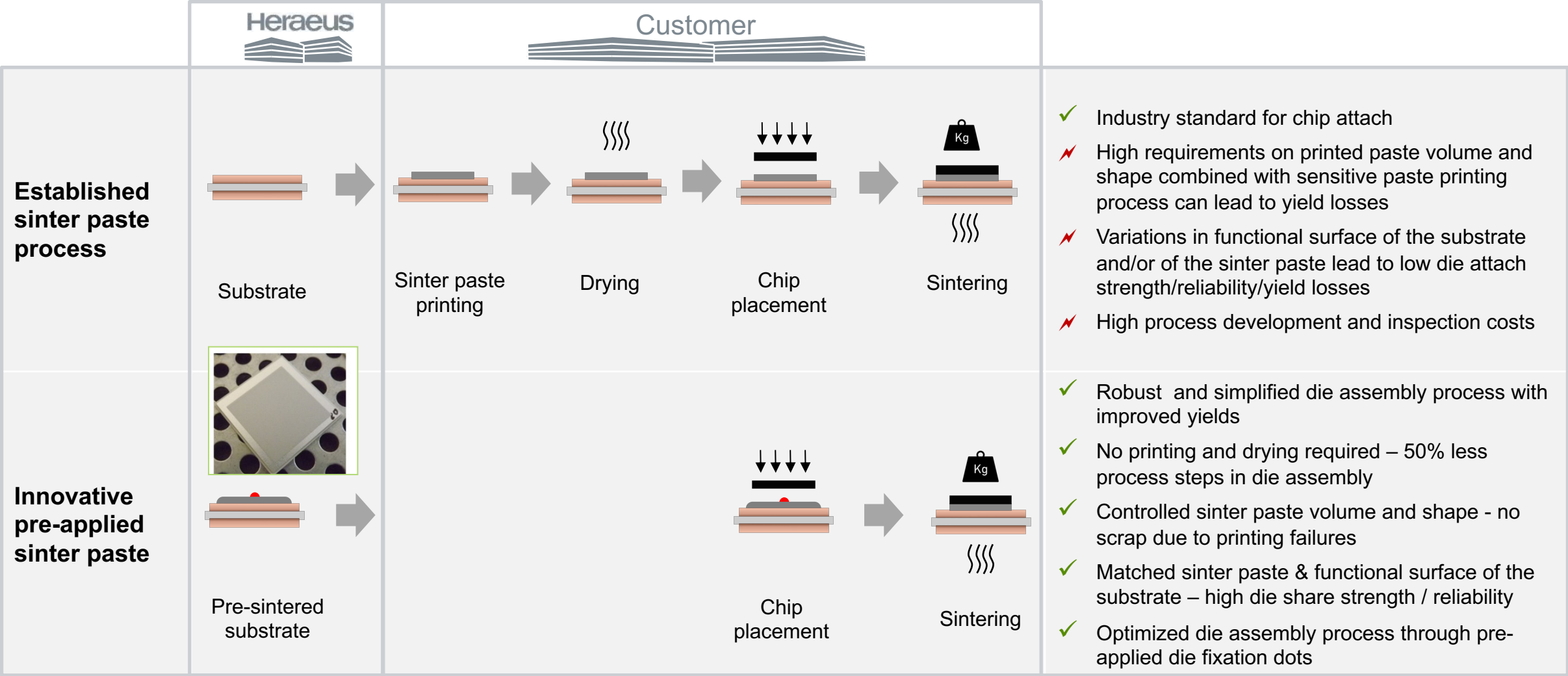
- › Copper foil with functional surfaces
- › Pre-applied sinter paste
- › Optional adhesive for DTS® fixation prior to sintering
- › Matched copper bonding wires

Reduce production complexity, optimize quality and yields:

- › Pre-applied sinter paste & adhesive dot to simplify the assembly
- › One step sintering process of the die and the die top system
- › Die Fixation System to prevent relative movement to the die prior to sintering
- › Functional surfaces optimized for sintering on the die (under side) and for bonding with Cu wire (upper side)



PRE-SINTERING SERVICE → SIMPLIFIED AND HIGH YIELD CHIP ATTACH



PROTOTYPING SERVICE SINTERING / DTS PROVIDED BY HET

Professional equipment

Innovative products

Professional service at HET

Satisfied customer

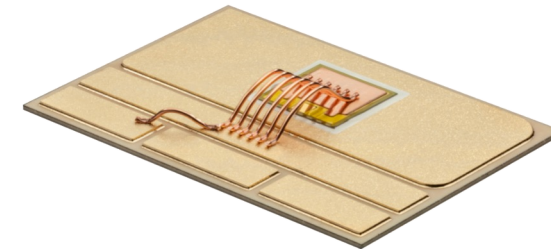
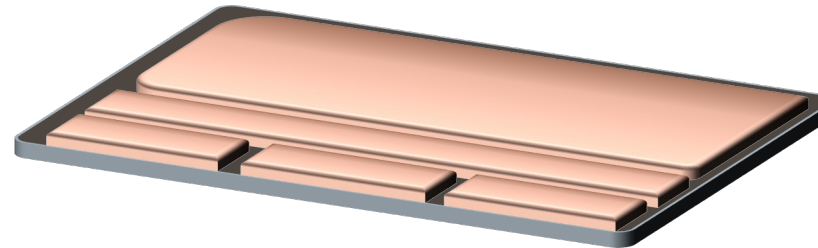
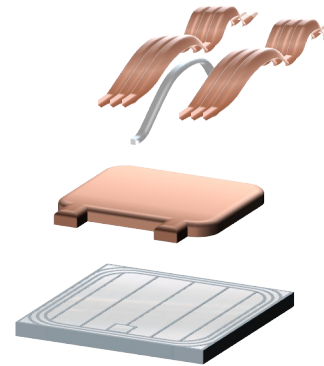
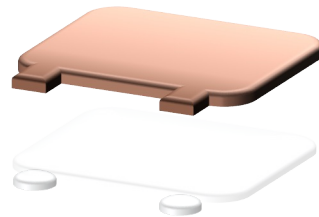
PINK SIN 200+



OR



Boschman
Sinterstar



ENGINEERING SERVICES TO ACCELERATE THE INTRODUCTION OF NEW DEVELOPMENTS IN PRODUCTION

ENGINEERING SERVICES



Simulation

- › Thermal simulation
- › Thermo-mechanical stress simulation
- › Lifetime prediction



Material Analysis

- › Fatigue analysis
- › Root cause analysis



Process Optimization

- › Parameter definition
- › Yield optimization



Prototype Design

- › Electrical design
- › Mechanical design



Prototype Assembly

- › Power modules
- › LED modules
- › Documentation, Traceability



Testing and Qualification

- › Environmental tests
- › Thermal cycling tests
- › Active cycling tests



CONCLUSION

- Integration of wide bandgap semiconductors like SiC and increasing requirements require optimized interconnection and packaging solutions
- Transformation to high-temperature interconnects from state-of-the-art soldering and wire bonding solutions is imminent
- Significant improvement of reliability and thermal stability can be achieved by
 - ..silver sintering as component topside and backside attach
 - ..die-top system in combination with copper wire bonding
 - ..replacement of conventional alumina bonded substrates to silicon nitride brazed substrates

THANK YOU FOR YOUR ATTENTION

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